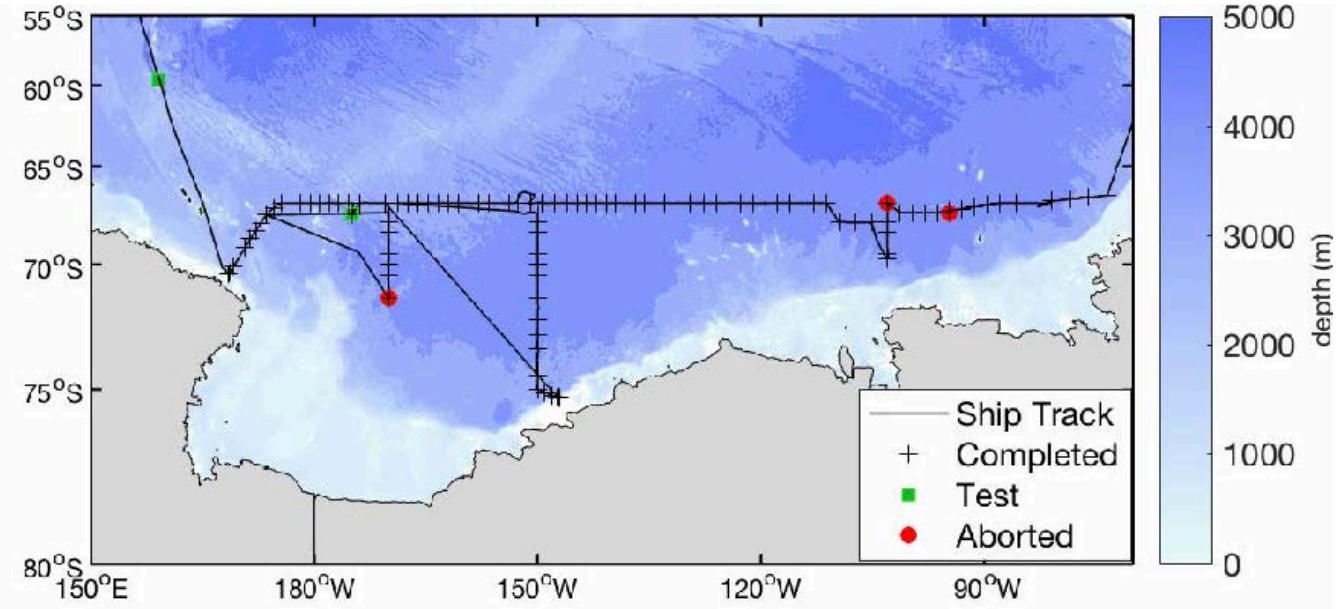
CRUISE REPORT: S04P

(Updated JUN 2018)



Highlights

Cruise Summary Information

Section Designation	**S04P**
Expedition designation (ExpoCodes)	**320620180309**
Chief Scientists	**Alison Macdonald / WHOI**
Dates	**2018 MAR 09 - 2018 MAY 14**
Ship	***NATHANIEL B. PALMER***
Ports of call	Hobart,Tasmania - Punta Arenas, Chile
Geographic Boundaries	-59.6176 159.1537 -73.499 -75.2905
Stations	122
Floats and drifters deployed	18 Floats & 20 drifters deployed
Moorings deployed or recovered	0

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Links to Select Topics

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

Cruise Summary Information	Hydrographic Measurements
Description of Scientific Program	**CTD Data:**
Geographic Boundaries	Acquisition
Cruise Track (Figure): PI	Processing
Description of Stations	Calibration
Description of Parameters Sampled	Temperature Pressure
Bottle Depth Distributions (Figure)	Salinities Oxygens
Floats and Drifters Deployed	**Bottle Data**
Moorings Deployed or Recovered	Salinity
	Oxygen
Principal Investigators	Nutrients
Cruise Participants	Carbon System Parameters
	CFCs
Problems and Goals Not Achieved	Helium / Tritium
Other Incidents of Note	Radiocarbon
Underway Data Information	**References**
Navigation Bathymetry	
Acoustic Doppler Current Profiler (ADCP)	
Thermosalinograph	
XBT and/or XCTD	
Meteorological Observations	
Atmospheric Chemistry Data	
Data Processing Notes	**Acknowledgments**

Cruise Report of the 2018 S04P US GO-SHIP Reoccupation

Release Draft 1

Alison MacDonald

May 15, 2018

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CHAPTER

ONE

GO-SHIP S04P 2018 HYDROGRAPHIC PROGRAM

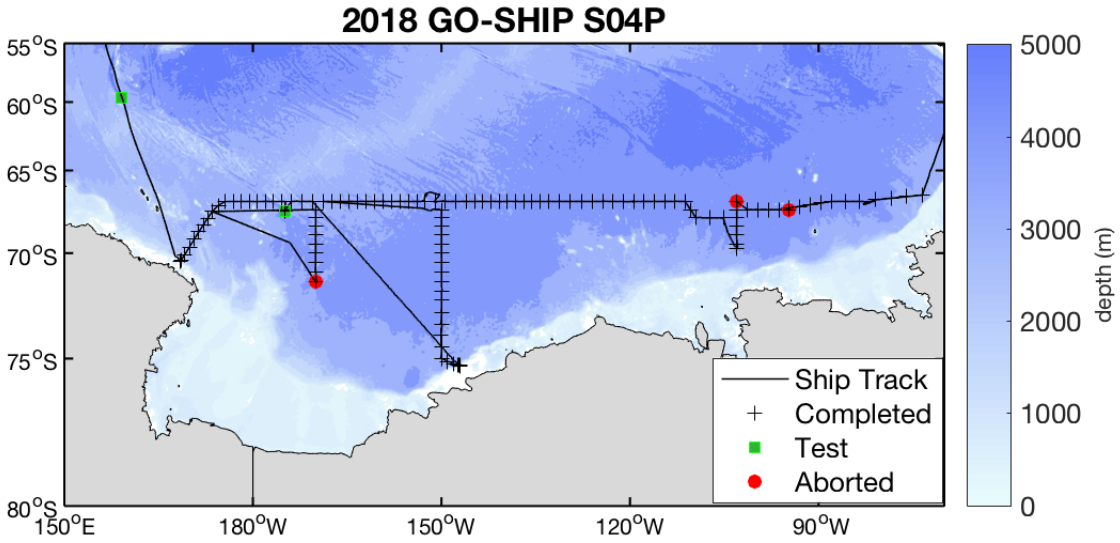


Fig. 1.1: Cruise track of S04P 2018

The Pacific Ocean S04P repeat hydrographic line was reoccupied for the US Global Ocean Carbon and Repeat Hydrography Program. Reoccupation of the S04P transect occurred on the RVIB Nathaniel B Palmer from March 9, 2018 to May 14, 2018. The survey of S04P 2018 consisted of *CTDO*, rosette, *LADCP*, *UVP*, water samples and underway measurements. The ship departed from the port of Hobart on the island of Tasmania, Australia and completed the cruise in the port of Punta Arenas, Chile.

A total of 122 stations were occupied with one CTDO/rosette/LADCP/UVP package. 122 stations and 125 CTDO/rosette/LADCP/UVP casts including 2 test casts were performed. The stations were, for the most part, a reoccupation of S04P 2011 and detailed in the following sections. 18 floats were deployed in total on S04P 2018 and

detailed in the *Float Deployments* section of the cruise report. 6 *SOCCOM* floats were deployed on S04P 2018 and are detailed in the *SOCCOM floats* section of the cruise report. 5 *FSU* floats were deployed on S04P 2018 and are detailed in the *FSU floats* section of the cruise report. 5 *CSIRO* floats were deployed on S04P 2018 and are detailed in the *CSIRO floats* section of the cruise report. 2 EM-APEX floats were deployed on S04P 2018 and are detailed in the *EM-APEX floats* section of the cruise report. 20 drifters were deployed on S04P 2018 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 UVP 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 δ^{15}N and δ^{18}N, δ^{18}O, *DOC*/*TDN*, 13C/14C, *POC*, *HPLC*, rare earth elements, Neodymium, and noble gases.

A sea-going science team assembled from 20 different institutions participated in the collection and analysis of this 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	*UCSD*	Andrew Dickson	adickson@ucsd.edu
SADCP	*UH*	Eric Firing	efiring@soest.hawaii.edu
LADCP	*LDEO*	Andreas Thurnherr	ant@ldeo.columbia.edu
CFCs, *SF6*, *N2O*	*UW*	Mark Warner	warner@uw.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*), HPLC/POC	*U Maine*	Emmanuel Boss	emmanuel.boss@maine.edu
UVP	*U Alaska* Fairbanks	Andrew McDonnell	amcdonnell@alaska.edu
Nitrate $\delta^{15}N$ and $\delta^{18}N$	*MPIC*	Gerald Haug, Francois Fripiat	gerald.haug@mpic.de, f.fripiat@mpic.de
REE	*Oxford*	Yves Plancherel	yves.plancherel@earth.ox.ac.uk
Noble Gases, $\delta^{18}O$	*OSU*, *SIO*	Nicholas Beaird, Fiamma Straneo	beairdn@oregonstate.edu, fstra-neo@ucsd.edu
Neodymium	Imperial College London	Tina van de Flierdt	tina.vandeflierdt@imperial.ac.uk
Argo Floats	*FSU*, *CSIRO*	Kevin Speer, Steve Rintoul	kspeer@fsu.edu, steve.rintoul@csiro.au
SOCCOM Floats	*UW*, *MBARI*, *UCSD*, *SIO*	Steve Riser, Ken Johnson, Lynne Talley	riser@ocean.washington.edu, johnson@mbari.org, ltalley@ucsd.edu
Surface Drifters	*NOAA*, *AOML*	Rick Lumpkin, Shaun Dolk	rick.lumpkin@noaa.gov, shaun.dolk@noaa.gov
EM-APEX Floats	*UW APL*	James Girton	girton@apl.washington.edu
Underway Bathymetry and Meteorological Data	*ASC*	*ASC*	admin@nbp.usap.gov

1.2 Science Team and Responsibilities

Duty	Name	Affiliation	Email Address
Chief Scientist	Alison Macdonald	*WHOI*	amacdonald@whoi.edu
Co-Chief Scientist, floats and drifters	Ellen Briggs	*UCSD*	ebriggs@ucsd.edu
CTD Watchstander	Ribanna Dittrich	*U Edin.*	ribanna.dittrich@ed.ac.uk
CTD Watchstander	Lauren Ferris	*W&M VIMS*	lnferris@vims.edu
CTD Watchstander	Taimoor Sohail	*ANU*	taimoor.sohail@anu.edu.au
CTD Watchstander, floats	Chanelle Cadot	*UW*	cadotc@uw.edu
CTD Watchstander	Bingkun Luo	*RSMAS*	LBK@rsmas.miami.edu

Continued on next page

Table 1.1 – continued from previous page

Duty	Name	Affiliation	Email Address
CTD Watchstander	Amir Barkhordary	*RSMAS*	abarkhordary@rsmas.miami.edu
Nutrients, *ODF* supervisor, *SOCCOM* floats	Susan Becker	*UCSD ODF*	sbecker@ucsd.edu
Nutrients	John Ballard	*UCSD ODF*	jrballard@ucsd.edu
CTDO Processing, Database Management	Joseph Gum	*UCSD ODF*	jgum@ucsd.edu
Salts, Rosette Maintenance	John Calderwood	*UCSD STS*	jcalderwood@ucsd.edu
Salts, Rosette Maintenance	Jeremiah Brower	*UCSD STS*	jjbrower@ucsd.edu
Dissolved O_2, Database Management	Andrew Barna	*UCSD ODF*	abarna@ucsd.edu
Dissolved O_2, CTDO Processing	Kenneth Jackson	*UCSD ODF*	k3jackson@ucsd.edu
SADCP, *LADCP*	Manuel Gutierrez Villaneuva	*UCSD*	mog002@ucsd.edu
DIC, underway pCO2	Andrew Collins	*PMEL*	andrew.collins@noaa.gov
DIC, underway pCO2	Patrick Mears	*AOML*	patrick.mears@noaa.gov
CFCs, SF6, N2O	Mark Warner	*UW*	warner@uw.edu
CFCs, SF6, N2O	Eugene Gorman	*LDEO*	egorman@ldeo.columbia.edu
CFCs, SF6, N2O student	Max Rintoul	*ANU*	mrintoul23@gmail.com
Total Alkalinity	Manuel Belmonte	*UCSD*	mbelmonte@ucsd.edu
Total Alkalinity	Sarah Barnes	*UCSD*	sbarnes@ucsd.edu
PH	May-linn Paulsen	*UCSD*	mpaulsen@ucsd.edu
DOC, *TDN*, Radio Carbon	Cole Hansell	*UW*	cole.hansell926@gmail.com
UVP	Rachel Lekanoff	*U Alaska*	rmlekanoff@alaska.edu
Rare Earth Elements, Barium, Noble Gases, Neodymium	Yves Plancherel	*Oxford*	yves.plancherel@earth.ox.ac.uk
Marine Projects Coordinator	Ken Vicknair	*ASC*	mpc@nbp.usap.gov
Marine Lab Technician	Jess Ackerman	*ASC*	mlt@nbp.usap.gov
Marine Technician	Jennie Mowatt	*ASC*	mt@nbp.usap.gov
Marine Technician	Tony D'Aoust	*ASC*	mt@nbp.usap.gov
Electronic Technician	Barry Bjork	*ASC*	et@nbp.usap.gov
Network Administrator	Chris Linden	*ASC*	admin@nbp.usap.gov

CHAPTER

TWO

CRUISE NARRATIVE

2.1 Summary

The 2018 occupation of the GO-SHIP S04P hydrographic line (Figure 1.1) measured the water column at 117 locations between Cape Adare (70.45°S, 168.48°E) in the western Pacific sector of the Southern Ocean to 73.48°W along a nominal 67°S between March 17 and May 9, 2018 (UTC, not including transits from/to ports, March 9-17 and May 9-15, respectively). The track included 4 spurs to the south at approximately 170°E, 170°W, 150°W and 103°W connecting to the GO-SHIP P14S, P15S, P16S and P18S lines, respectively. There were two test stations (green dots in Figure 1.1): one at the start of the cruise, which sampled to ~1400 m (Station 901, 59.62°S, 159.16°E) and one, which had no samples, but was used to re-lay the wire (Station 902, 67.56°S, 174.95°W). There were 3 aborted stations (red dots in Figure 1) that were not sampled at all (Station 9: 71.50°S, 170.00°W; Station 104: 66.00°S, 103.00°W; Station 109: 67.50°S, 94.66°W)

The rosette instruments included dual CTDs, one with oxygen, a secondary separate RINKO oxygen sensor, fluorometer, backscatter fluorometer, tranmissometer, upward and downward looking LADCPs and an underwater vision profiler (UVP) flow cytometer. There were also EM-APEX, ALTO, biogeochemical, and Argo float deployments as well as GDP drifter deployments carried out between 21 March and 22 April 2018 (173.5°E-129.5°W). Along with underway bathymetry, TSG and met data, there was also underway sampling (S, O2, DIC, pH, TAlk, pCO2). Please see individual sections for further detail.

After MOB (March 6th – 9th), the RVIB N.B. Palmer departed Hobart, Australia on March 9th at 16:30 (local, 08:30 UTC) and steamed for 8 days before reaching the first station at 70.9°S, 168.5°E. A test cast was done along the way. Sampling began on March 17 and ended May 9 (UTC). The cruise track, originally based on the 2011 occupation, turned out to be less than straightforward and it is the intention of this narrative to explain the reasoning behind the complexity of the 2018 track.

Three words best describe the idiosyncrasies of the 2018 S04P expedition: “weather”, “wire”, and “wonderment”. The weather, which not unexpectedly, caused delays, also determined many of the decisions to change the planned track and/or direction. Sea state and ice conditions, often forced by non-local winds, determined when and where it was possible to put the rosette in and whether or not it was possible to hold station. Our difficulties with the wire (see Chapter 3.5) either caused delays or spurred decisions to transit. While our instrumentation performed, if not flawlessly, at least better than might have been hoped for, on many occasions it was weather and wire that turned what could have been simple situations into difficult ones. But, then there was also the wonderment. Every time we headed south the shear excitement of entering this southern ice-filled realm (the first time, the second time, and yet again) brought an air of expectation to all aboard. Our turns to south were morale boosters on this; the longest of the GO-SHIP cruises. After succeeding at fulfilling much of originally planned science and after many long hours trying to fit the final needs of the science (to measure the last boundary current and shelf) into the remaining time, the cruise was abruptly cut short on May 9 (sta. 120) by a medical situation that NSF deemed serious enough to require the ship to head with all due speed to Punta Arenas. Although the order and choice of stations may well cause frustration for data analysts well into the future, please know that no turn or choice was made without care or forethought.

2.2 Narrative - In the Beginning

The 2018 occupation of the S04P line was scheduled for 67 DAS (Days at Sea), 68 DAS including the dateline crossing, from March 9 2018 (Hobart, Tasmania, Australia) to May 14, 2018 (Punta Arenas, Chile) (Figure 1.1). Like its 2011 predecessor, the cruise would take place on the RVIB Nathaniel B. Palmer (NBP) a global-class vessel unique to U.S. GO-SHIP in that, under charter to the U.S. National Science Foundation, it is operated by the commercial entity, Edison-Chouest Offshore (ECO).

The NSF's U.S. Antarctic Program (USAP), through a contract with Raytheon Polar Services whose personnel are Antarctic Support Contractors (ASC), provides the pre-cruise and onboard support. All pre-cruise planning, shipping management and onboard science is supported by ASC. Every member of the science party (and ASC personnel) underwent a rigorous USAP physical qualification prior to joining the cruise, and while each science group was responsible for their own shipping and customs, ASC/DAMCO (the shipping company used by USAP) personnel facilitated and coordinated getting the shipments to and from the ship in both ports.

The science parties arrived to meet the RVIB Nathaniel B. Palmer (NBP) in Hobart, on March 6, 2018 to begin the mobilization (MOB) process of loading the vessel, unpacking equipment, setting up the lab spaces and training student personnel who would be carrying out a number of the science activities. Arriving by the 6th was not made easy as weather, which later became the driving factor in many cruise decisions, made it difficult for a number of those coming from Europe and the U.S. eastern seaboard where many thousands of flights were cancelled in the early days of March due to two separate storms on either side of the Atlantic. Nevertheless, we all eventually arrived. There had been the intention for the chief and co-chief to tour the NBP the day before (March 5th) the S04P MOB but the chief scientist was one of those delayed by weather related flight cancellations, so the early walk-through did not occur and March 6th was very busy and full of numerous decisions.

2.3 The Spaces (i.e. Deck/Lab Plan)

The NBP cruise that took place prior to S04P had radiation sources so there was concern about contamination of the lab and hold spaces. However, numerous negative swipes of the decks, the container hold and in particular the bio lab where the isotope samples would be prepped gave the science party confidence that they could continue with the initial layout plan It was decided to place two vans on the helo-deck (ODF storage and the working CFC van) and one in the container hold (DIC – hold would keep temperatures above freezing and allow easy access to power if it were needed). This turned out to be a reasonable decision as results from swabs that were sent away for more accurate lab analysis were returned a couple of weeks later. Their results showed that the only place that remained contaminated was inside the previous cruise's lab van, which sat in the container hold. In spite of several swabs and swipes in the area, no tested location in the container hold outside the interior of the contaminated van returned positive results.

For S04P, the ODF team had full rein of the Hydro Lab for oxygen and nutrient analysis and HPLC/POC sample prep. The rest of the onboard measurements were done in Aft Dry Lab (Figure 2). These groups included: TAlk (using the bench next to starboard bulkhead and half the next one over); pH (using the backside of the TAlk interior bench and half the next one over); DIC (using the backside of the pH bench and half the next one over) leaving a corridor of generally unused space on the interior (port) side of the Main Lab closest to the passageway. When necessary δ15N/ δ18O isotopes in nitrate (N-isotopes) used this space for prep and δ18O secured their samples here while they were warming to room temperature. DOC/radiocarbon used the forward end of the Main Lab bulkhead bench behind the freezers for prep and post-sampling work. N-isotopes used the -20 freezers in the main lab. DOC used one of the -80 freezers. HPLC/POC used the other. The Bio Lab was used as a clean space for stowage and sampling prep for some of our sailing and non-sailing partners/ancillary measurements (REE, Neodymium, Helium/noble gases, and δ18O). The temperature controlled Salts Room was also in the Bio Lab. The CTD Watch had full rein of the forward Dry Lab, and we all made use of the computers in the E-Lab space across the passageway, which was also used as the daily crossword space. The LADCP and UVP used the Aft Dry Lab bench closest to the Baltic Room door so they could easily run their data/recharging cables and used forward Dry Lab space for working on their laptops. Floats and drifters were secured in the Wet Lab. All in all there was ample space and some to spare for all science stowage requirements and operations.

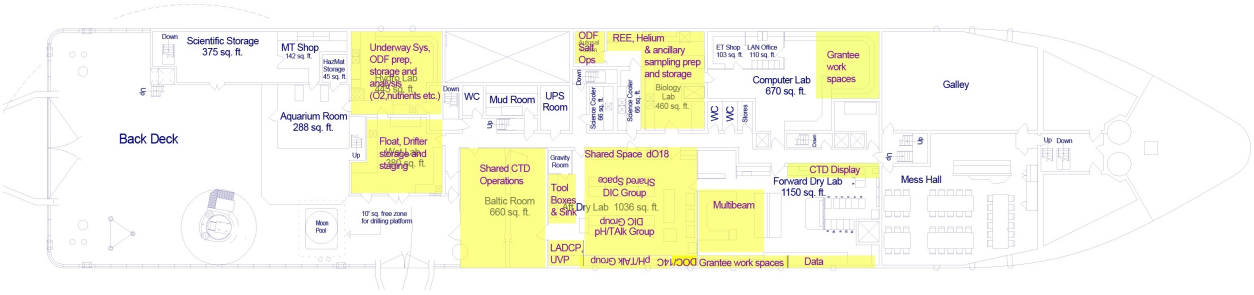


Fig. 2.1: S04P 2018 lab layout on the NBP according to the different groups measuring and sampling.

2.4 Shipping and MOB

While most of the S04P equipment showed up on the dock as scheduled and was loaded on the first day of the MOB, there were a few issues. In particular, there was trouble finding and tracking the SOCCOM and APL floats and the GDP drifters, but it was managed. With the tremendous efforts of Don Hill (from DAMCO) all equipment arrived at the ship in time for pre-cruise prep and student training (the floats) and before departure (the drifters). The NBP was loaded, science set up, and equipment stowed in time for the scheduled departure. This state of readiness was thanks in no small part to the efforts of the MPC, K. Vicknair who worked tirelessly coordinating people and logistics through constant emails and phone calls and lending his good humor to distress in moments when the knots appeared too difficult to untangle.

On March 7, those with the time followed up on an invitation to tour the French research vessel Astrolabe, which was docked next to us at Macquarie Wharf. On the evening of March 7th the NBP science parties from both S04P and the cruise preceding S04P, as well as ASC and ECO personnel were invited, along the crew of the French ship Astrolabe, to a reception held by the Tasmanian Polar Network. This is a group of local business people, academics and government officials with a strong interest in supporting the collaboration amongst all those exploring and living in Antarctica. It was a wonderful evening filled with interesting conversation and discussion and even awards for the youngest voyagers. The S04P science party was grateful for the opportunity to have met all those who attended.

Overnight from the March 7 to 8 the ship moved from Macquarie Wharf (easily accessible to the downtown hotels, restaurants, shopping and oceanographic institutions) to Selfs Point fueling pier a few miles away. All science personnel were asked to arrive at the ship on the 8th ready to stay onboard the night before we sailed. Most of the science party arrived in cabs, some in rental vehicles. M. Rintoul (a local and our CFC student) gave numerous rides and one or two hiked the distance. But, in the end everyone made it, and along with continuing the setup, on the 8th and 9th the S04P science party gave tours of the ship and in particular, the DIC, pH and TAlk setup, to nearly 50 friends and Australian colleagues. Shortly before the NBP sailed, there was an interview by a local newspaper. The chief and co-chief scientists along with the float student (C. Cadot) answered questions about the Palmer, Hobart, and GO-SHIP as well as the international collaborative effort these long-line cruises entail. The ship left a little earlier than the originally planned departure (19:00) and was underway heading generally southeast by 16:30 (local). The following sections of the narrative divide the cruise into the various areas of the basins that were sampled divided by the transits that took place in between.

2.5 The Transit South (Figure 1.1)

The preliminary cruise plan would take the NBP directly to the western side of the Ross Sea off Cape Adare at 70.65°S, 168.07°E (between the northern end of Borchgrevink Coast and western end of Pennell Coast). Although S04P had clearance to sample within the Australian Economic Exclusion Zone (EEZ), it had been decided not to apply for clearance for the Commonwealth Marine Reserves (CMR). As most of the EEZ waters surrounding Tasmania proper are also CMR, the ship track was chosen so that once the NPB was first out of EEZ around Tasmania, underway

systems could be turned on and although it would travel through the Australian EEZs around Macquarie Island it would not enter the CMR or the New Zealand EEZ.

Not long after departure, the science party had their first weekly abandon ship drill (where everyone tried on ECW gear and gumby suits) and a general alarm drill the next day. However, on the afternoon of the 9th the general alarm went off and it was not a drill, but rather it was found out later that an electrical short that tripped the alarm. It was good to know that the entire science party could get to the muster station in short order when required. From that point on drills occurred every Tuesday at 12:30 (ship time). The following day there were numerous orientation meetings for both USAP and ECO/Palmer, and the students got a tour of the rosette.

While in transit (March 9 – 17) the MPC, MTs, co-chief and chief scientist and ODF leads met to discuss over the side operations, timing and definitions. We had a how to sample workshop for the students with information on not just salts but also pH, TAlk and finally radiocarbon. Before the start of actual sampling students were chosen from both shifts to assist with TAlk, radiocarbon, and helium sampling and to handle the δ18O and N-isotope sampling.

On the March 10th the Captain decided to turn directly eastward because the rough seas were causing large rolls on the southeasterly heading. (The turn can be seen as a slight bend in the cruise track in Figure 1.1). Although, the eastward turn bought the NBP a smoother ride, it also brought the ship closer to Macquarie Island and into the Australian EEZ. The ship never crossed into the CMR or New Zealand EEZ on the eastern side of the island, and so it was not necessary to turn off underway equipment or discontinue underway sampling and analysis (see Chapter X). Some of the ship's empty hazardous waste bins sitting in metal frames on the deck took waves while in transit. Compressed air was used to pop out the ones that had been deformed. Leak tests showed that no leaks resulted from the temporary damage. Science talks were begun on this transit and the practice of having presentations from the science party while in transit continued throughout most of the cruise. The transit also saw the beginnings of a continuous effort to update the station plan and track.

The ship moved 1 hour forward on the 11th and again on the 12th, and had a Ground Hog's Day repeat of March 13th (we did not change the day after this regardless of whether or what direction we crossed the Dateline). All hour changes, which were done at the discretion of Captain Souza are listed in Table 1.

Table 2.1: 2018 S04P Ship Time Changes

Date	Time (local)	Became Date	Became Time (local)	Relation to UTC	Comment
3/9/18				UTC+11	Note: Hobart AEST UTC+10
3/11/18	22:00	3/11/18	23:00	UTC+12	Transit to Station 1
3/12/18	02:00	3/12/18	03:00	UTC+13	Transit to Station 1
3/13/18	24:00	3/13/18	00:00	UTC-11	Transit to Station 1
3/14/18	05:00	3/14/18	06:00	UTC-10	Transit to Station 1
3/16/18	09:00	3/16/18	10:00	UTC-9	Transit to Station 1
4/8/18	13:00	4/8/18	14:00	UTC-8	Transit back to 67°S (Sta. 54)
4/9/18	18:00	4/19/18	19:00	UTC-7	Transit back to 67°S (Sta. 54)
4/29/18	09:00	4/29/18	10:00	UTC-6	Transit to 103°W (Sta. 98)
5/10/18	18:00	5/10/18	19:00	UTC-5	Transit to Punta Arenas
5/11/18	09:00	5/11/18	10:00	UTC-4	Transit to Punta Arenas
5/12/18	13:00	5/12/18	14:00	UTC-3	Transit to Punta Arenas
5/12/18	13:00	5/12/18	14:00	UTC-3	Transit to Punta Arenas

Note: Ship time changes bore no relation to actual time zones crossed by the ship.

2.6 The Test Cast

The original plan was for a test cast on the morning of March 11, but the cast was delayed until the 13th due to rough weather/seas. It began ~12:40 (local = UTC-9) and it took nearly 50 minutes to get the bottles cocked and the rosette prepared the first time. Obviously this improved with time and familiarity. On the test cast one student deployed, another did the "bottom approach" and a third did the recovery. Everybody was able to fire 6 bottles. After the test cast, new cables were put on the transmissometer as the data appeared to be very noisy. The LADCP cables also did not perform, and therefore several Niskins were removed to allow access to instrumentation. The issue turned out to be a faulty star cable (the cable that allows both the upward and downward looking LADCPs to operate simultaneously). Further information can be found in the LADCP section of this report.

The test cast (Station 901) helped sort out issues of timing and where to get information – e.g. the pH/TAlk group wanted the salinity record after a cast but the salinity record is not an automatic output of the initial processing, nevertheless ODF was able to make this information available online in short order. The cast also made it clear that smoking could even on the smoking (waterfall) deck could be an issue. This information was passed to the crew by the Chief Mate and was rarely an issue for sampling again. It also became clear that there was an inadequate supply of gloves and it was decided that only those who absolutely had to wear them would. Originally it was thought that it might be necessary move DOC up in the sampling order, but the DOC and REE PIs (C. Carlson, Y. Plancherel) decided it was not necessary for those going before them in the sampling to wear gloves as long as they were careful not touch the Niskin nipples.

On the last day of transit, it was brought to the science parties' attention that there were unspecified complaints about food from unknown personnel and there was the issue arising of people hoarding or wasting food, particularly fresh fruit. Emails were sent to ask everyone to be more accepting and more aware that the ship was at the beginning of a very long voyage with limited supplies. Similar complaints arose at various times throughout the cruise and each was followed up with a similar request from chief scientist and/or caption. There was little need for such behavior as throughout the cruise the galley did an amazing job producing 4 hot meals a day (breakfast, lunch, dinner and mid-rats). Certainly, the components of the meals had less variety as the cruise progressed, but the fresh lettuce lasted until Day 46, the apples and grapefruit lasted a couple more weeks and there were still fresh avocados for the Taco Tuesday's guacamole on Day 61.

The weather picked up (NW 40 knot winds) the last day of this first transit. Icebergs began to appear along the way, including a growler with an Adélie penguin pack that dove in once they saw the ship go by. The sight of ice, penguins, whales and seals remained a morale booster through the long days of the voyage.

2.7 The Beginning of Sampling: 170°E (P14S repeat) Line (March 17–19, Stations 1– 8)

The initial plan was to have the first station on the shelf in ~200 m of water and have the ship move northward back toward the 67°S on a line perpendicular to the shelf. Having received weather and ice updates, on the 16th, the Captain believed it would be possible to sail around the pack ice to where the 200 m station would located in more easily moved newer ice. However, this was not to be. Unable to sail around because the wind was blowing new ice into the packed multi-year on the shelf, hydrographic casts began well off the Cape Adare shelf in 1400 m of water at 70. 90°S, 168.48°E (sta. 1) and continued to the northeast from 168°E to 170°E toward the 67°S line with the nominal 30 nm spacing (Figure 3). There were issues with the altimeter on the first 3 stations resulting in the need to use LADCP data to back out the bottom depth (see Chapter 22). On station 3, the rosette made contact with the bottom and it was determined that incorrect reprogramming caused the altimeter to begin reporting at 10 m above the bottom rather than at 200 m. Replacing what should have been a 200-m-altimeter with the 100-m version from the NBP solved this problem. The latter was used for the rest of the cruise with no issues. On March 19, having completed Station 8 half way up the 170°E line and waiting with the ship doing weather patterns for 12 hours, a major storm threating a 5-day delay forced the decision to head southeast to the southern end of the 170°W spur.

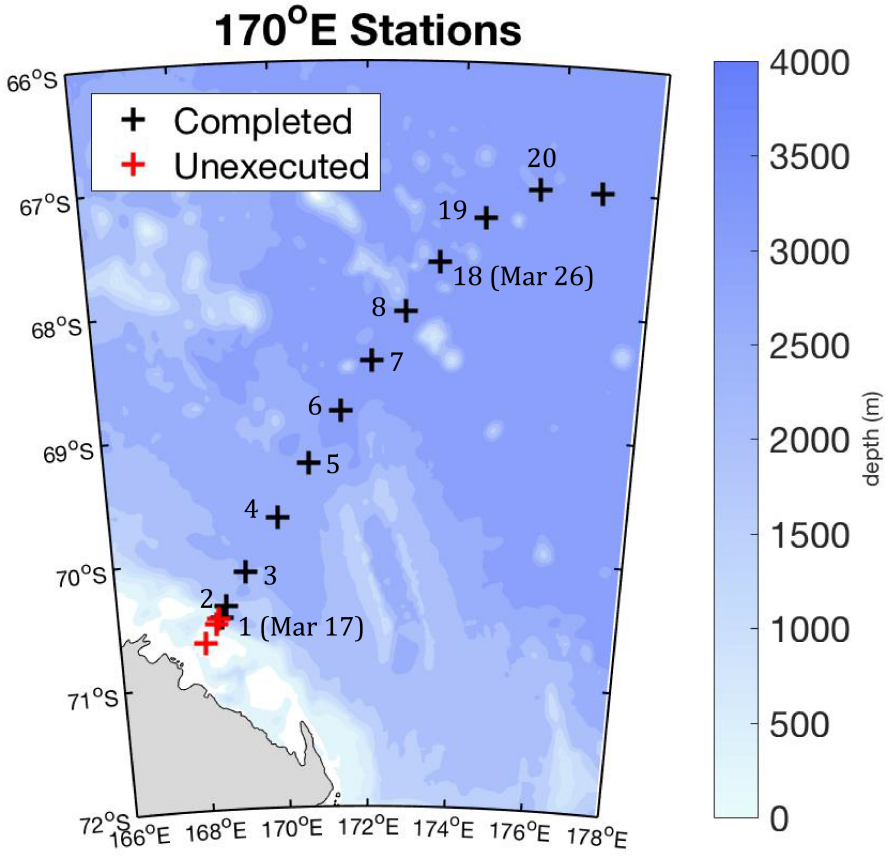


Fig. 2.2: 2018 S04P station locations in the vicinity of 170°E. Station numbers are labeled. Planned stations that were not executed due to ice are shown in red. See Figure 1 for transit tracks.

2.8 The 170°W (P15S repeat) Meridional Line (March 21–23, Stations 9–17)

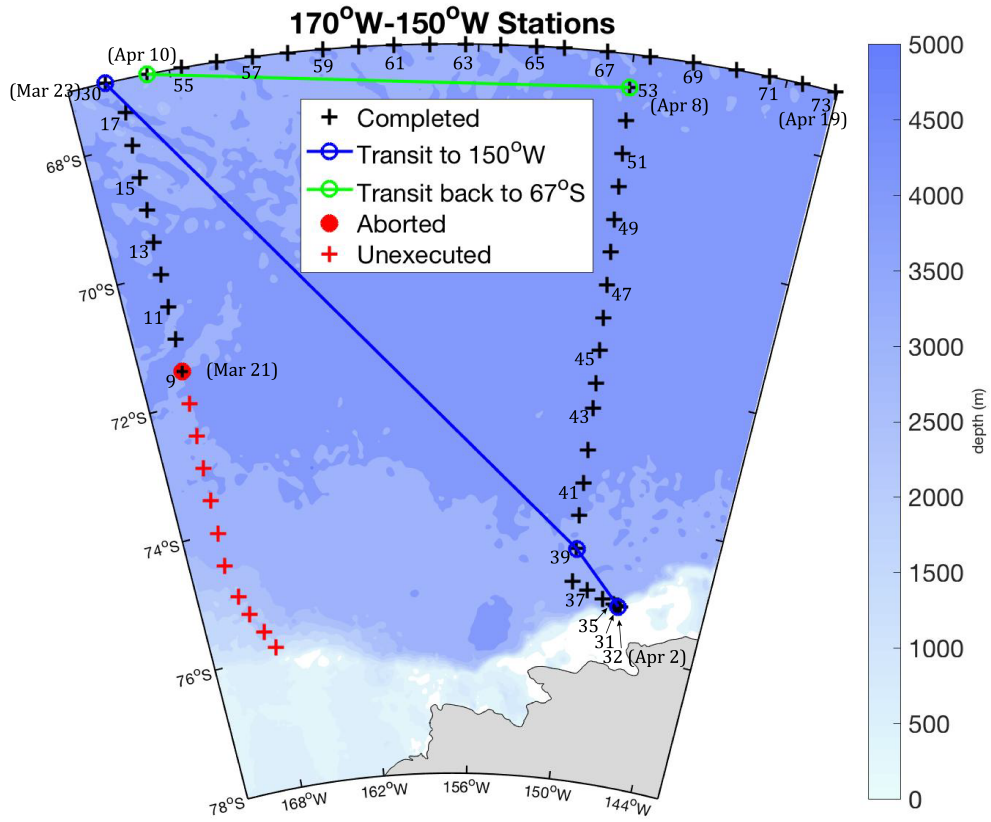


Fig. 2.3: 2018 S04P station locations in the vicinity of the 170°W and 150°W meridional lines. Planned stations that were not executed due to the combined forces of ice and wind are shown in red. See Figure 1 for transit tracks.

The transit took approximately 1.75 days. Ice maps from SIO and through the bridge had already suggested that the ship could not make it to the planned start of the 170°W at 75.86°S (depth = 900 m) (Figure 3, red crosses) given the time constraints on the cruise. In turned out that, limited by freezing surface waters and swell, even Station 9 at 71.5°S, 170°W was aborted. Observations on the 170°W line began at 71°S (sta. 10, Figure 3 black crosses) and continued northward with 0.5° (30 nm) spacing to 67.5°S (sta. 17) before the ship transited back to the 170°E line to pick up at 67.62°S, 173.54°E (sta. 18, 28.8 nm from sta. 8). On Station 12 the question of ship roll came up. After discussion, the bridge was asked to make less use of the Dynamic Positioning System (DPS) because although it allowed position to be maintained, it was also the cause of the roll. As the bridge said position could be maintained to within 0.1 nm in position without DPS, it was decided not to use it while in sea state/weather conditions similar to what was being seen at the moment. It was also at this point that the chief scientist confirmed that there would be no argument with any decision the bridge would make concerning station position when it concerned safety. This agreement first came into play on Station 14 where there was an iceberg sitting on the planned position.

2.9 The End of 170°E to the Zonal 67°S Line to 170.5°W (March 24–29, Stations 18–30)

A 44 hour transit took the ship back to the nominally 170°E line at 173.54°E (sta. 18, Figure 3). As kinks had been found at the top of the wire after Station 17, while transiting to Station 18, 24 m of wire was cut and the wire was reterminated on March 24 (Table 2). Sampling continued along the line (to sta. 27) until wire issues (the lay of wire on the drum and a visually noticeable distortion of the wire) appeared on Station 22. The details of these wire issues are discussed in Chapter 3.5 and are not repeated here. Suffice to say, the net result of the issue for science was that it slowed casts, by reducing winch speed and breaking the otherwise seamless downcasts, requiring longer waits at bottle stops and eventually demanded an attempt to unwind and rewind the wire in deeper water (sta. 902, between stations 27 and 28). The rewinding was unsuccessful and was followed by a decision to transit (after sta. 29, 67.00°S, 172.15°W) to the southern end of the 150°W spur so as to use the underway time to remove 935 m of wire (leaving 7652 m) and reterminate on March 30.

Table 2.2: 2018 S04P Timing of Reterminations

Date	Time (local)	Became Date	Became Time (local)	Relation to UTC	Comment
3/9/18				UTC+11	Note: Hobart AEST UTC+10
3/11/18	22:00	3/11/18	23:00	UTC+12	Transit to Station 1
3/12/18	02:00	3/12/18	03:00	UTC+13	Transit to Station 1
3/13/18	24:00	3/13/18	00:00	UTC-11	Transit to Station 1
3/14/18	05:00	3/14/18	06:00	UTC-10	Transit to Station 1
3/16/18	09:00	3/16/18	10:00	UTC-9	Transit to Station 1
4/8/18	13:00	4/8/18	14:00	UTC-8	Transit back to 67°S (Sta. 54)
4/9/18	18:00	4/19/18	19:00	UTC-7	Transit back to 67°S (Sta. 54)
4/29/18	09:00	4/29/18	10:00	UTC-6	Transit to 103°W (Sta. 98)
5/10/18	18:00	5/10/18	19:00	UTC-5	Transit to Punta Arenas
5/11/18	09:00	5/11/18	10:00	UTC-4	Transit to Punta Arenas
5/12/18	13:00	5/12/18	14:00	UTC-3	Transit to Punta Arenas
5/12/18	13:00	5/12/18	14:00	UTC-3	Transit to Punta Arenas

2.10 The 150°W (P16S repeat) Meridional Line (April 2–8, Stations 31–53, 75.29°S-67.5°S)

The transit south took 3.3 days (Figure 3, blue line). The first station to be sampled on this line was Station 31, 75.287° S, 147.107°W in 544 m of water surrounded by ice. However, having arrived this far south and with leads in sight, it was decided head further onto the shelf. The southernmost station on the 150°W line (sta. 32, 75.291, 147. 000°W) was done 285 m of water on the shelf. With closer spacing on the shelf, stations were occupied every 0.5° (30 nm) up to 67.5°N starting at Station 38 (75.0°S, 150°W).

The wire continued to be an issue and by April 3rd (sta. 37) the discussion of the MPC and MTs with those onshore lead to the decision to scrap the wire after the cruise. The thinking at the time was that up to 1400 m of could be removed leaving ~7600 on the drum, which was considered adequate as there were no stations expected with bottom depths greater than 5000 m.

By Station 38, issues with the combination of drifting ice and wind were causing major problems with maintaining station position. It should be noted that using the DPS in ice is not recommended as it can literally push the ship and

the rosette into ice. On Station 38 wind and ice caused the ship to "miss" the planned position by nearly 0.5 nm by the time bridge decided they were setup on station. The decision was made to attempt to set up on a position that would allow the ship to drift back over the planned position by the time the rosette reached the bottom. It was not clear that this tactic worked. Station 41, was started at 73.503°S, 149.935°W (1.3 nm to the west of 73.500°S, 150.000°W) and at the bottom the position was 73.514°S, 150.060°W, 1.3 nm to east of the planned position. However, there is little that could be done about this. Station 43 was moved 7.5 nm miles to the north to avoid an iceberg field. Station 44 was placed to the east of a westward moving berg. During these period maneuvering of the ship around icebergs, which were mostly picked up on radar and through fields of smaller ice, but still significantly sized lumps, was made more difficult by fog. Ship speeds through this region were therefore quite slow.

Station 49 found the portions of the wire presenting for the first time, but not the last, with strands that could be caused to separate just by twisting the wire by hand, i.e. the outer armor was starting to open and separate from the inner core. The upper 552 m of the wire were removed (Table 2) and the wire reterminated on April 7 on the transit back to 67°S (between stations 53 and 54). Just prior to rosette going in on Station 50 the GPS signal was lost so the Seabird SEASAVE software could get the NMEA information it needed to initialize. The IT was able set up the secondary GPS system and the rosette went on station 50 about 5 hours after it was supposed to begin. From this point on the 150°W line went as expected and the sampling continued up the line to 67.5°S (sta. 53), before the ship began the 46.5 hour transit back to the 67°S line. On our way back to the zonal line we passed the B30 iceberg and the field of smaller icebergs accompanying it – again ship speeds were slowed by both the ice field and fog.

2.11 The Continuation of the 67°S Line (April 10–28, Stations 54–97, 168.88–105.16°W)

Sampling along 67°S continued beginning at 168.88°W (sta. 54, Figure 3) 43 nm from Station 30 finishing off the ~40 nm spacing we had been maintaining since Station 27, when we lost time to the wire re-wind. The winds began to rise on Station 56, but we managed to continue with slow casts through Station 57 where every bottle after the bottom was fired on the fly to get us out of the water more quickly. It was on station 58 that the manner in which casts were being directed came under question as the swell produced tension swings and it was apparent that the winch speed was too high. Although it only took two actual cast attempts, there was a delay of some 3 hours as reassessments of the winds and swell occurred and much discussion ensued on the dynamics of the cast. Eventually, the cast went in and the MT was asked to try to go slower than the generally used 25 m/min. Anything slower than 15 m/min, wasn't possible given the winch controls, but once it was realized that 15 to 17 m/min could be maintained and 0 tensions usually avoided it became the norm on casts when heave was an issue.

The enormous B30 iceberg that ship had passed on its transit back from 150°W, turned out to be sitting the planned position for Station 66. As the iceberg was C-shaped and moving to the west (as the sampling moved to the east), the ship stopped for Station 66 about 7.7 nm west of the berg making the distance between stations 65 and 66 about 25 nm, which increased the spacing to station 67 to about 41 nm. A dense field of icebergs of every size and shape surrounded the B30 iceberg and the ship at Station 66 so it was decided not to go through with the planned drifter deployment. This last drifter deployment occurred as we were underway to Station 67.

As the ship left station 66 and steamed north to avoid the bergs, the wind picked up to 40-45 kts. It was too dangerous to try to maneuver around the enormous field, so there was a 3-day weather delay (much of the time with sustained winds of 40 kts and gusts to 50 kts, but also large low frequency swell before the ship finally reached Station 67 on the eastern side of B30. Once the rosette got in the water on Station 67, sampling continued with 30 nm spacing and only minor issues (e.g. fog and ice slowing transits between stations, LADCP star cable/junction box failure – see Chapter 22; concern about northward moving ice flows for float deployments; oxygen pump requiring replacement) until Station 79 when it was noticed that although the wire was laying reasonably well on the drum and having no conduction issue, the outer armor was beginning separate again. Nevertheless, the floats went in without a hitch on Station 80 (no ice in sight) and sampling continued through Station 87, when another weather delay occurred.

Taking advantage of the break in a sampling, 302 m of wire were cut (Table 2) and the wire was reterminated. The rosette was back in the water on Station 88 after about 17 hours later than originally anticipated. It is apparent that even when the ship is not in a heart of the storm that it is affected by low frequency signals, presumably emanating

from where the winds are stronger, that sometimes interfere to reduce heave and sometimes interfere so as to enhance the heave. For this reason, even when the local winds calm and the seas generally lay down, there are still fairly regular larger swells that come through. It is thought that it would help with getting the rosette in the water more quickly after storms if the winch could go slower than 15 m/min. That being said stations 88-91 continued with slow descents and with varying numbers of near surface bottles being tripped on the fly, to reduce the chance of tension spikes on the way up. Note there was discussion as to whether the spikes occurred on the stops or on the acceleration after the stops. If the latter, it would again come back to the idea of needing finer control of the winch speed. At this point the wire again began having problems with winding on without gaps, which in turn slowed upcasts. It is here that it should be mentioned that a better view (or in fact any view) of the wire and ocean for the winch operator so as to better time speed and acceleration with the swell would have greatly eased operations. Also, many times during this cruise casts were delayed because the direction of swell relative to winds for ship positioning created the threat of waves crashing into Baltic room to douse both the MT and the winch operator and controls. The situation would be far less of an issue if the operator and the controls were raised above the height of such swell.

Before Station 93, the ship was issued a warning to divert due to weather and seas. The decision was made to divert south to 68°S after Station 93 (67.00°S, 111.21°W) so that sampling could continue (Figure 6). So once again, a long weather delay was averted by "running away." Station 94 was occupied at 67.5°S, and Stations 94-96 at 68°S. This southward diversion tactic worked for just a few stations as wind began to pickup on Station 95 (30-40 kt sustained winds and 50 kt gust) where most of the bottles were tripped on the fly. After a 13-hour weather delay, on Station 96, there was a 2.5-hour down cast to 4200 m and bottles in the top 500 m were tripped on the fly.

Station spacing was stretched to allow more time for the seas to calm and to make up for 5 hours of the delay. To make up the other 8 hours it was decided to transit directly to 70.5°S, 103°W from Station 97 and to cut the southernmost stations (1000m, 1500m, 2500m), on the 103°W line (Figure 5). This plan made sense because it was unlikely the ship could have made it to the southernmost planned stations with the remaining time due to ice, and even if it could have, it still would not have reached the shelf.

2.12 The 103°W (P18 repeat) Meridional Line (April 29–8, Stations 54–, 75.29°S-67.5°S)

The transit to the southern end of the 103°W line took only 14.5 hours because it quickly became apparent that getting even as far as 70.5°S would have taken more time than was available as the area was thick with multi-year ice that had blown in to form solid pack. The short transit allowed time for a required life boat drill for the crew (2 hours after Station 98) and the hope that perhaps the station spacing on the zonal 67°S line could once again be reduced to 30 nm. The opportunity was also taken to cut another 300.5 m of wire (Table 2), removing the section that where the outer armor was opening up, and to reterminate.

The southernmost station on this line was done in 4000 m of water on Station 98 at 69.75°S, the next station was occupied 15 nm miles to the north at 69.50°S, after which half degree (30 nm) station spacing maintained until 67.5°S (Figure 5). Reaching even this station took some effort as the ice was unforgiving and on more than one occasion backing and ramming had to be used to make the path northward. As at other stations surrounded by ice, although the seas were flat making for excellent profiles, positions at the start of the stations sometimes differed considerably from those at the end as the ship had no choice but to drift with the ice and wind. Nevertheless, stations continued along the meridional line without any major difficulties.

As the ship headed north and out of the ice the weather once again became problematic and the 67°S station (104) was aborted due to weather; not local weather – winds were only blowing 20 kts, but from a storm that was producing intermittent 9-10 amplitude heaves. The storm sitting to the north showed no intention of moving away, so the ship once again diverted south and continued eastward along 67.5°S until it was thought that weather would permit a move back to 67°S. The station spacing was variably stretched further down the line to make up for the 10 hour delay produced by the attempt to measure 67°S, 103°W position (sta. 104).

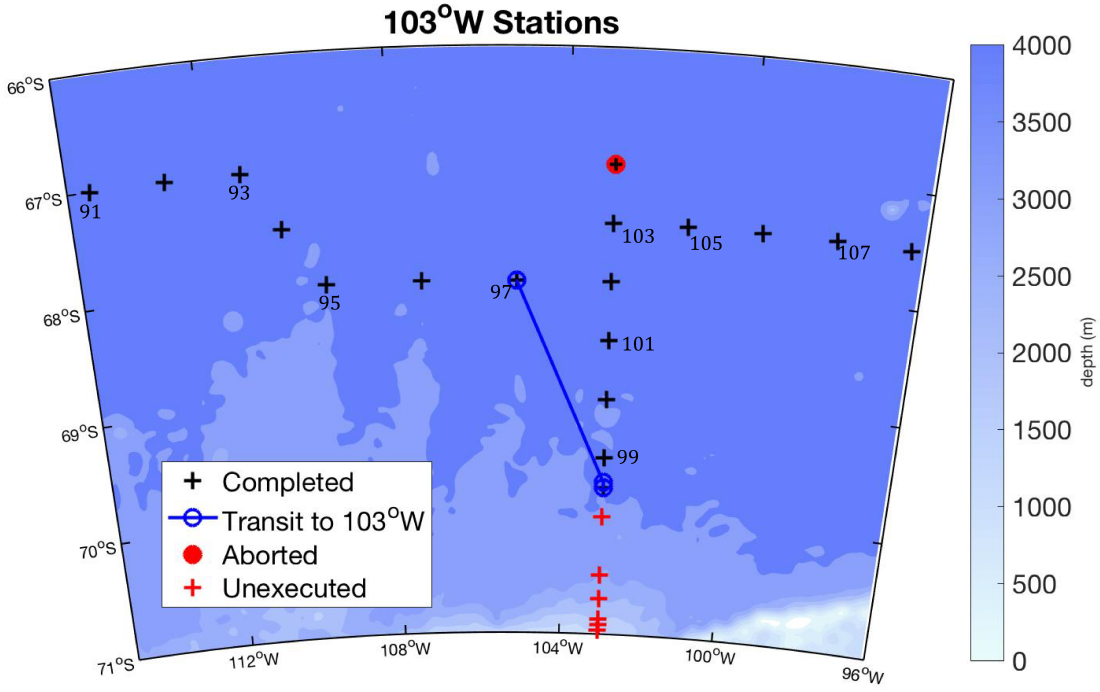


Fig. 2.4: 2018 S04P station locations in the vicinity of the 103°W meridional lines. Planned stations that were not executed due to ice are shown in red. See Figure 1 for transit tracks.

2.13 The Eastern End of the S04P Line

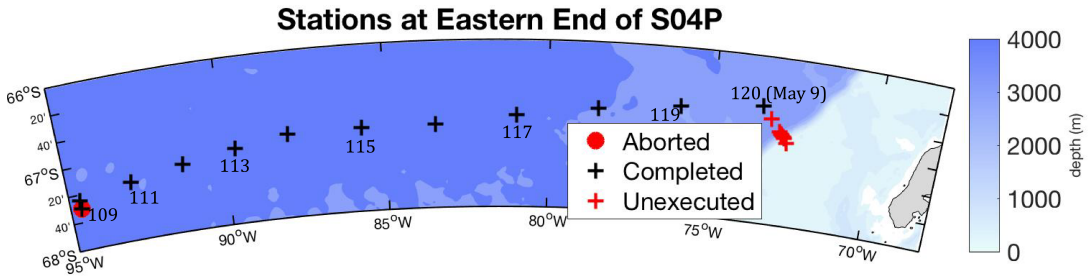


Fig. 2.5: 2018 S04P station locations along the eastern end of the nominally 67°S line. Planned stations that were not executed due to a medical situation are shown in red.

A couple of days of decent weather and slow downcasts to handle heave ensued. After four stations at 67.5°S (105-108) and an attempt to outrun a storm coming from northwest, Station 109 was aborted when the wind picked up to 45 kts as the ship came onto station (Figure 6). Forecasts had predicted the storm, but not its severity. Knowing that spacing would have to be stretched once again and there was the eventual need to return to the 67°S line, the position of Station 109 was changed to be 6 nm to ENE and it became Station 110, which in spite of several intermediary assessments, took place after an 11.5 hour delay.

Stations continued with 40+ nm spacing and no particular issues until Station 113, which was once again inflicted with stronger winds than expected and resulted in a 13-hour weather delay. A couple of days later there was yet another storm. This one turned out to be a major event, which topped out with sustained 50+ kt winds, a gust at 80.2 kts and a weather pattern turn that sent everything flying and tipped those off shift out of bed. Not wishing to repeat that roll the ship continued westward into the wind some 40 nm away from the planned station position and the final toll was a full day weather delay. In the meantime, station spacing was stretched to 50-60 nm for the remaining pre-slope/pre-boundary current section of 67°S line.

After the weather delay, the rosette went in the water on Station114 (the first station to the north of the 67°S line in preparation for the coastal approach). Winch speeds were kept to the 15-17 m/min range down to 800 m, after which accelerations were made as slowly as possible carefully avoiding the periods of strong swell (heave). It was a long, but successful cast. It was around this time that it was once again noted that the outer armor of the wire was beginning to open up, so on the long transit between stations 117 and 118 another 300 m of wire was cut and the wire reterminated

(Table 2). As the weather continued to improve and promised to stay that way, hopes rose for a successful completion of the cruise with the chance to resolve the boundary current with 10 nm spacing and the slope to shelf region with a perpendicular approach and 500 m jumps in bottom depths.

Unfortunately, this was not to be. After a coastal approach at the eastern end of the line had been finalized and the timing agreed upon by science, the MPC and Captain, and not long after Station 120 (the last station prior to the 10 nm spacing) had gone in the water, a medical situation arose causing a stop to science per NSF. Station 120 was completed and the ship proceeded transit to Punta Arenas with all possible speed.

2.14 The Final Tally

A total of 117 of the 120 attempted stations were successfully occupied producing CTD-O/rosette/fluorometer/transmissometer/LADCP/UVP profiles. For a variety of reasons (See individual sections of this report) of these 117 stations: 110 provided UVP results (no UVP on stas. 4, 6,7-8, 45-47); 111 provided LADCP results (no LADCP on sta. 3, no upward looking on 6-7, no downward looking on 4, 5 and 117); for 2 stations (901 and 115) the FLBB was dark; and on 3 (stas. 1-3) the altimeter failed. There were 3 aborted stations (9, 104 and 109). With a few notable exceptions, casts were made to within 8-15 m of the bottom. Water samples (up to 36) were collected in 10 L Bullister style Niskin bottles at all stations providing water samples for CFCs/SF6/NO2, Total DIC, TAlk, pH, dissolved oxygen, nutrients, salinity, and on some stations for DOC, DI13/14C, HPLC, POC, Rare Earth Elements (REE), neodymium, Helium/noble gases, δ18O, and Nitrate δ15N/δ18O. Underway surface pCO2, temperature, salinity, dissolved oxygen, DIC, pH, TAlk, samples were measured, and multi-beam bathymetry and meteorological measurements were collected during most transits. Underway samples were not taken on the final transit to Punta Arenas from Station 120. All other underway measurements ended before entering at the Chilean EEZ at 09:13 (UTC) on May 10th. It should be noted that clearance for sampling was requested and eventually granted by the Chilean government. However, notice was not given until the beginning of May when it was requested that a Chilean observer be picked up on May 8. This action would have put end to science, so the clearance was not used. A total of 18 floats (6 biogeo –chemical, 2 EM-APEX, 5 Argo, 5 ALTO) floats were deployed for the SOCCOM program, APL, FSU and CSIRO, respectively. 20 surface drifters were deployed for the Global Drifter Program. The ship arrived in Punta Arenas harbor on May 13th one day early due to the medial situation, however as there was no place to tie up. Late in the evening a place was found on the dolphin extension at the end of the pier and on the 14th, cleared by customs science was allowed to go onto dry land. Loading and unloading howver could not be done from this pier and there was no promise of a place at the regular Prat Pier until 16:30 on May 15th. On the 14th, one set of frozen samples was picked up and the rosette was lifted by the crane from the winch outside the Baltic Room to be placed on the deck for loading, but full deMOB was planned for the 15th, finishing up with the container offload on the 16th.

Although difficult to assess due to constantly changing plans, some rough estimates can be made as to the overall success of the cruise. Initially over the scheduled 67 DAS an ambitious 158 stations were roughly sketched out covering ~4107 nm of track with nominally 30 nm or less spacing along with another 1011 nm of transit (not including the transit to/from the last stations). Including the planned 8 day transit at the start, 5 day transit at the end, the 4.67 days of transit between lines, and the extra day supplied by the Dateline crossing this left 50.33 days, i.e. an average of 3.2 stations/day. On the outside this sounds like a reasonable number, however it overlooks: a) the average between station ship speed of the NBP = 9 kts and long transit speed of 10 kts, the slow progress of the ship in older ice, and the 1-3 weather days occurring 4-5 days on average in the Southern Ocean, particularly for an eastbound cruise.

The 2018 cruise managed 117 stations (74% of the planned stations), to cover 3766 nm (91.7%) of the planned track and had 2042 nm of transit (twice that planned). However, there are a number caveats to these raw numbers.

Although the intention was to get to 500 isobath on all the shelves with 500 m jumps in bathymetry on the slope approaches, none of the planned meridional lines did either.

The 2018 occupation did manage to do both on the 150°W line.

The inability of the 2018 cruise to do the same on the 170°E, 170°W and 103°W lines had everything do with ice and lack the time to break through it.

The inability of the 2018 cruise to do the same at the eastern end of the line was due to the necessity of stopping the science due to the medical situation.

The lack of time (as well as the ice extent itself and intensity of storms) noted above was to some degree caused by the late departure date resulting from ship scheduling conflicts. For example, one can compare the extent of ice in Ross Basin in the middle of March to that seen on April 2nd when the ship arrived at Station 31 (Figure 7).

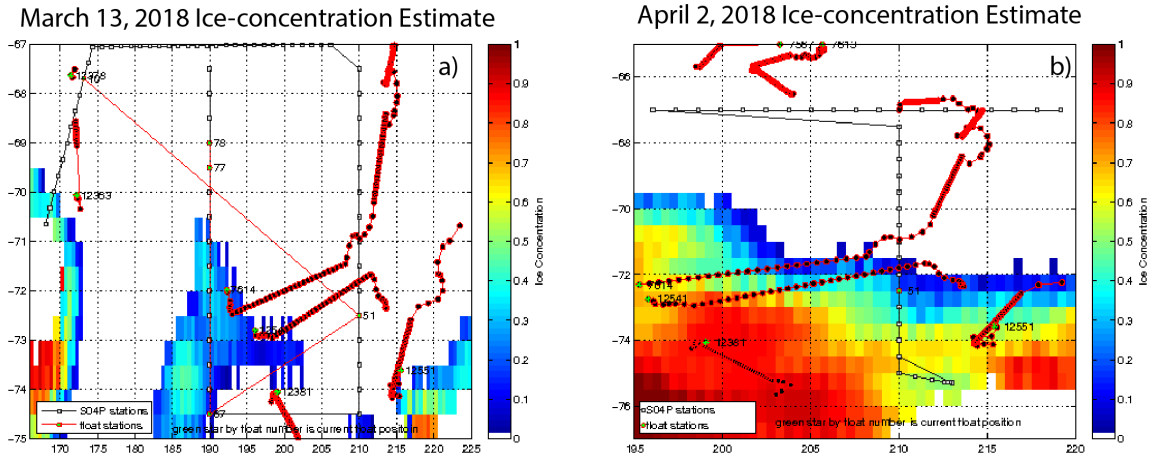


Fig. 2.6: Winch and between station speeds: upper left panel - time from the time of start of cast to the time of end of cast divided by the total distance from surface to bottom and back again; upper right panel – same as left panel but removing the time necessary for tripping bottles; lower left panel – time between casts compared for distance from the first station, color shading indicates latitude; lower right panel - time between casts compared for station number, color shading indicates distance between stations. Note that the cast used to re-lay the wire has been relabeled as station 132.

There were a total of 6.5 days of obviously weather related delays and no time that can clearly be described as a wire related delay. However, it is difficult to measure the true impact of the weather or the wire separately because more often than not bad weather not only caused the inability to put the rosette in the water, it also caused slow winch speeds, and worsened the state of the wire, which in turn led to the need to cut and reterminate. Bad weather in the north, more often than not combined with the need to reterminate, led to the decisions to head south (i.e. the multiple transits). The time lost to reterminations as well as weather was mitigated by the turns to the south, but clearly the integrated length of these transits also had a delaying effect. It should be noted that one advantage of the multiple shorter transits, compared to the initial plan allowed the various science groups to recoup and always be ready for full sampling of upcoming stations. Also, the original plan which mimicked the 2011 westward transit from the southern end of 150°W line to the southern end of the 170°W clearly would not have ben possible given the ice conditions found in March/April in 2018.

Have said this, the integrated effects of wire and weather can be discussed in terms of the winch and ship speeds (Figure 8). Beginning with the time it took to complete casts (upper left panel). The up/down average speed of casts on S04P was 36.1±5.1 m/min. There were 12 fast casts with average speeds greater than the mean plus the standard deviation accounting for a time savings of about 7 hours. There were 14 slow casts with average speeds less the mean minus the standard deviation accounting for delays of ~13 hours. If one takes the number of bottles tripped into account (assuming 45 seconds for each bottle), the average winch speed was 41.3±5.8 m/min (upper right panel). There were 18/15 fast/slow casts according to winch speed accounting for a time savings/delay of 1/19 hours. So one could say that slower than average winch speeds (caused by wire and weather/sea state) offset by faster than average winch speeds produced a loss of about 18 hours.

The speed between casts can also be considered. Note, this is not actually ship speed because it includes weather delays and anything else that might have slowed the start or end of cast. Nevertheless, for starters one can compare

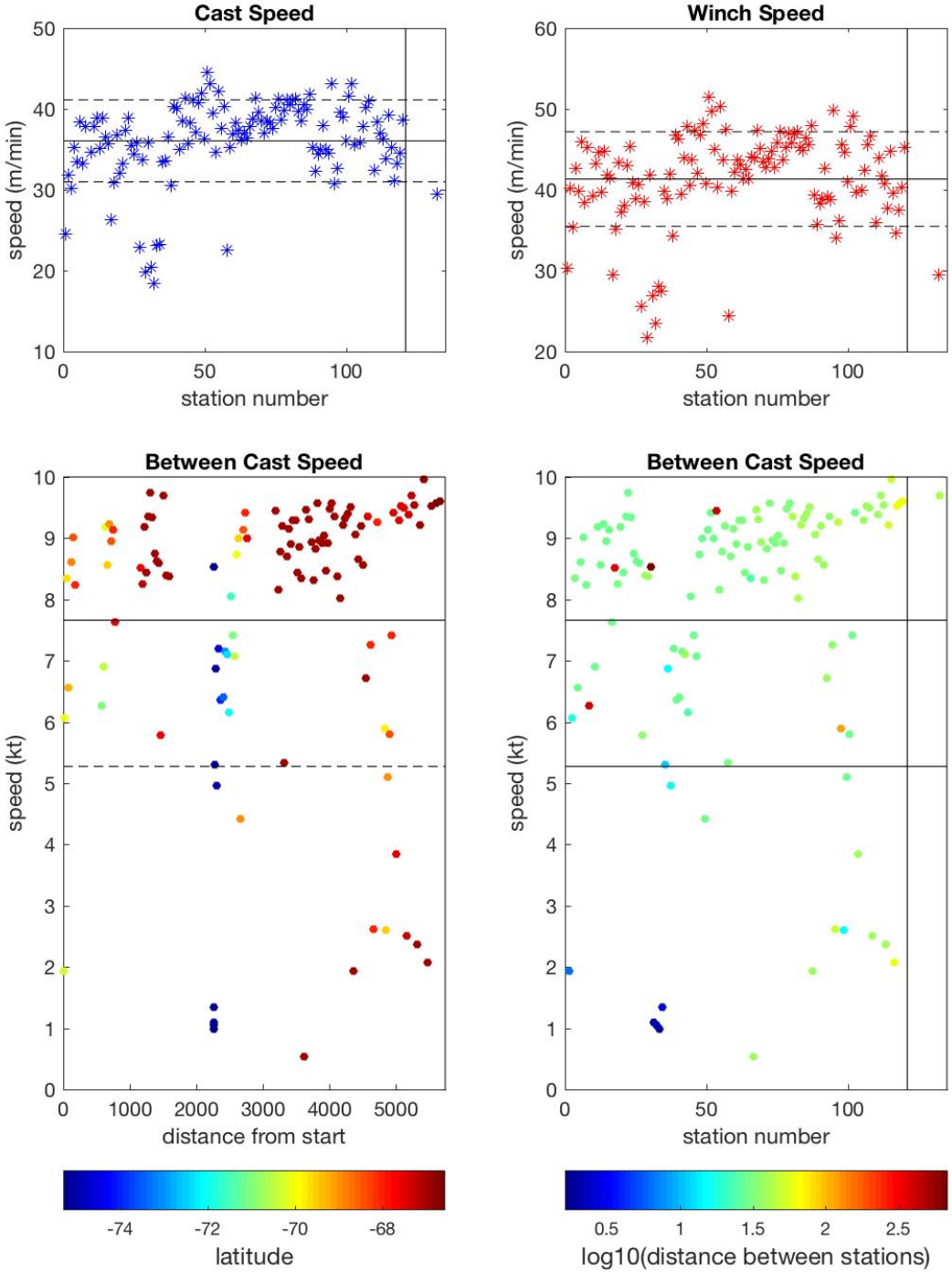


Fig. 2.7: Ice concentration from satellite mapped by S. Escher at UCSD/SIO: a) ice concentration estimate for March 13, 2018; b) ice concentration estimate for April 2, 2018.

to what might have happened had there been no delayed start or end of casts, and no weather, sea state or ice delays. The original number for average ship speed between stations supplied by the NBP was 9 kts. Over the 117 transits between the first and last station, the mean speed between casts (vbc) was 7.7±2.4 kts (lower left and lower right panels). The distance weighted mean vbc was 8.0 kts. There were 43/74 transits that averaged faster/slower than 9 kts. When distances are short however, one should not expect to see the average speed approach such value. Considering only the 69 transits (totaling 3637 nm) for which the average vbc was less than 9 kts over distances greater than 10 nm, the total time used was 626 hours. Had these between cast speeds occurred at 9 kts the time used would have been 404 hours, suggesting that slow times between casts (due to weather, sea state, ice, fog or technical delays, but not slow winch speeds) accounted for a loss of 9.25 days. Figure 5 also highlights the affect of ice at lower latitudes (lower left panel) and the fact that longer distances between station did not necessarily correlate with faster speeds, though very close stations (~10 nm apart) did see slower speeds.

The 2018 S04P cruise presented a great many challenges. We would like to thank the officers and crew of the RVIB N.B. Palmer who have done an excellent job supporting S04P science. In particular, we wish to thank the Captain and Mates on the bridge for their efforts to get us where we needed to go and to keep us all safe in rough conditions. In particular, we would like to thank the galley crew for the abundance and quality of the food produced on this very long voyage. We also wish to thank all the ASC personnel onboard (MPC, MTs, IT, ET) for their constant assistance and sincere support throughout the cruise, and give a special note thanks to our MPC for all his diligent efforts to provide both science and the bridge with what was needed in all situations. The successes of this expedition have been in no small part due to efforts of all the ECO and ASC personnel: they have worked with us every step of the way, to fix everything from the smallest detail to the greatest problems, all the while speeding us along so that we could sample as much of the full line as possible. Last but not least we wish thank all those who sent us ice and weather reports and up to date circulation information without which the choices we made would not have been possible and far more time would have been lost to delays and failed attempts to reach the most southern positions. These include: S. Escher, S. Purkey and L. Talley (SIO/UCSD), J. Girton (APL) and those at the Fleet Weather Center (San Diego), SOPP Meteorology (McMurdo) and the National Ice Center.

CHAPTER

THREE

CTD AND ROSETTE SETUP

For S04P 2018 the new STS 36 place yellow rosette and bottles, built in 2017, were used. These rosette and bottles was built before P06 2017, making this the second time this package has been deployed. The bottles were made with new PVC, with new non-baked o-rings and electro-polished steel springs. This represents a change from the past, where on GO-SHIP cruises using ODF equipment before P06 2017 o-rings were baked for 3 days at 100°C at 1-3 Torr in a sweeper gas of hydrogen. Springs were painted and Tygon tubing added to the ends to prevent paint wearing away from bottle firing. As on P06 2017 no sample contamination has been noticed by the change in o-rings and springs. The package used on S04P 2018 weighs roughly 1350 lbs in air without water, and 2200 lbs in air with water. The package used on S04P 2018 weighs roughly 800 lbs in water. In addition to the standard CTDO package on GO-SHIP cruises two LADCPs and one UVP were mounted on the rosette. During the cruise we encountered numerous problems, most notably the unravelling of the wire through the cruise resulting in multiple re-terminations. We describe all of the above in more detail in the sections below.

3.1 Underwater Sampling Package

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

CTD and cage were horizontally mounted at the bottom of the rosette frame, located below the carousel for all stations. The temperature, conductivity, dissolved oxygen, respective pumps and exhaust tubing was mounted to the CTD and cage housing as recommended by SBE. The reference temperature sensor was mounted between the primary and secondary temperature sensors at the same level as the intake tubes for the exhaust lines. The transmissometer was mounted horizontally on the lower LADCP brace with hose clamps around both of its ends, avoiding shiny metal or black tape inside that would introduce noise in the signal. The fluorometer and backscatter meter, oxygen optode, and altimeters were mounted vertically inside the bottom ring of the rosette frames, with nothing obstructing their line of sight. The 150 KHz bi-directional Broadband LADCP (RDI) unit was mounted vertically on the bottom side of the frame. The 300 KHz bi-directional Broadband LADCP (RDI) unit was mounted vertically on the top side of the frame. The LADCP battery pack was also mounted on the bottom of the frame. The LADCP and LADCP battery pack were mounted next to each other at the beginning of the cruise. If we imagine the LADCP being north on the rosette, the LADCP battery was mounted west, the CTD mounted east, and the UVP mounted south.

Equipment	Model	S/N	Cal Date	Stations	R
Rosette	36-place	Yellow	_	901-120	S
CTD	SBE9+	1281	_	901-120	S
Pressure Sensor	Digiquartz	136428	Dec 17, 2017	901-120	S
Primary Temperature	SBE3+	35844	Jan 30, 2018	901-120	S
Primary Conductivity	SBE4C	44546	Feb 8, 2018	901-120	S
Primary Pump	SBE5	54377	_	901-12, 75	U
Primary Pump	SBE5	58691	_	13-14	U
Primary Pump	SBE5	51646	_	15-74	A
Primary Pump	SBE5	58692	_	76-120	U
Secondary Temperature	SBE3+	32309	Jan 30, 2018	901-120	S
Secondary Conductivity	SBE4C	41880	Feb 2, 2018	901-120	S
Secondary Pump	SBE5	54890	_	901-14	U
Secondary Pump	SBE5	55644	_	15-120	A
Transmissometer	Cstar	CST-1803DR	Sep 16, 2016	901-120	T
Fluorometer Chlorophyll and Backscatter	WetLabs	FLBBRTD-3698	Sep 23, 2014	901-120	U
Primary Dissolved Oxygen	SBE43	430255	Nov 22, 2017	901-120	O
RINKO Oxygen Optode	JFE Advantech RINKO-III	0296	Apr 7, 2017	901-120	S
Reference Temperature	SBE35	0035	Feb 01, 2018	901-120	S
Carousel	SBE32	1178	_	901-120	S
Altimeter	Tritech LPA200		_	901-1	U
Altimeter	Valeport 500	59116	_	2-3	U
Altimeter	Valeport 500	51520	_	4-120	A
Underwater Vision Profiler 5 HD (UVP)	Underwater Vision Profiler 5 HD	207	_	901-120	U
DL *LADCP*	150 kHz Teledyne RDI WHM150	19394	_	901-120	L
UL *LADCP*	300 kHz Teledyne RDI WHM300	12734	_	901-120	L

3.2 Winch and Deployment

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 S04P 2018, and multiple times afterwards.

The deck watch prepared the rosette 10-30 minutes prior to each cast. The bottles were cocked and all valves, vents and lanyards were checked for proper orientation. Any biofouling noted was cleaned off the outsides of the rosette before the next cast, and the insides of the bottles were checked for biofouling and sprayed down. LADCP technician would check for LADCP battery charge, prepare instrument for data acquisition and disconnect cables. The UVP battery was monitored for charge and connectors were checked for fouling and connectivity. Once stopped on station, the Marine Technician would check the sea state prior to cast and decide if conditions were acceptable for deployment. Recovering the package at the end of the deployment was the reverse of launching. The Marine Technician would perform a quick check and rinse of the rosette and block before allowing samplers into the Baltic room. The block was rinsed with water to remove ice that would form, preventing ice from landing on heads or in samples.

3.3 Maintenance and Calibrations

During S04P 2018 routine maintenance was done to the rosette to ensure quality of the science done. Actions taken included rinsing all electrical instruments on the rosette down with fresh water after each cast. Care was taken not to rinse the spigots and other parts of the bottle that might be touched by samplers in order to not contaminate the samples. After each cast salt water filled syringes were connected to the plumbed lines to rinse the sensors between casts. Salt water was used instead of fresh water due to the lower freezing point to prevent it from freezing when

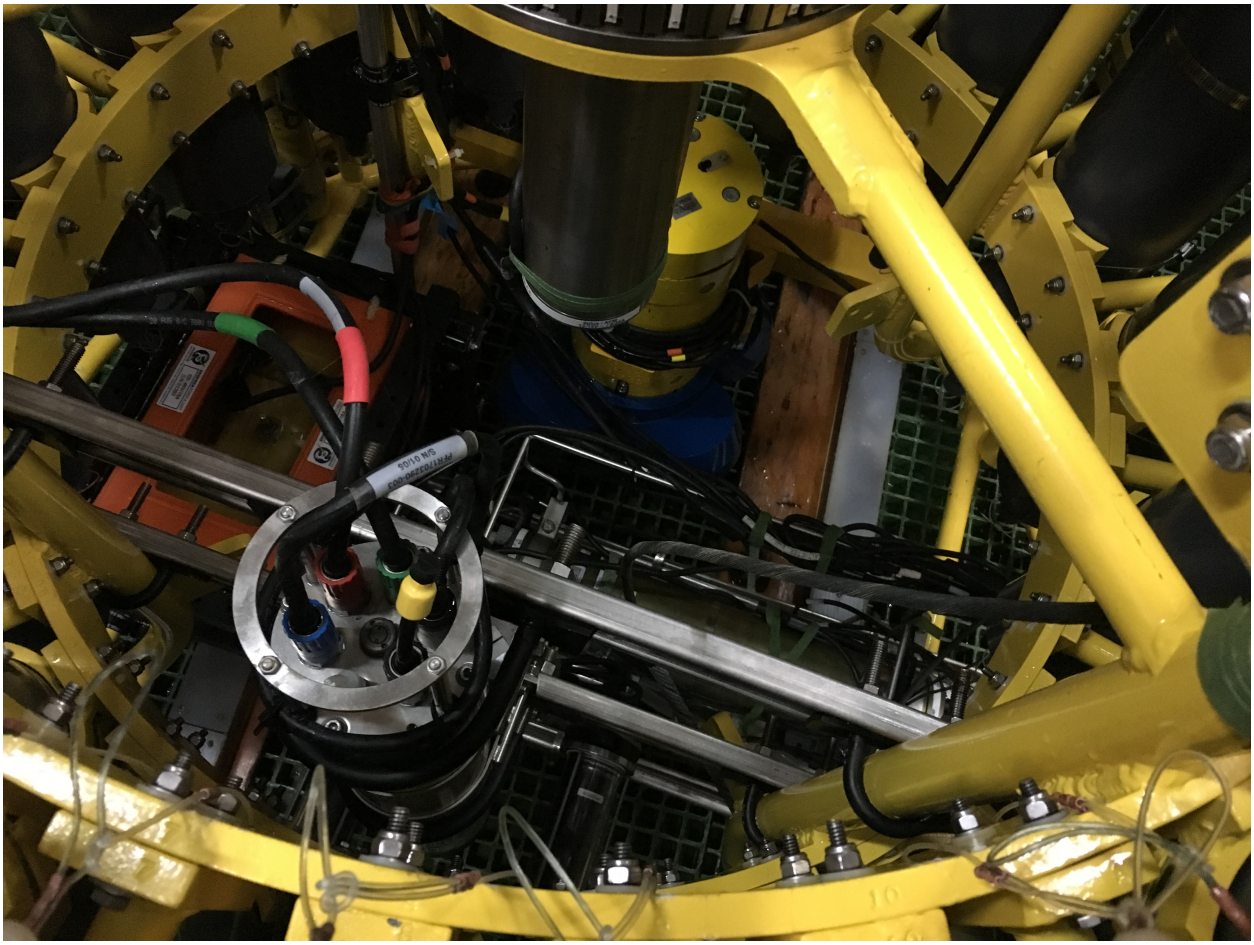


Fig. 3.1: Package sensor setup from top down, with the top of the picture as north.

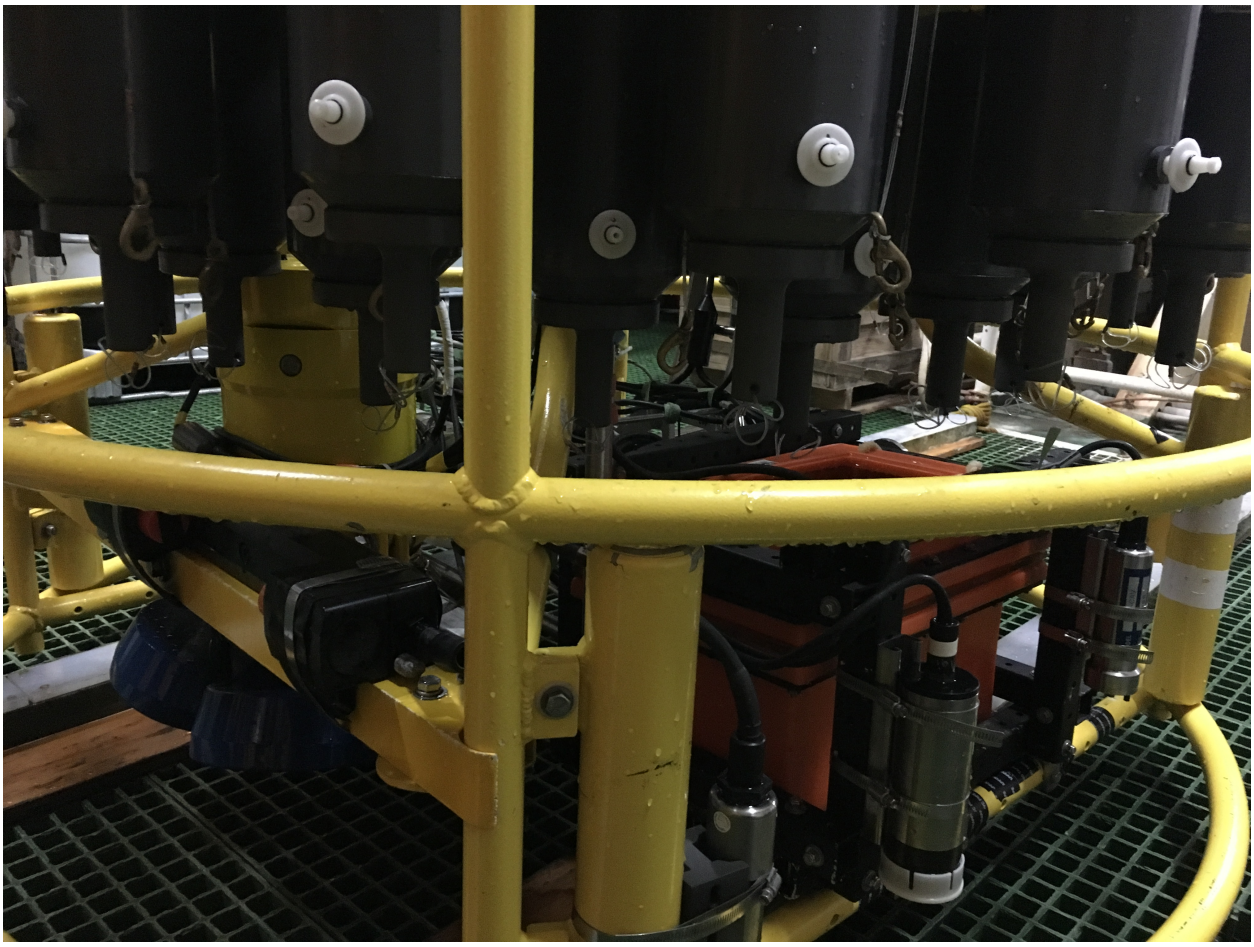


Fig. 3.2: Package sensor setup from northwest, to show in order from left to right downward LADCP, transmissometer, altimeter, fluorometer and backscatter meter, and RINKO oxygen optode.

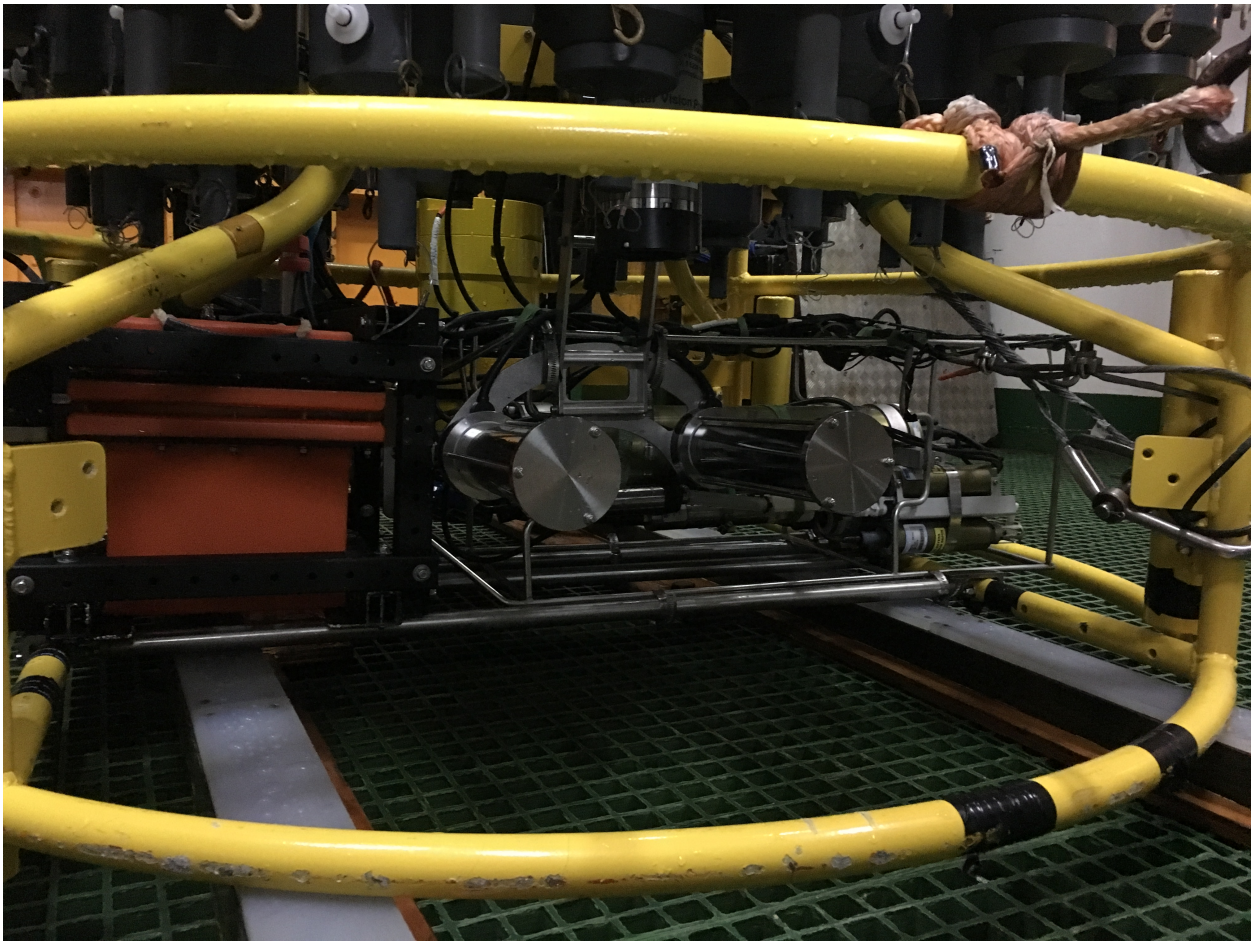


Fig. 3.3: Package sensor setup from south to show UVP, CTD, LADCP battery.

exposed to the outside air. The rosette was routinely examined for valves and o-ring leaks, which were maintained as needed. SBE35RT temperature data was routinely downloaded each day.

Every 20 stations, the transmissometer windows were cleaned and an on deck blocked and un-blocked voltage readings were recorded prior to the cast. The transmissometer was also calibrated before and after the start and end science operations. The RINKO oxygen optode was also taken off during transit to station 54 to perform a zero saturation and full saturation calibration. The same calibration was performed at the of the cruise during transit to Punta Arenas. Black tape was put on the outside of the FLBB sensors to do a calibration "dark cast". Dark casts were done at the beginning and end of the cruise to measure pressure effects on the sensor. A dark cast was performed on casts where depths reached at least 2000 meters, preferably average full ocean depth for the cruise, and where previous profiles showed little FLBB activity.

3.4 Problems

Some complications were overcome to complete CTDO/rosette/LADCP/UVP station casts for S04P 2018. Throughout the cruise the primary and secondary sensors would occasionally report a small spike in salinity every 10-20 casts, at odds with the other line. This occasional spike was small and intermittent, leading to the decision to allow the spike to be removed in processing without further inspection of the CTD. 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. In rough weather more bottles would be fired on the fly, ranging from the top two bottles to the extreme case of a whole cast fired on the fly.

On station 2, cast 1 the primary line froze before entering the water. The package was recovered, tepid salt water was run through the plumbing, and the package was put in on cast 2 with no problems. On station 3 the package touched the seafloor due to altimeter problems. An estimated 20 meters of wire was paid out before stopping and pulling the rosette back up, of which the tension did not change appreciably after touching the bottom. The 20 meters of wire paid out lead to a small increase in slack across 2700 meters of water. On station 18, cast 1 the cast was canceled due to large wire tensions and large variations in wire tensions early on in the cast. On station 58, cast 1 the cast was canceled due to large wire tensions and large variations in wire tensions early on in the cast.

We were required to switch Niskin bottles on the rosette due to leaking. On station 17 bottle 22 was observed to be leaking from the bottom collar seam, prompting the replacement with a new bottle. On stations 77 and 78 bottle 26 was observed to be leaking. Prior to station 79 the bottle was inspected and a scratch was noticed across the surface of the bottom collar. A bottle swap was attempted before station 79, but during leak testing the replacement bottle was also found to be leaking. The previous bottle was put back on with minor sanding in order to keep to schedule for station 79. When the bottle came up for sampling after station 79 and was still leaking, another spare bottle that passed leak testing was found and placed on the rosette. On station 80 bottle 26 did not leak. On station 111 bottle 9 was observed to leak from the bottom, and upon inspection scratches were noticed. The bottom of bottle 9 was resurfaced and on station 112 the bottle 9 did not leak. When bottle 9 leaked on station 115, the bottom end cap was replaced, and for the remainder of the cruise the bottle did not leak.

During cocking and uncocking the rosette we had inner cap lanyards snap at multiple times during the cruise. The lanyards were thought to develop excessive wear due to the force required to cock the bottle, where the lanyard would rub against the inner lower collar of the bottle. The wear on the lanyards were thought to build up over 2 cruises, as few if any cap lanyards were replaced after P06 2017 or before S04P 2018. At multiple points during the cruise the bottles were checked for wear on the inner lanyards, and any suspicious lanyards were replaced.

We had multiple problems with altimeters at the beginning. A Tritech LPA 200 altimeter was initially installed at the beginning of the cruise with range of 200 meters. The test cast did not reach full ocean depth and so we did not have a chance to test the altimeter in water. On the first station the altimeter did not lock in at all, returning a 200 meter reading at all times. After navigating the rosette to within an estimated 30 meters off the bottom with multibeam reading, we stopped and started ascent. The Tritech altimeter was taken off and replaced with a SIO Valeport altimeter with effective range of 100 meters.

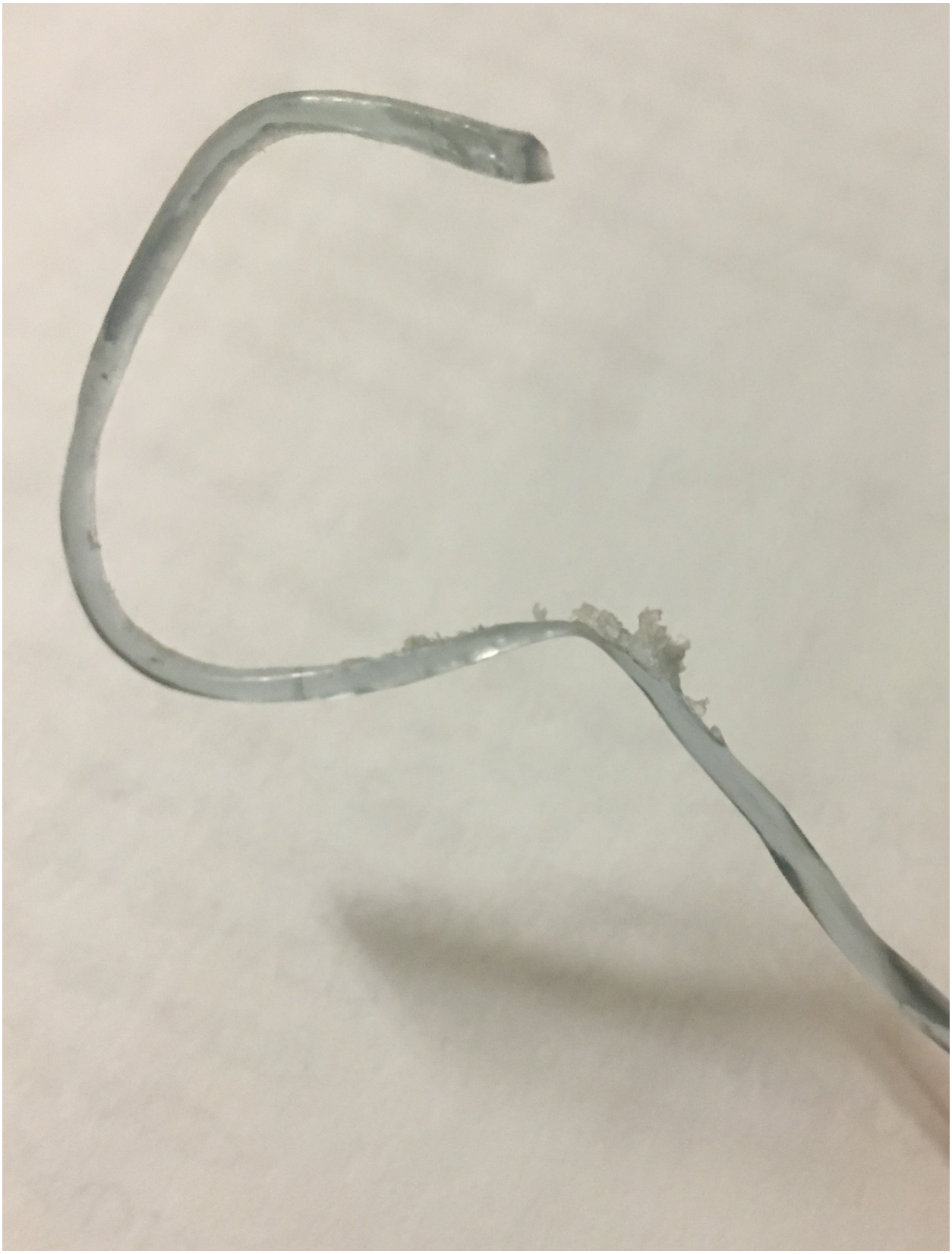


Fig. 3.4: Wear on an inner cap lanyard. This lanyard was cut and replaced before it snapped.

On station 2, cast 2 the Valeport altimeter also did not show a change in reading. The package descended to a maximum pressure of 2011 decibars, where while soaking the rosette we saw a small dip in the altimeter from ~100 meters to 94 meters. Post cast we decided that the reading was real, and we simply stopped descending too early. On station 3, cast 1 we continued past the multibeam depth, hoping the altimeter would kick in while we proceeded at 20 meters per minute. At some point the altimeter quickly dropped from ~100 meters to 1 meter and then kicked back to ~100 meters, at which point the pressure and the tension held constant while the winch continued to pay out at 20 meters per minute. The bottom bottle was fired, then the rosette was pulled up, at which point the altimeter quickly changed from ~100 to 10, 20, 30 meters and rising until it reached 100 meters in less than a minute. While not having the cables to interrogate the altimeter, it is believed that the SIO Valeport altimeter was previously used on an ROV, which would have been set to 0 to 10 meters instead of 0 to 100 meters. After station 3 an ASC Valeport altimeter was placed on the rosette, which worked as expected in the 0 to 100 meter range for the remainder of the cruise.

Post cruise, salt formation and corrosion was noticed on the Tritech altimeter at the seams. This suggests that water leaked into the altimeter during the first cast, shorting electronics and rendering the altimeter inoperable. This interpretation is consistent with recollections of previous failures of the Tritech altimeter due to water seeping into the case. The altimeter was not opened up on the ship and will be further inspected back in San Diego.

We encountered multiple problems with SBE 5P pumps on this cruise. On stations 10, 11, 12, and 14 we encountered situations where all sensors on the primary line would suddenly show an offset and vastly increased noise at depth on the downcast. This offset and noise would disappear later on the upcast, within a few hundred meters of the problem's starting depth. Triage included flushing the plumbed line with fresh water at the surface for 30 minutes, swapping the pump cable, and finally swapping the pump. On station 13 the cast proceeded smoothly with no problems on the plumbed line with the new pump. On station 14 the plumbed line with the new pump proceeded to show the same symptoms as the previous pump. Both the second failed pump and the pump on the working line were replaced with ASC SBE pumps as a precautionary measure. Both pumps were judged to have failed within a short period of time. Looking at the service logs from Seabird the pumps were checked out, considered to not show problems, and sent back out. A more extensive writeup has been written and will be sent to Seabird alongside the pumps.

On station 74 the ASC pump on the primary line failed similarly to the pump failures between stations 10 and 14. By mistake, a failed pump was put on to replace the ASC pump, which showed the same failure as it did before on station 75. A new SIO pump was put on before station 76 and was used for the rest of the cruise without problems. The pumps on the secondary line worked well for the majority of the cruise, with one odd failure on station 52. Thorough flushing of the pump after station 52 was done, and subsequent casts showed no problems.

We encountered repeated biological fouling on multiple stations in the latter half of the cruise. On multiple casts sea snot was found draped on and in the package, on occasion getting inside the bottles. On two casts we caught what looks like a jellyfish, once on a spring inside a bottle and once on the lanyards. All biological fouling was removed promptly and any sign of biological fouling prompted the checking of bottles for inner fouling. While checking inside the bottles for fouling some discoloration was noticed on a few of the springs. The springs were removed and inspected, of which the discoloration was found to be dried biological matter. Upon removing the matter the springs were found to be rougher in those locations. It is not known whether the springs were rougher to start due to imperfections in electro-polishing, creating surfaces for the matter to stick onto, or the biological matter created the roughness on the springs. Regardless, all springs will be sent for polishing after the cruise.

3.5 Wire Situation

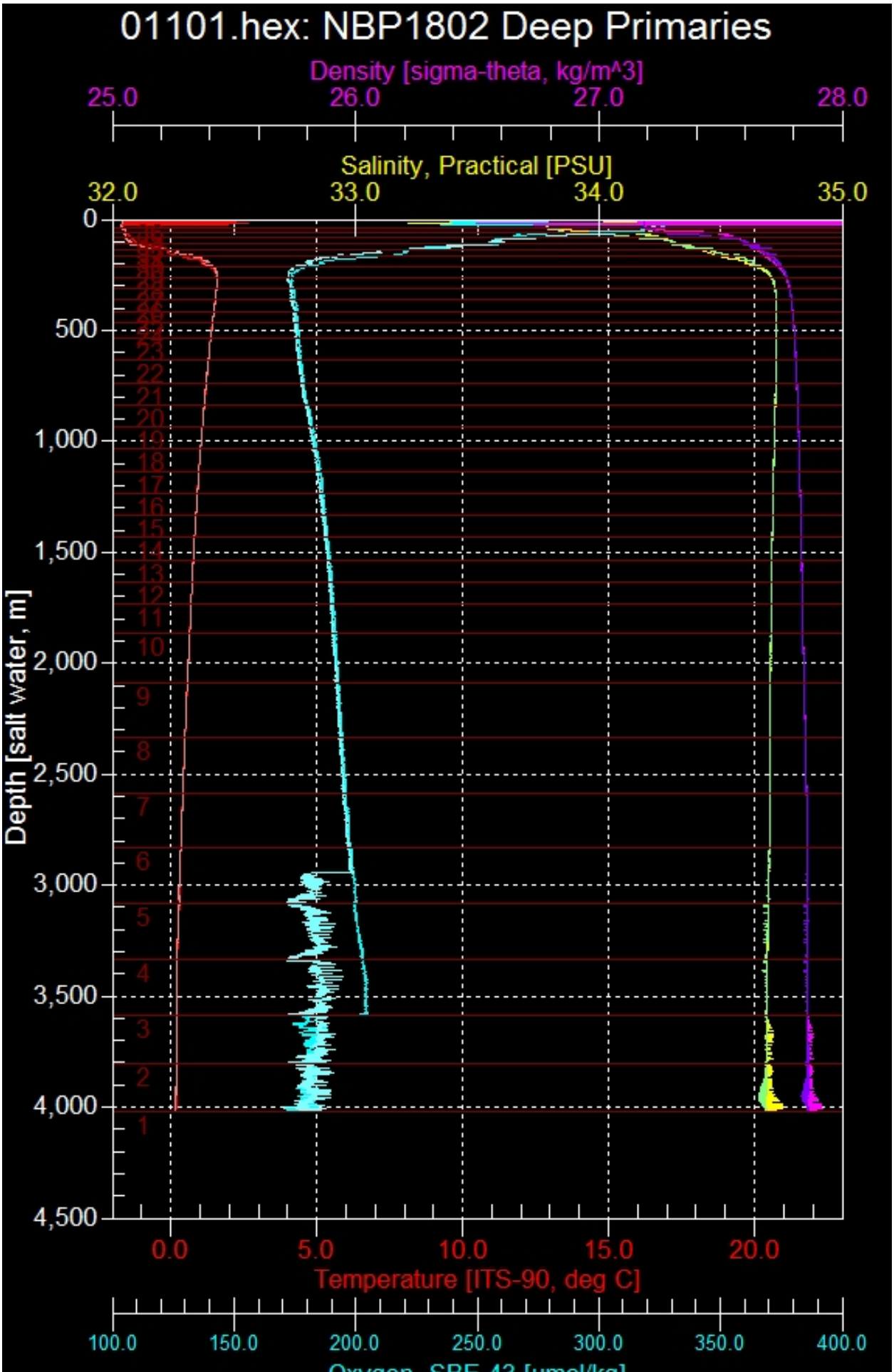
We re-terminated the .322 cable several times during the trip. The first instance was to remove a kinked section. Subsequent re-terminations were done after the marine techs removed questionable sections of cable.

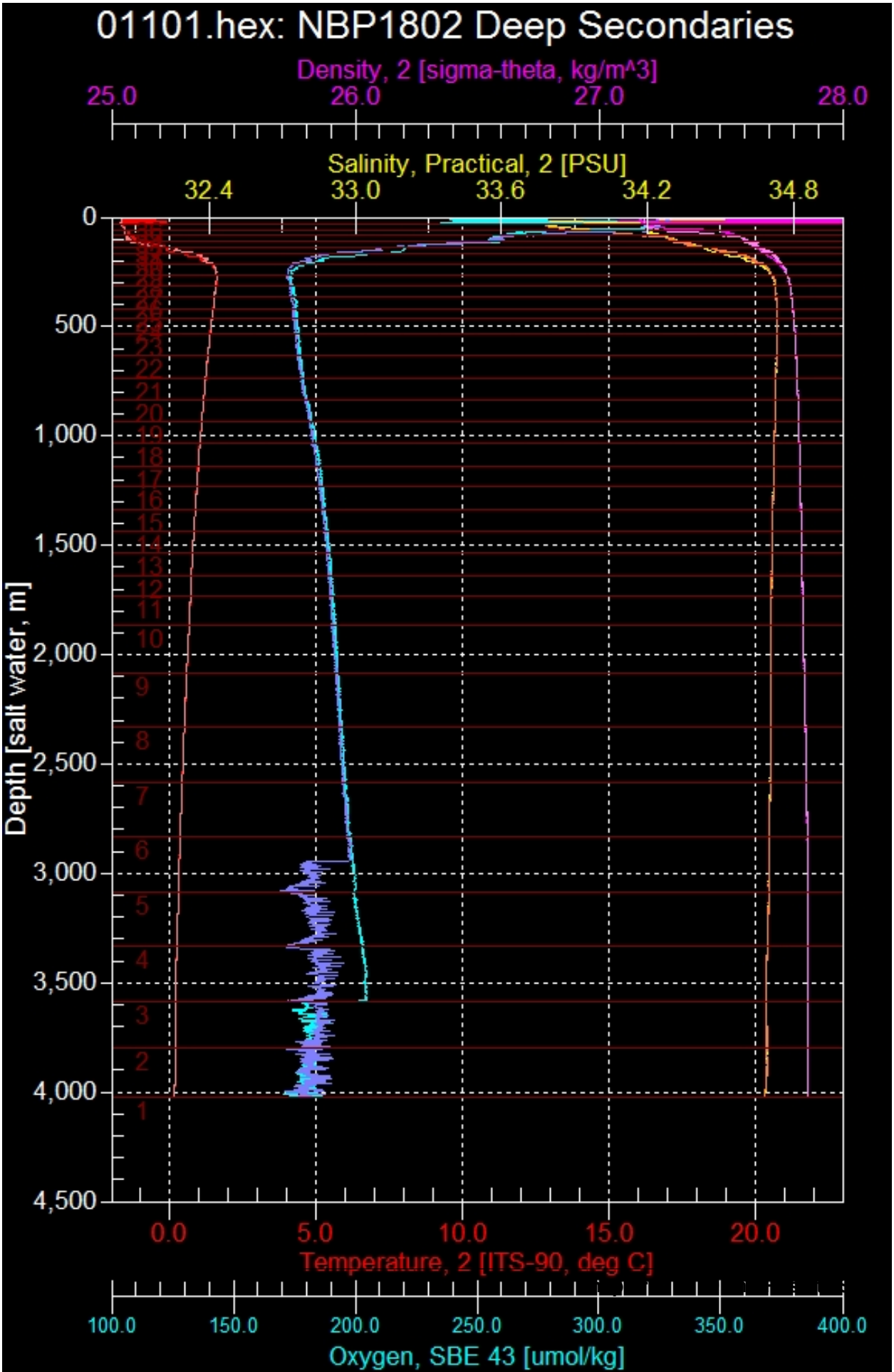
The kink(s) were probably caused by rough seas during deployment and recovery of the rosette at the air/sea transition. They appeared around the point on the cable that would be running on the overboarding sheave as the rosette entered the water and during periods of high seas and high winds.

The outermost layers of cable on the drum were not winding on to the drum evenly and exhibited a 'rumpled' appearance as though the outer layer of wire had been pushed back over the inner layer. Also, the outer layer became more


14 V
0-5 V
2 - 200m
Iritech
MODEL: LRPA200/10-S
SER.NO: 9147.221666

Fig. 3.6: Corrosion formation at the seam of the Tritech altimeter where the altimeter rested.


01101.hex: NBP1802 Deep Primaries
Density [sigma-theta, kg/m^3]
25.0
26.0
27.0
28.0
Salinity, Practical [PSU]
32.0
33.0
34.0
35.0
Depth [salt water, m]
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
0.0
5.0
10.0
15.0
20.0
Temperature [ITS-90, deg C]
100.0
150.0
200.0
250.0
300.0
350.0
400.0


01101.hex: NBP1802 Deep Secondaries
Density, 2 [sigma-theta, kg/m^3]
25.0
26.0
27.0
28.0
Salinity, Practical, 2 [PSU]
32.4
33.0
33.6
34.2
34.8
Depth [salt water, m]
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
0.0
5.0
10.0
15.0
20.0
Temperature, 2 [ITS-90, deg C]
100.0
150.0
200.0
250.0
300.0
350.0
400.0
Oxygen, SBE 43 [umol/kg]

and more loosely wrapped about the core over time.

It is unlikely that the new 36 place GO-SHIP rosette is the cause of the 'rumpling', as a plausible means for the rosette and EverGrip termination to pull the inner core or push back the outer layer of the cable has not been proposed. However, the 'unravelling' of the outer armor may be related to the net spin of the rosette, which in turn may relate to the positions of the instrumentation mounted on it.

On previous legs aboard the Palmer, ODF has seen net negative rotations (CCW?) from the ADCP data. Initially, the rosette spun the same direction during both pay out and pay in. But, as the cruise progressed, the absolute number of spins would decrease and the direction of the spin would reverse on retrieval. Eventually, on pay out the rosette would spin 10 to 20 times and on retrieval about the same number in reverse; the net spin per cast would be about zero with a slight bias toward negative spin totals.

On S04P (NBP18-02) the rosette's spin was similar save for a reversal in direction. The down cast showed positive spin counts, and eventually the up cast showed negative counts. The net spin trended toward zero and the number of spins towards low double digits.

If the cable's outer armor is twisted in the direction corresponding to a clockwise rotation of the rosette (viewed from above,) the outer armor can loosen. Spun the opposite way, the outer armor would tighten and the inner armor loosen. Assuming that the rosette induces a spin, a clockwise rotation will see less opposition (inner armor winding tight, outer armor loosening up) than ccw spin (outer armor contracting while inner armor tries to expand.)

Sheaves, level wind, previous wire history (hysteresis) can also contribute rotation. There may be some evidence in the ADCP record and wire log to show that there is a contribution to spin correlated with the rotation of the overboarding sheave when wire was trimmed back.

Arranging the instruments to accommodate the UVP and lower ADCP placed the ADCP battery adjacent to the lower ADCP (each over 100lbs) and the upper ADCP opposite the battery, with the UVP opposite the lower ADCP. This created an imbalance the caused a slight tilt to the battery and lower ADCP, and may have presented a skewed drag profile. Mirroring the instrument arrangement could have shown if it affected spin, but we were reluctant to disturb the instrumentation during the cruise. In a future deployment with similar instruments, we could try that mirrored arrangement or stand the CTD vertically and place the battery in opposition to the ADCP.

CHAPTER

FOUR

CTDO AND HYDROGRAPHIC ANALYSIS

PIs

- Susan Becker
- James Swift

Technicians

- Joseph Gum
- Kenneth Jackson

4.1 CTDO and Bottle Data Acquisition

The CTD data acquisition system consisted of an SBE-11+ (V2) deck unit and a networked generic PC workstation running Windows 7. SBE SeaSave7 v.7.26.1.8 software was used for data acquisition and to close bottles on the rosette.

CTD deployments were initiated by the console watch operators (CWO) after the ship had stopped on station. The watch maintained CTD cast logs for each attempted cast containing a description of each deployment event. This cast log included the bottle scheme, any phenomena, and any possible problems.

Once the deck watch had deployed the rosette, the winch operator would lower it to 20 meters in good weather. In rougher weather, the winch operator would lower the rosette to 25 or 30 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 the UVP to activate, and instructed the winch operator to bring the package to the surface. The Marine Technician would signal to the winch operator what was acceptable for rising to the surface. The winch was then instructed to lower the package to the initial target wire-out at 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 would monitor altimeter readings, taking notice 100m from the bottom and slowing quickly to a final stop 10m 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 13 samples.

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

Additionally, the watch created a sample log for the deployment which 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. Syringes filled with salt water was also used due to the higher freezing point, to prevent the fresh water from freezing when exposed to the elements. The tubing was left on the CTD between casts, with the temperature and conductivity sensors immersed in fresh or salt 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.

4.2 CTDO Data Processing

Shipboard CTD data processing was performed after deployment using SIO/ODF python CTD processing software v. 0.3. 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 122 CTD stations were occupied including one test station. A total of 125 CTDO/rosette/LADCP/UVP casts were completed. 122 standard CTDO/rosette/LADCP/UVP 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 S04P 2018 that directly impacted CTD analysis. Issues that directly impacted bottle closures, such as slipping guide rings, were detailed in the Underwater Sampling Package section of this report. Temperature, conductivity and oxygen analytical sensor issues are detailed in the following respective sections.

4.3 Pressure Analysis

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

The Paroscientific Digiquartz pressure transducer S/N: 831-99677 was calibrated on December 12th, 2017 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 901 - 120

	Start P (dbar)	End P (dbar)
Min	-0.6	-0.5
Max	-0.0	0.8
Average	0.2	0.1
Applied Offset		-0.0539

An offset of -0.0539 was applied to every cast performed by CTD 1281. On-deck pressure reading for CTD 1281 varied from -0.6 to -0.0 dbar before the casts, and -0.5 to 0.8 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 -0.0539 dbar.

4.4 Temperature Analysis

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

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

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

A functioning SBE3plus sensor typically exhibit a consistent predictable well modeled response. The response model is second order with respect to pressure, a first order with respect to temperature and a first order with respect to time. The functions used to apply shipboard calibrations are as follows.

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

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

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

Corrected temperature differences are shown in the following figures.

The 95% confidence limits for the whole water column differences are ±0.0046°C for SBE35RT-T1, ±0.0043°C for SBE35RT-T2, and ±0.0026°C for T1-T2. The 95% confidence limits for the deep temperature residuals (where pressure ≥ 2000dbar) are ±0.00067°C for SBE35RT-T1, ±0.00066°C for SBE35RT-T2, and ±0.00059°C for T1-T2.

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

- 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.

4.5 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.

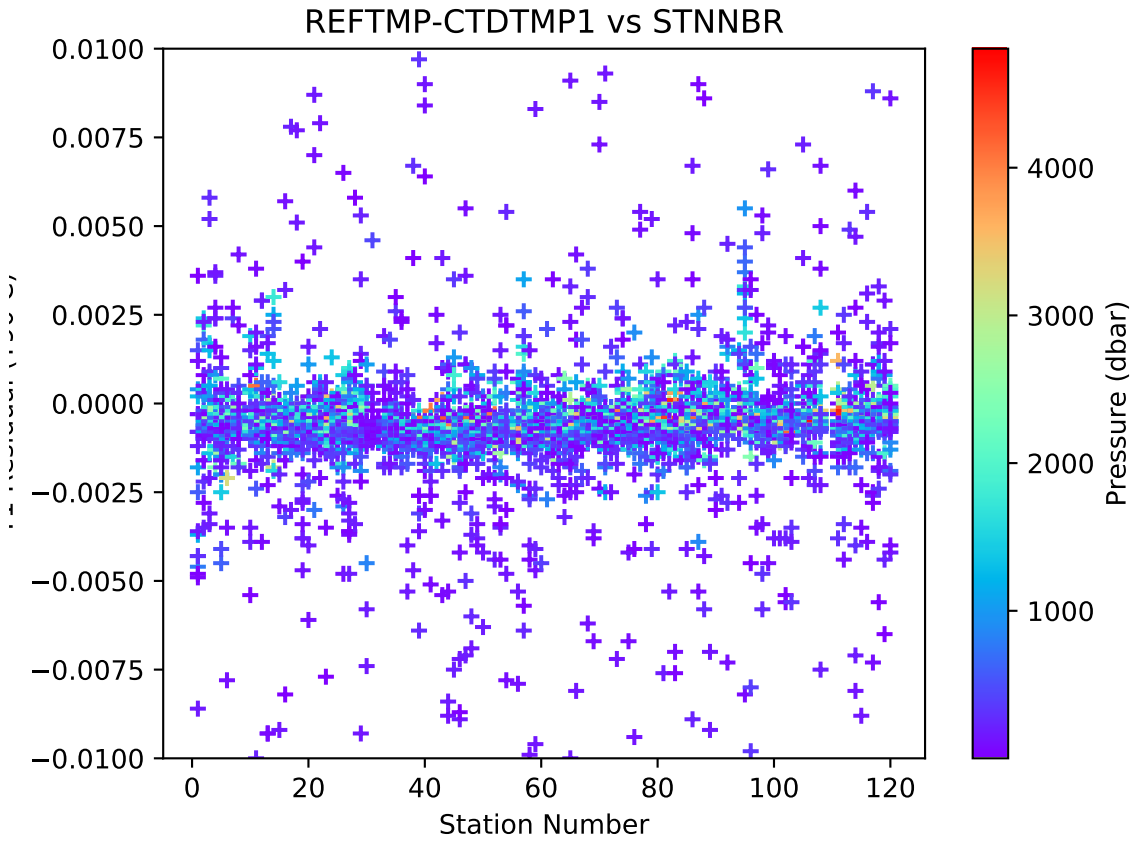


Fig. 4.1: SBE35RT-T1 by station (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

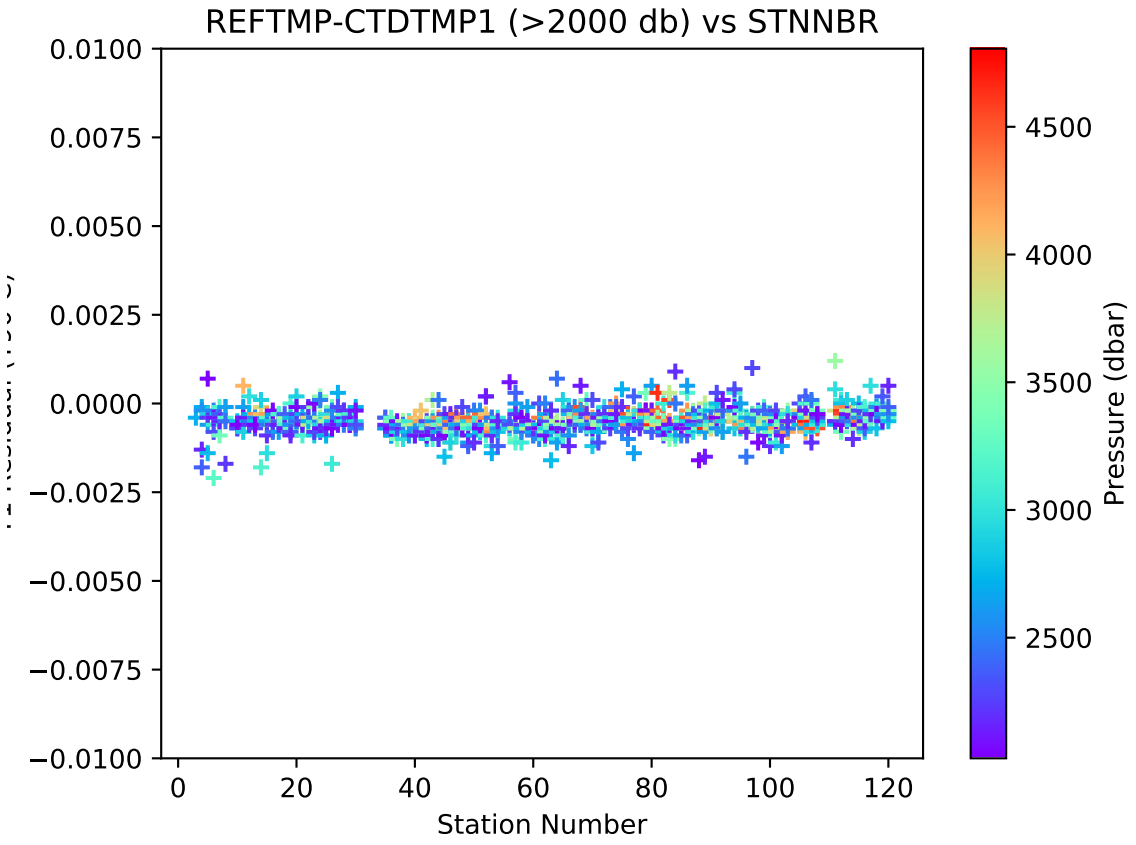


Fig. 4.2: Deep SBE35RT-T1 by station (Pressure $\geq$ 2000dbar).

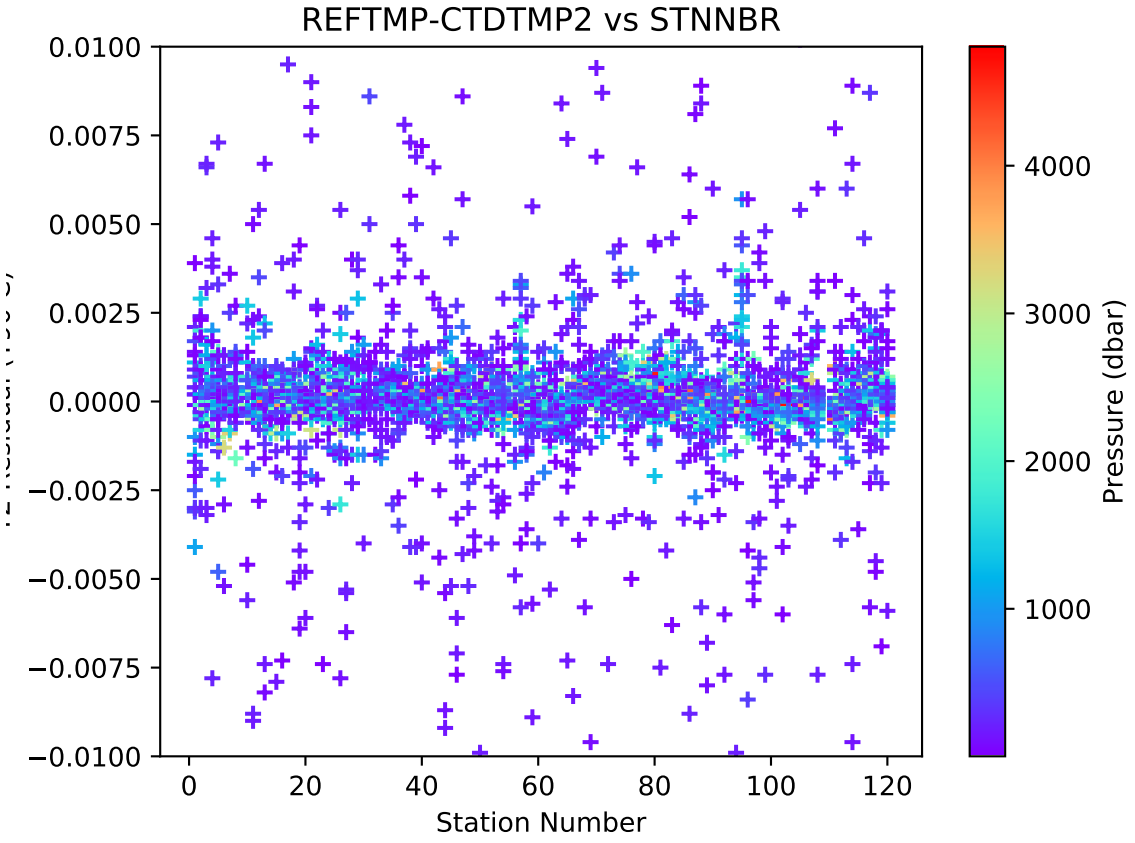


Fig. 4.3: SBE35RT-T2 by station (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

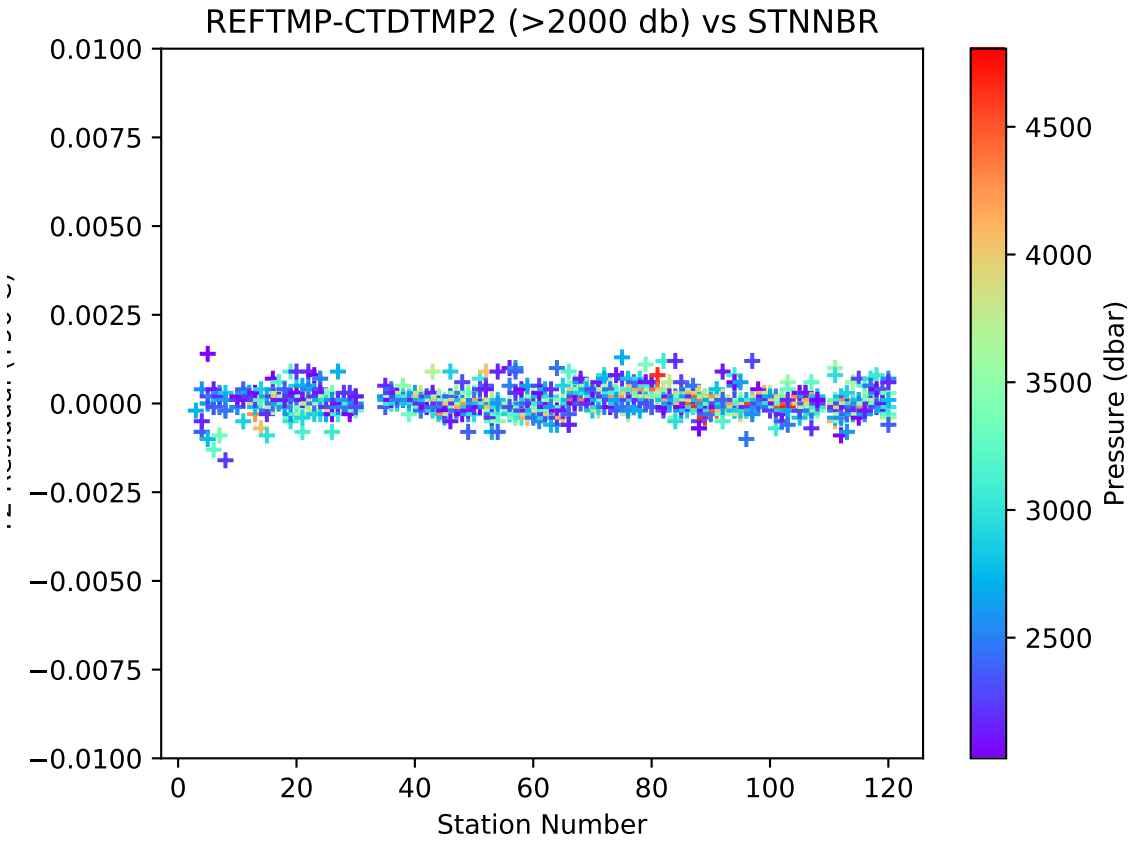


Fig. 4.4: Deep SBE35RT-T2 by station (Pressure $\geq$ 2000dbar).

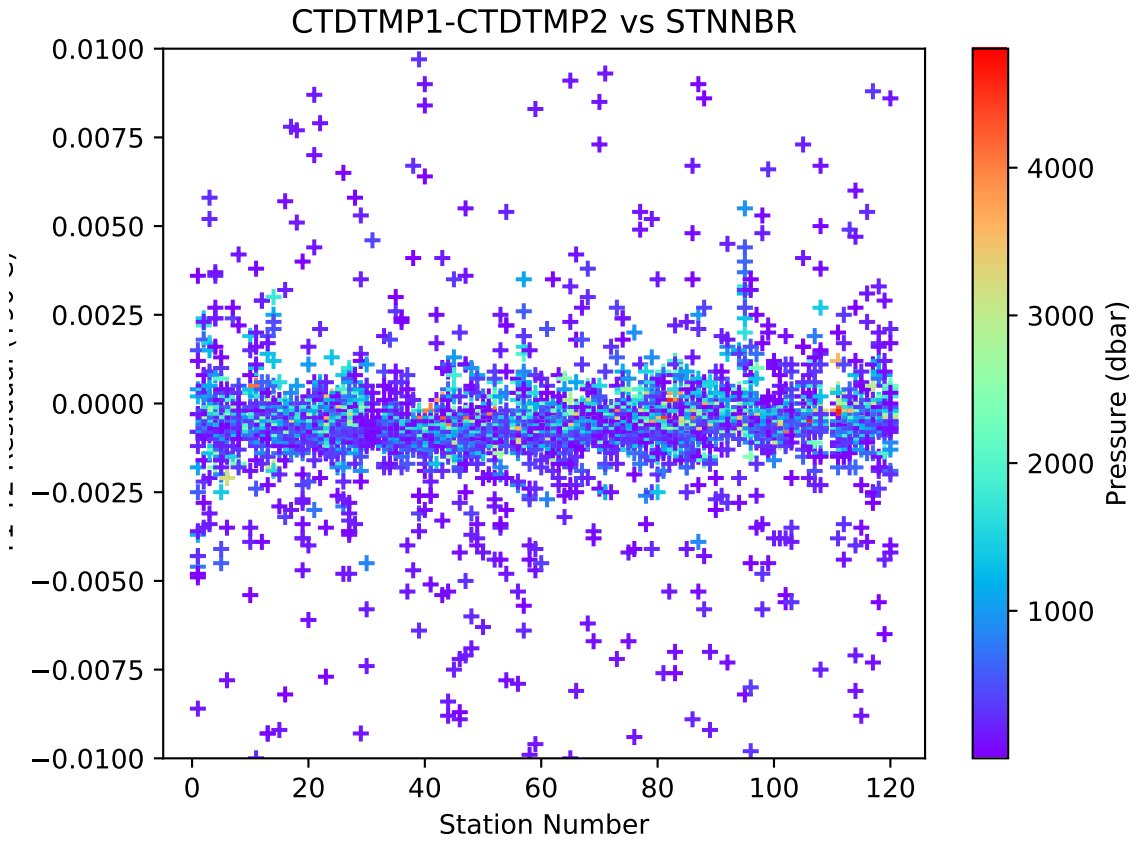


Fig. 4.5: T1-T2 by station (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

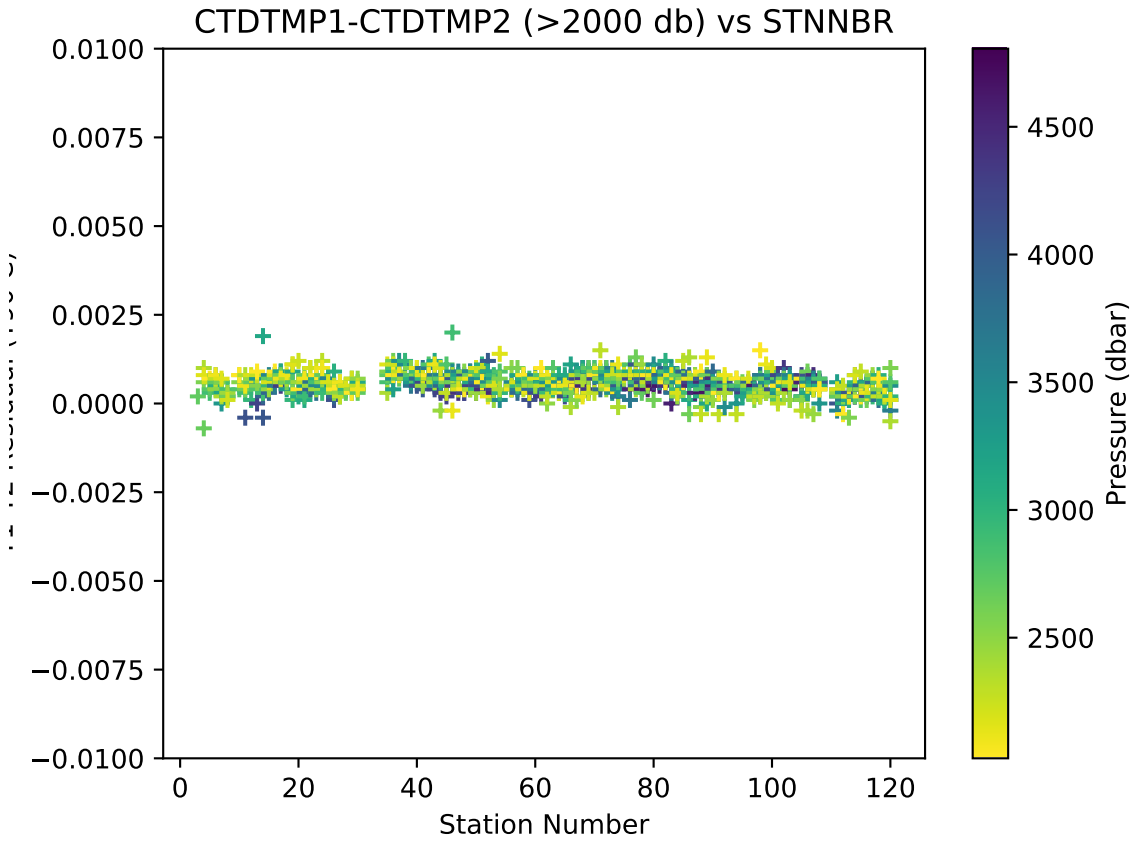


Fig. 4.6: Deep T1-T2 by station (Pressure $\geq$ 2000dbar).

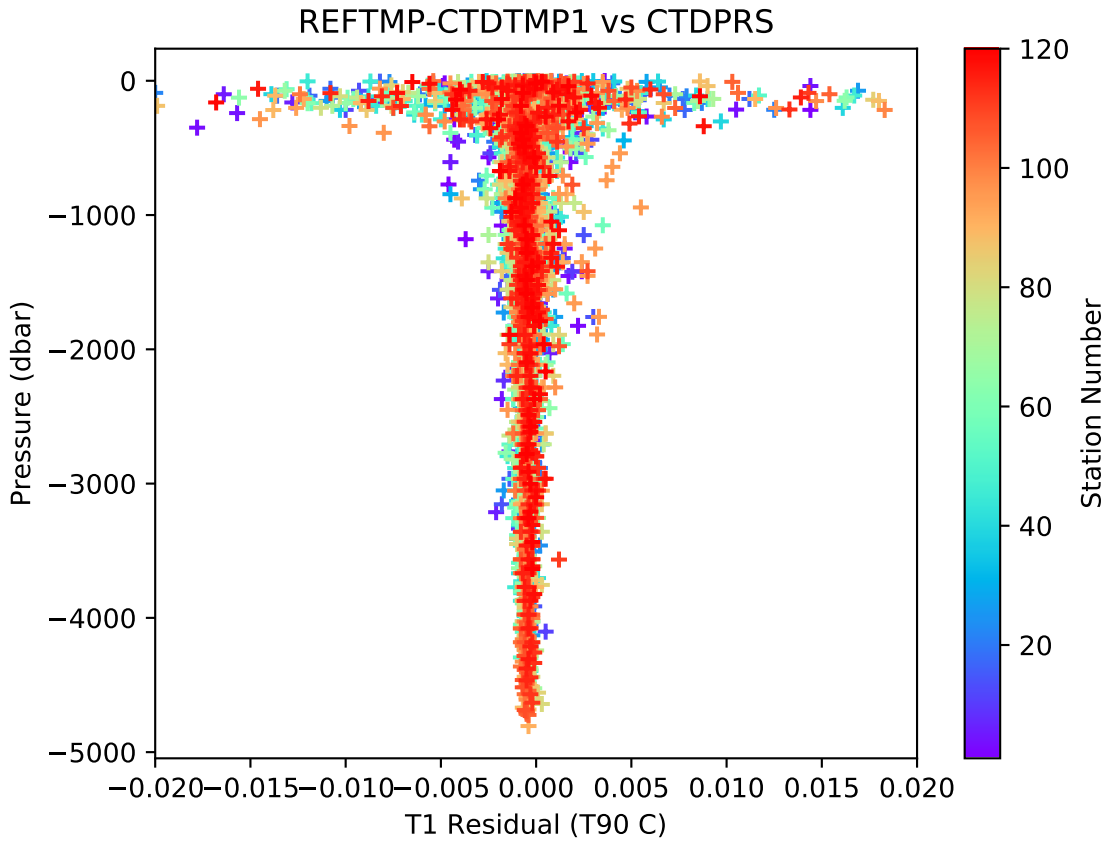


Fig. 4.7: SBE35RT-T1 by pressure (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

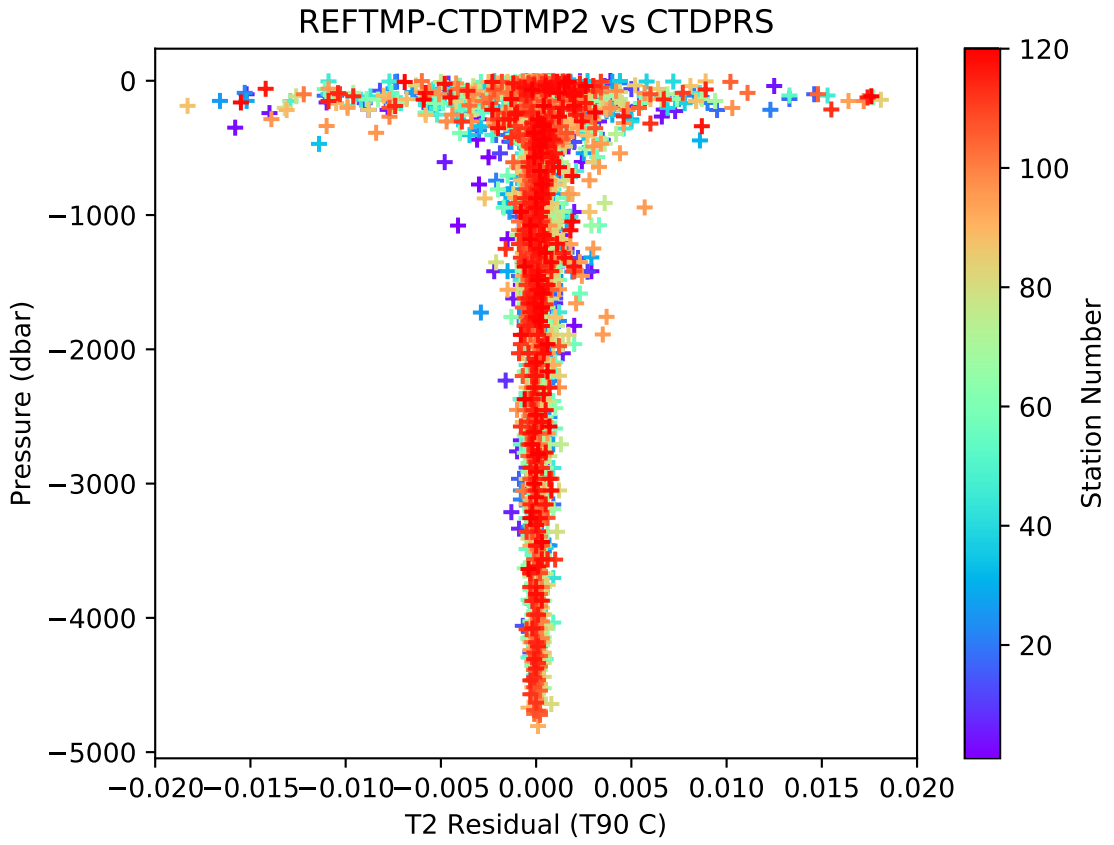


Fig. 4.8: SBE35RT-T2 by pressure (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

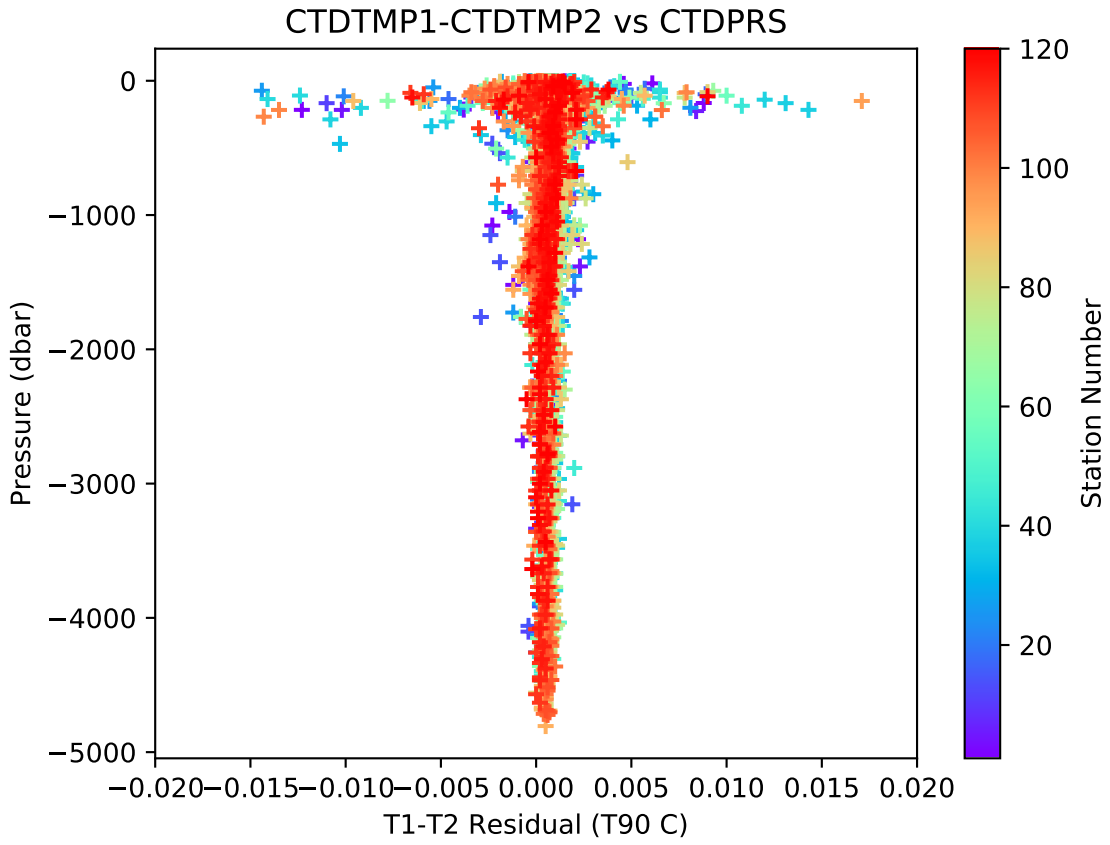


Fig. 4.9: T1-T2 by pressure (-0.002°C $\leq$ T1-T2 $\leq$ 0.002°C).

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

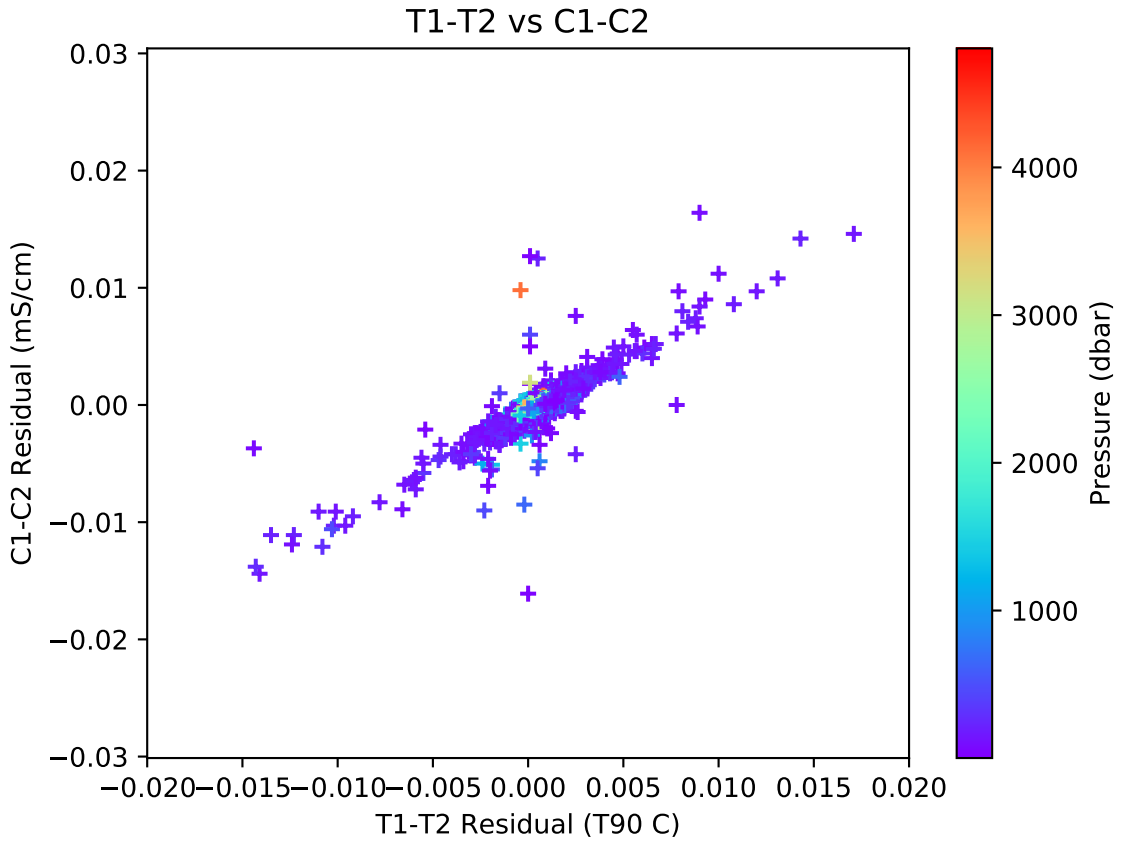


Fig. 4.10: Coherence of conductivity differences as a function of temperature differences.

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).*.

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:

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

The 95% confidence limits for the whole water column differences are ±0.0041 mS/cm for BTLCOND-C1, ±0.0045 mS/cm for BTLCOND-C2, and ±0.0027 mS/cm for C1-C2. The 95% confidence limits for the deep temperature

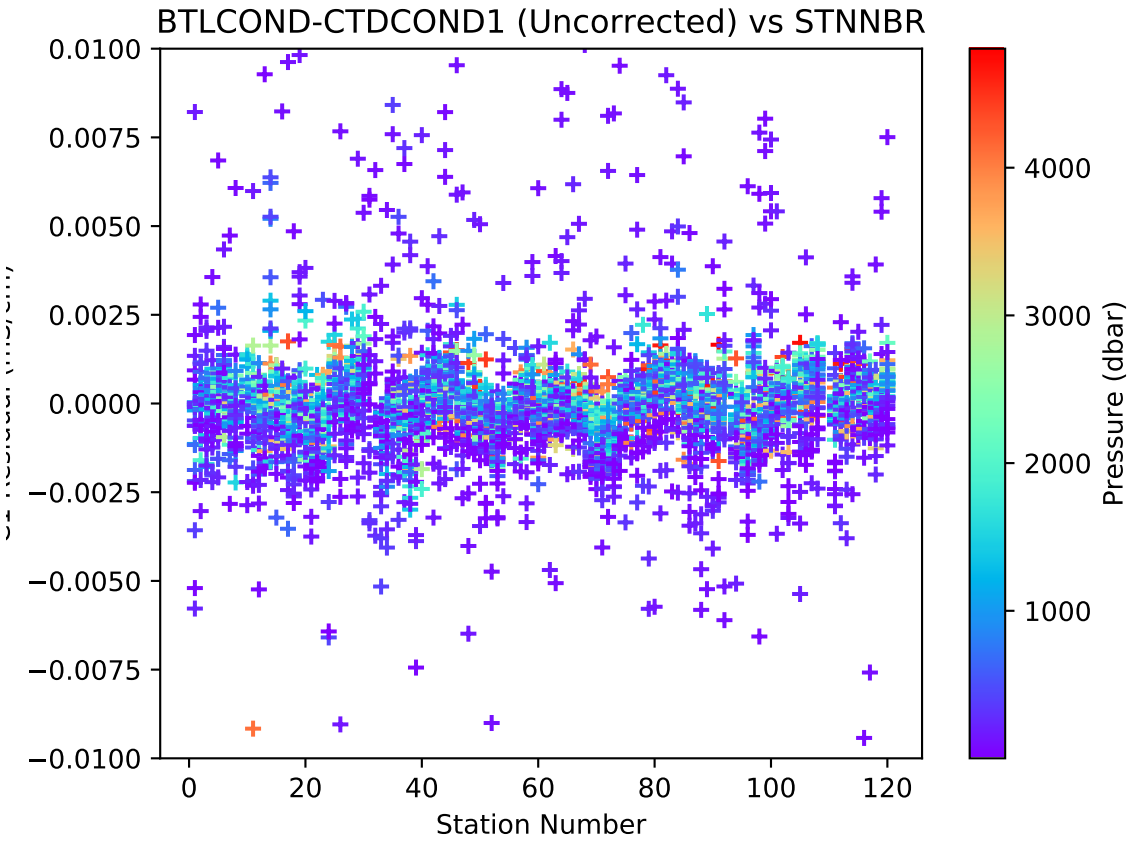


Fig. 4.11: Uncorrected C_{Bottle} - C1 by station (-0.002 mS/cm $\leq$ BTLCOND-C1 $\leq$ 0.002 mS/cm).

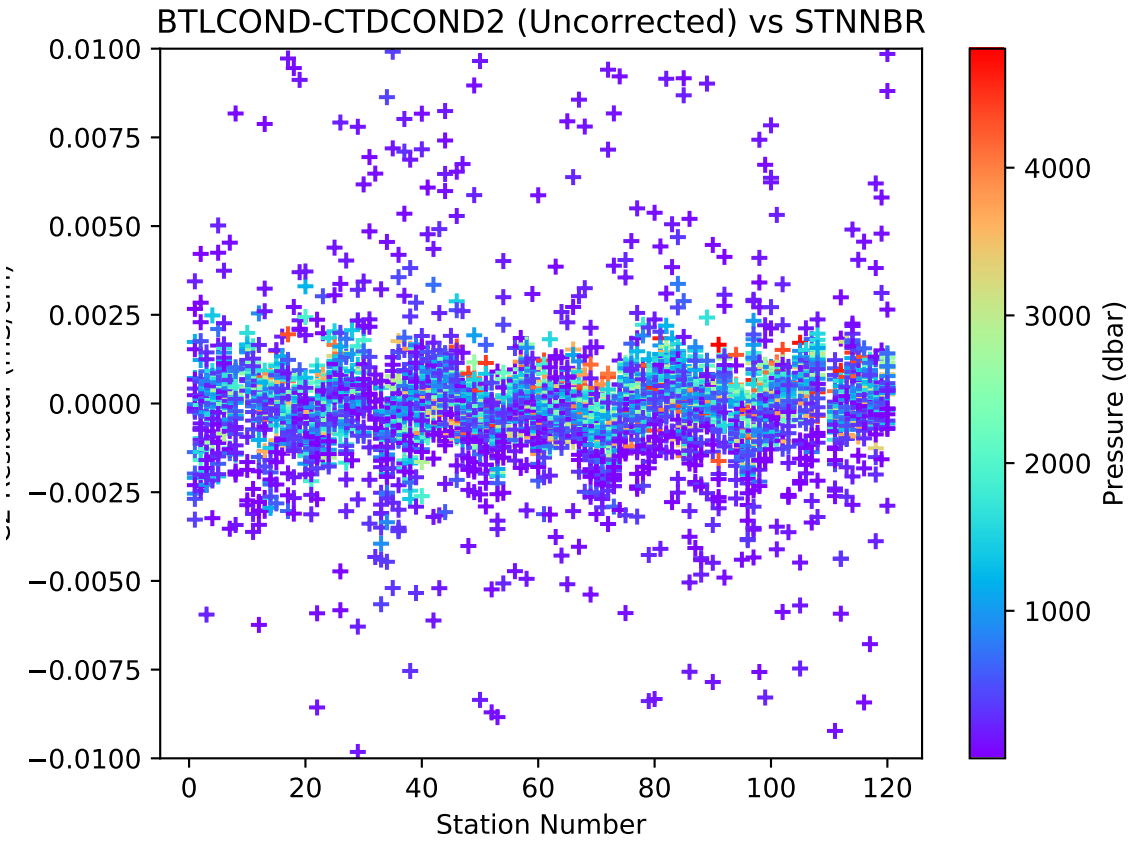


Fig. 4.12: Uncorrected C_{Bottle} - C2 by station (-0.002 mS/cm $\leq$ BTLCOND-C2 $\leq$ 0.002 mS/cm).

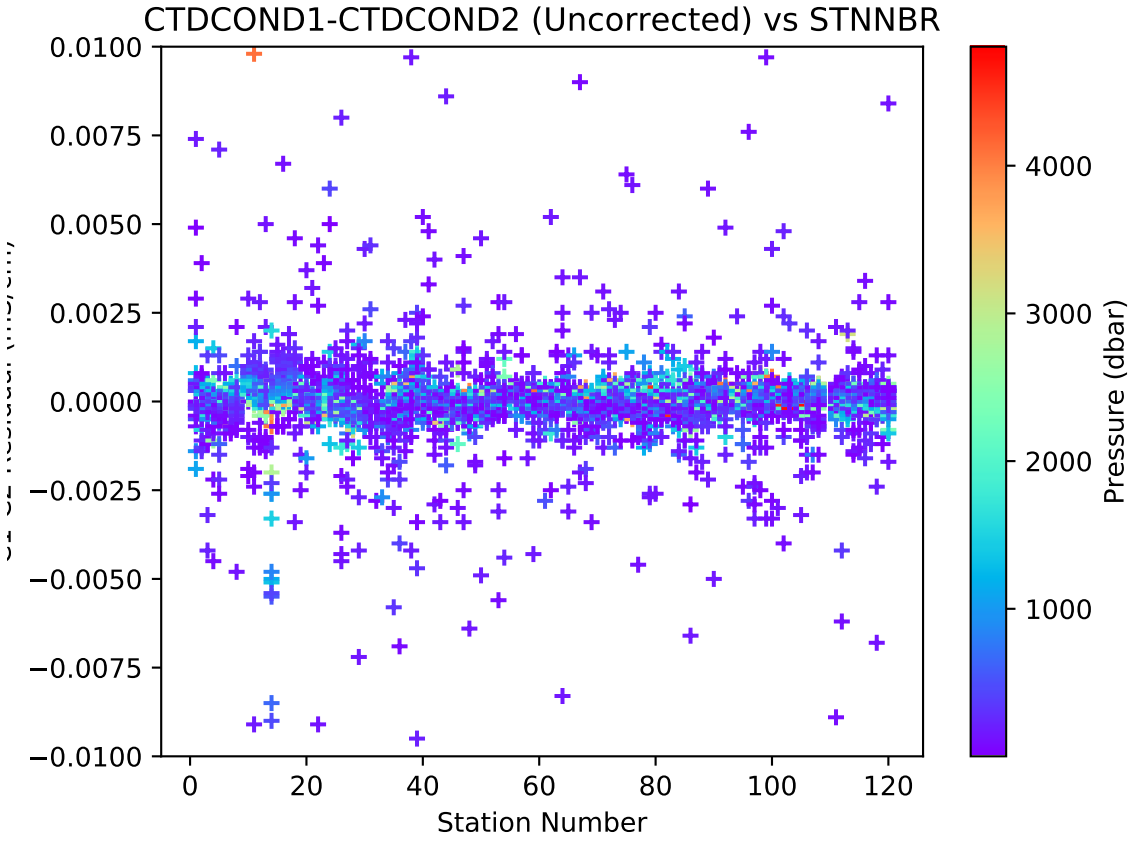


Fig. 4.13: Uncorrected C1-C2 by station (-0.002 mS/cm $\leq$ C1-C2 $\leq$ 0.002 mS/cm).

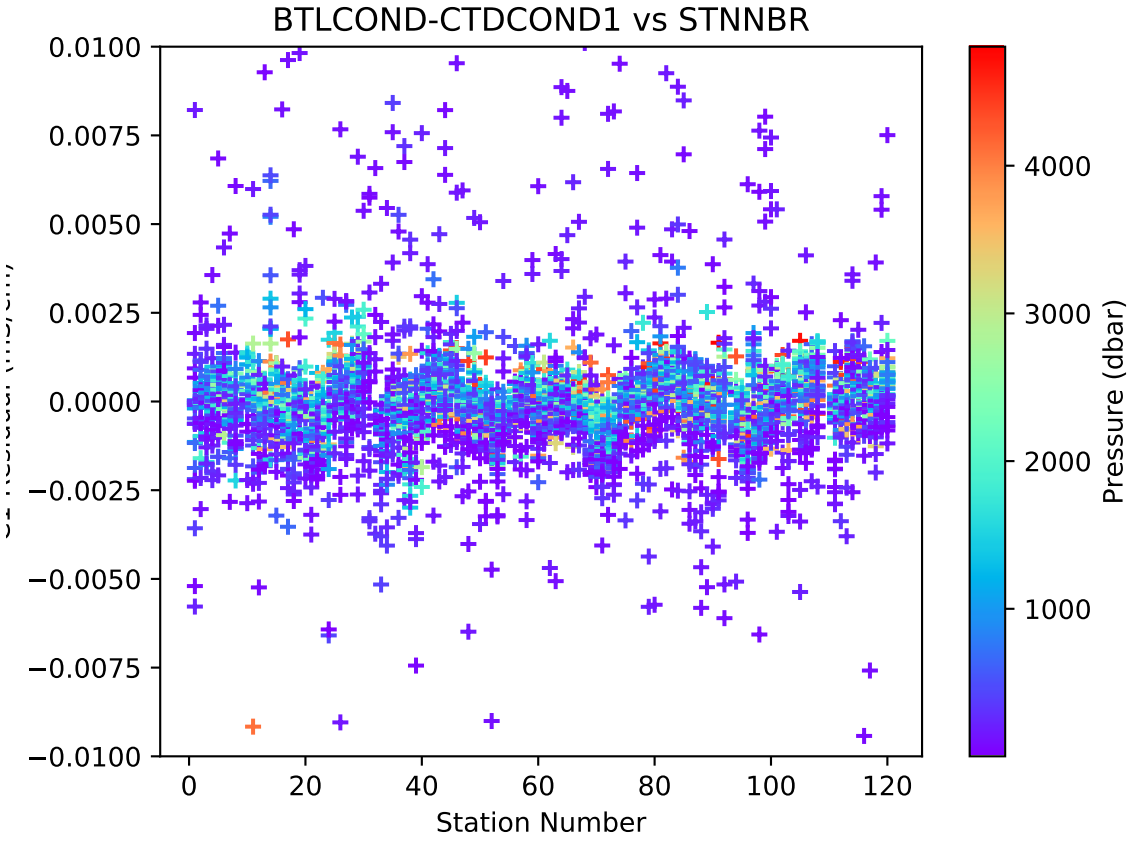


Fig. 4.14: Corrected C_{Bottle} - C1 by station (-0.002 mS/cm $\leq$ BTLCOND-C1 $\leq$ 0.002 mS/cm).

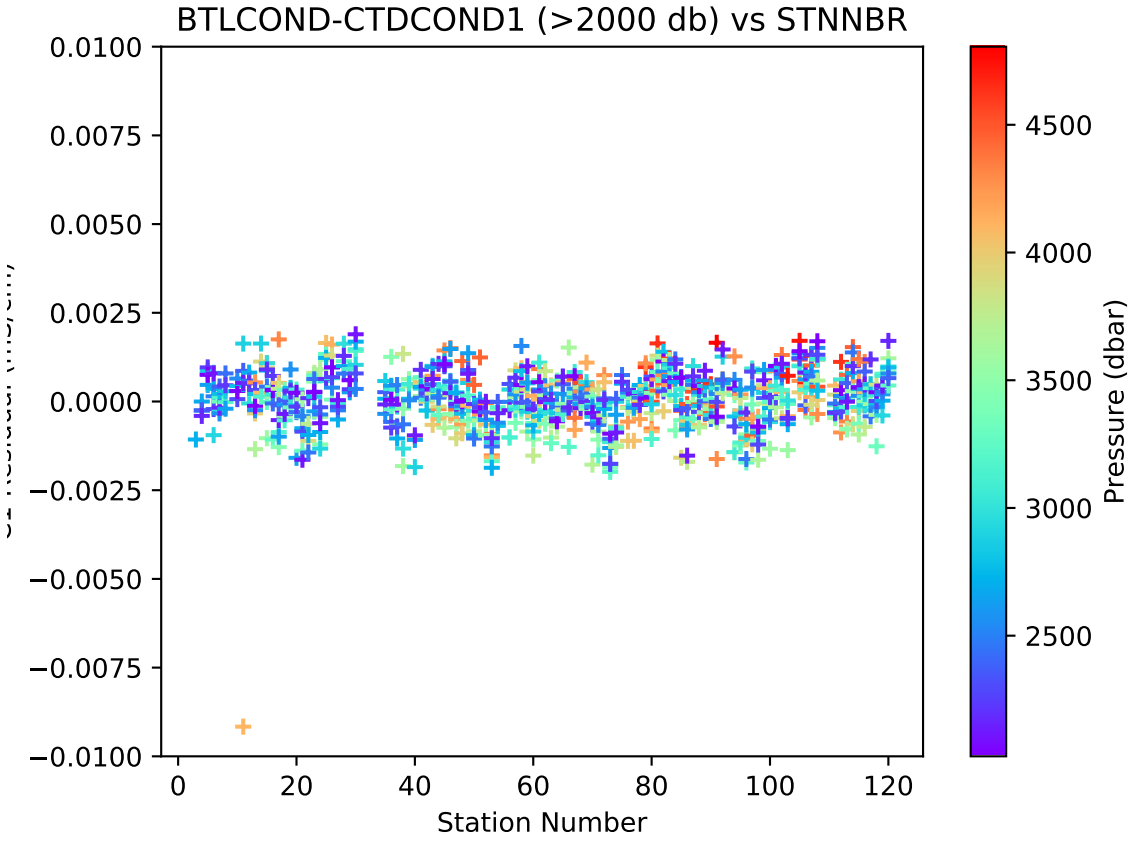


Fig. 4.15: Deep Corrected C_{Bottle} - C1 by station (Pressure >= 2000dbar).

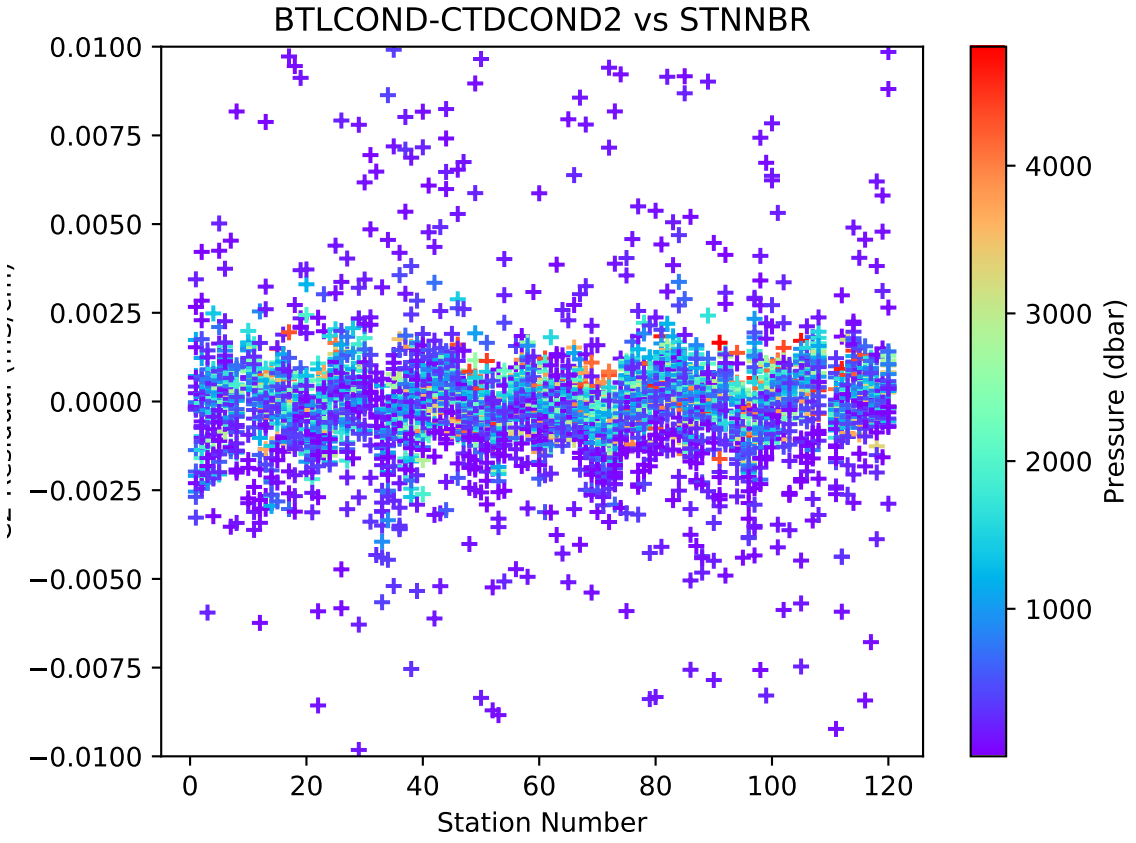


Fig. 4.16: Corrected C_{Bottle} - C2 by station (-0.002 mS/cm $\leq$ BTLCOND-C2 $\leq$ 0.002 mS/cm).

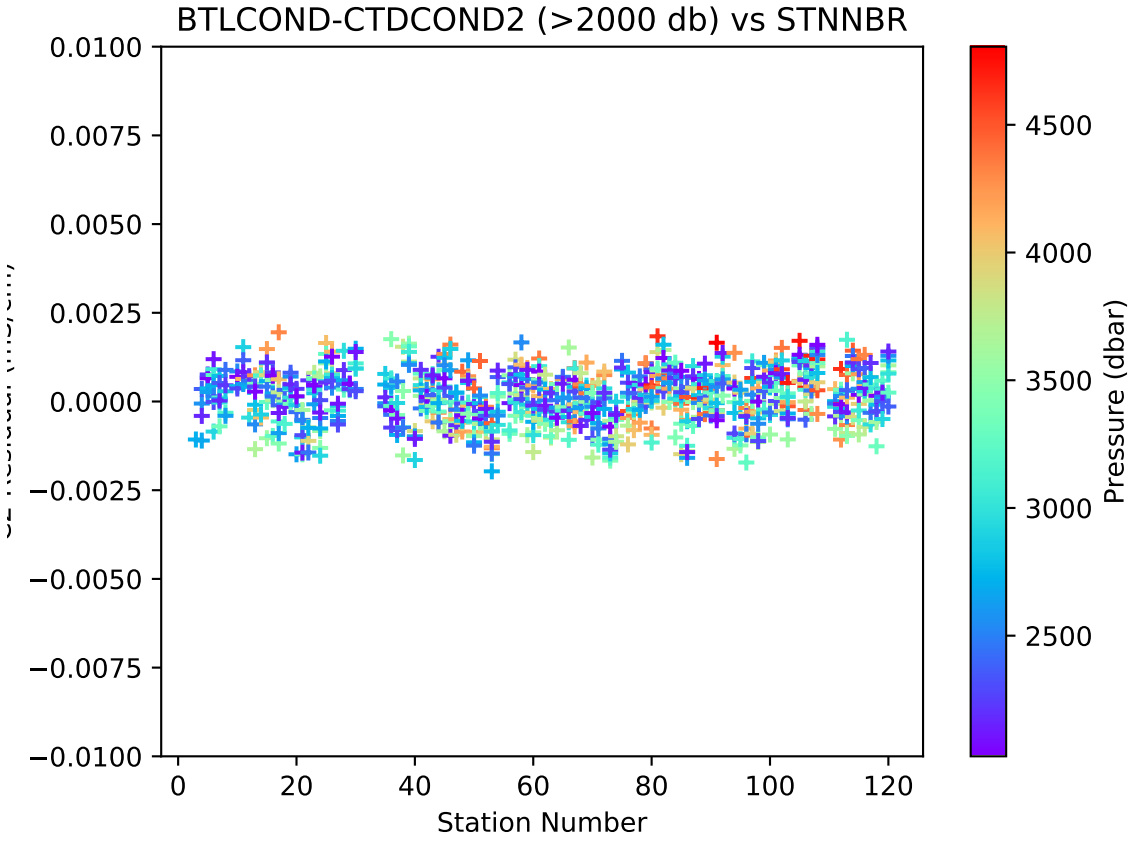


Fig. 4.17: Deep Corrected C_{Bottle} - C2 by station (Pressure >= 2000dbar).

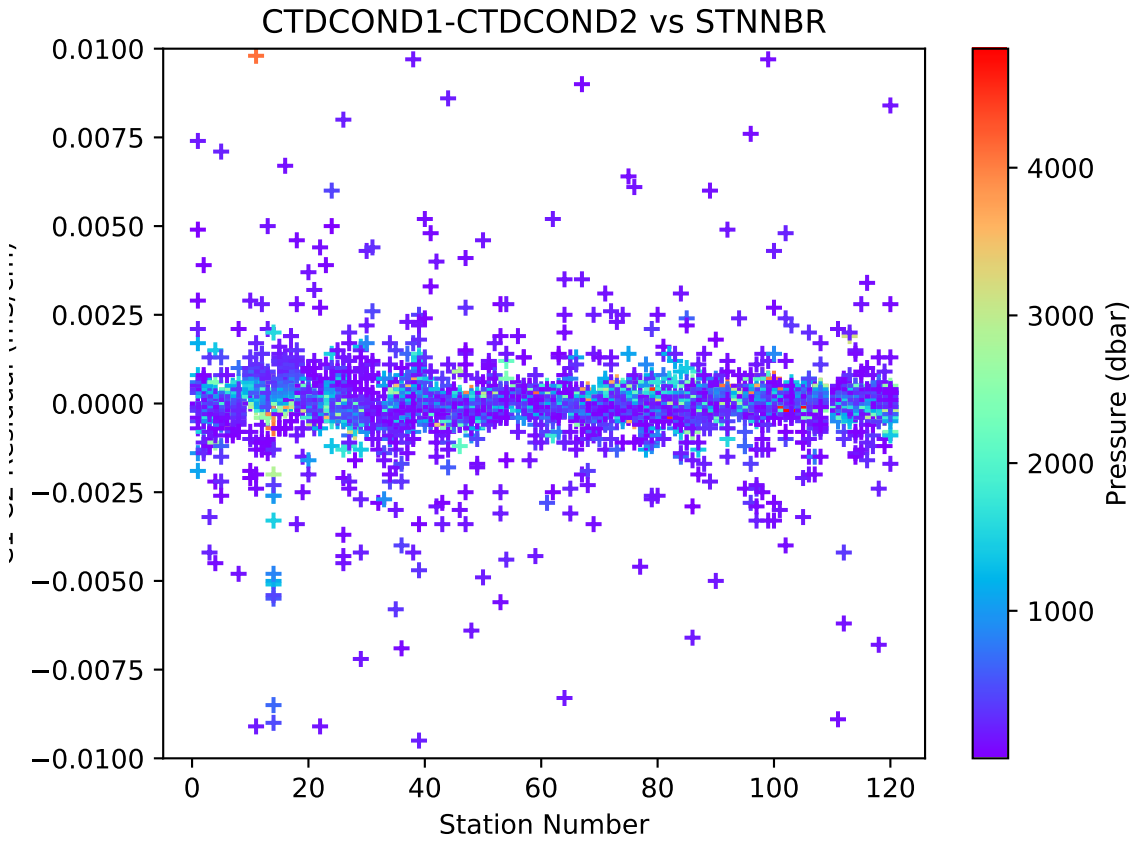


Fig. 4.18: Corrected C1-C2 by station (-0.002 mS/cm $\leq$ C1-C2 $\leq$ 0.002 mS/cm).

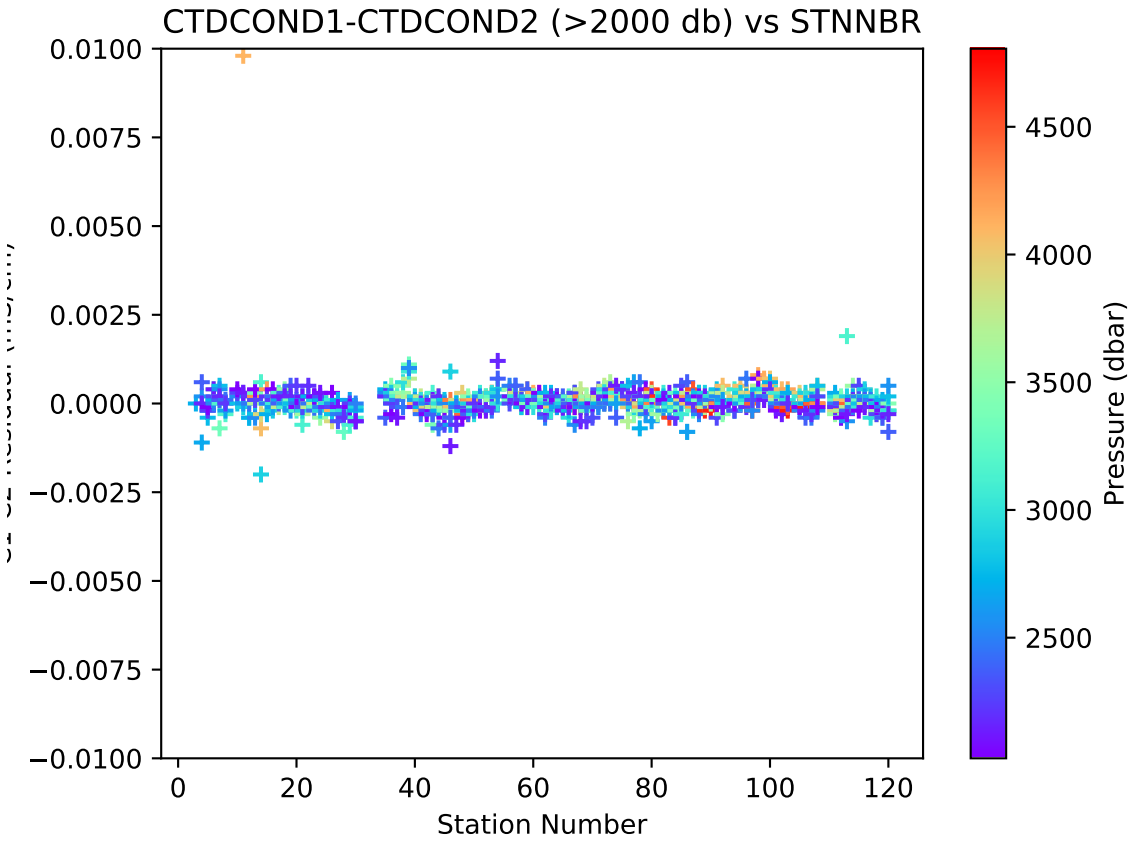


Fig. 4.19: Deep Corrected C1-C2 by station (Pressure >= 2000dbar).

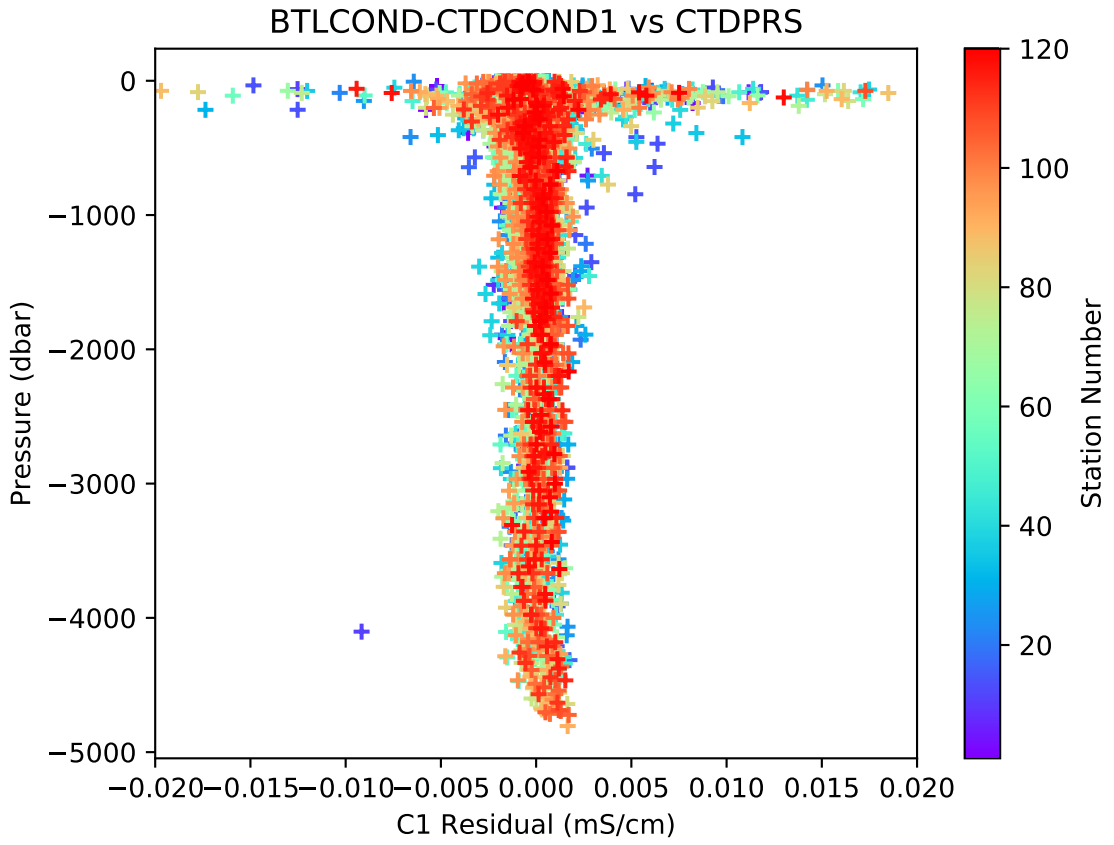


Fig. 4.20: Corrected C_{Bottle} - C1 by pressure (-0.002 mS/cm $\leq$ BTLCOND-C1 $\leq$ 0.002 mS/cm).

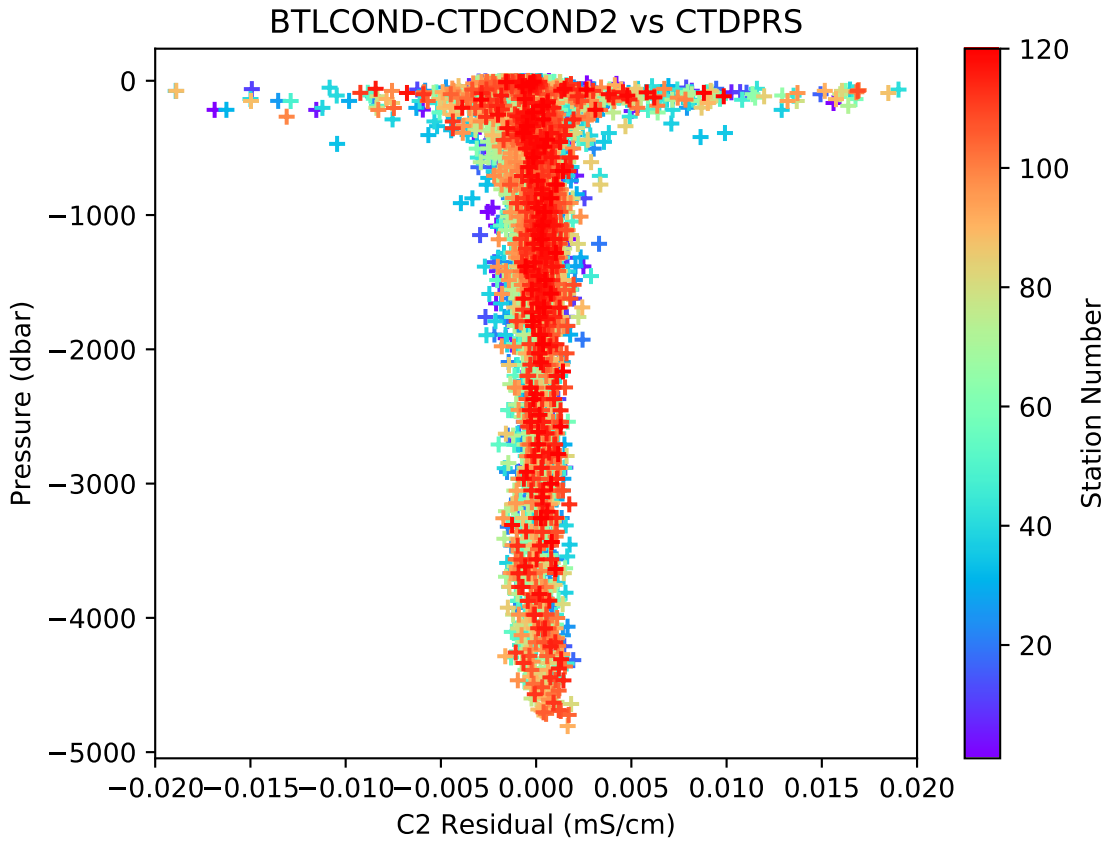


Fig. 4.21: Corrected C_{Bottle} - C2 by pressure (-0.002 mS/cm $\leq$ BTLCOND-C2 $\leq$ 0.002 mS/cm).

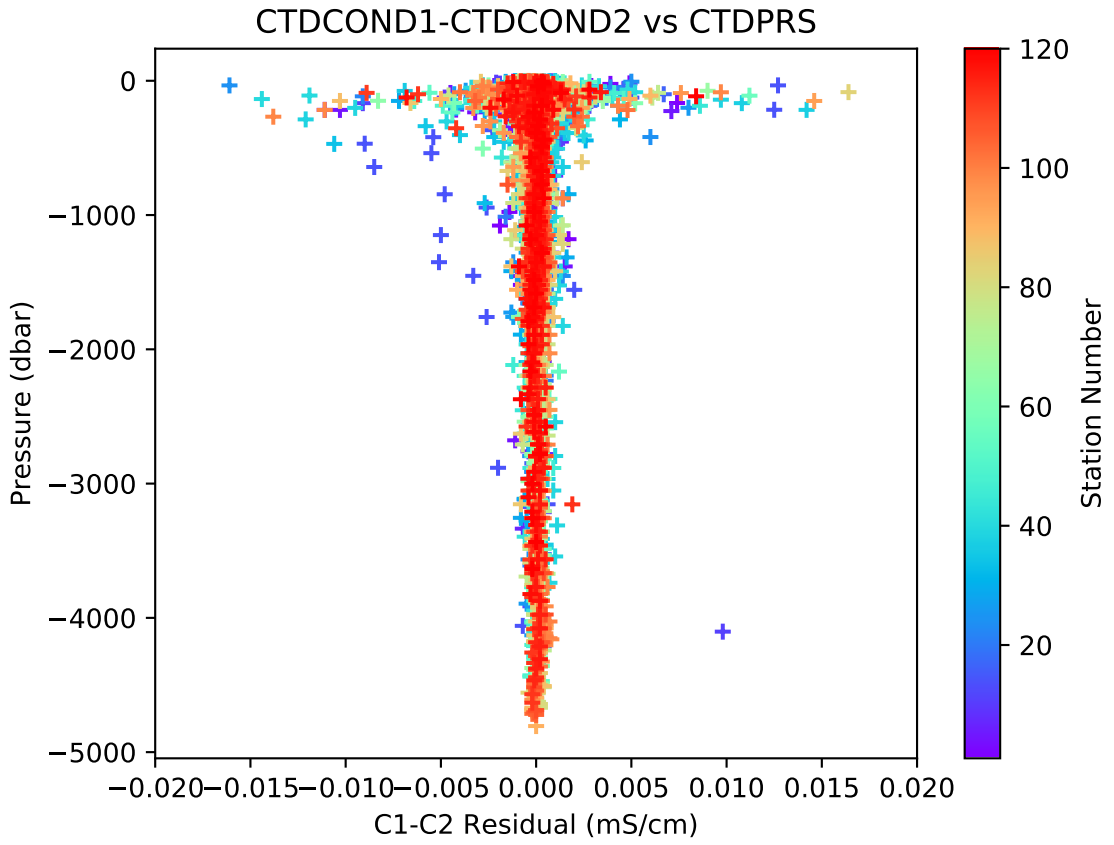


Fig. 4.22: Corrected C1-C2 by pressure (-0.002 mS/cm $\leq$ C1-C2 $\leq$ 0.002 mS/cm).

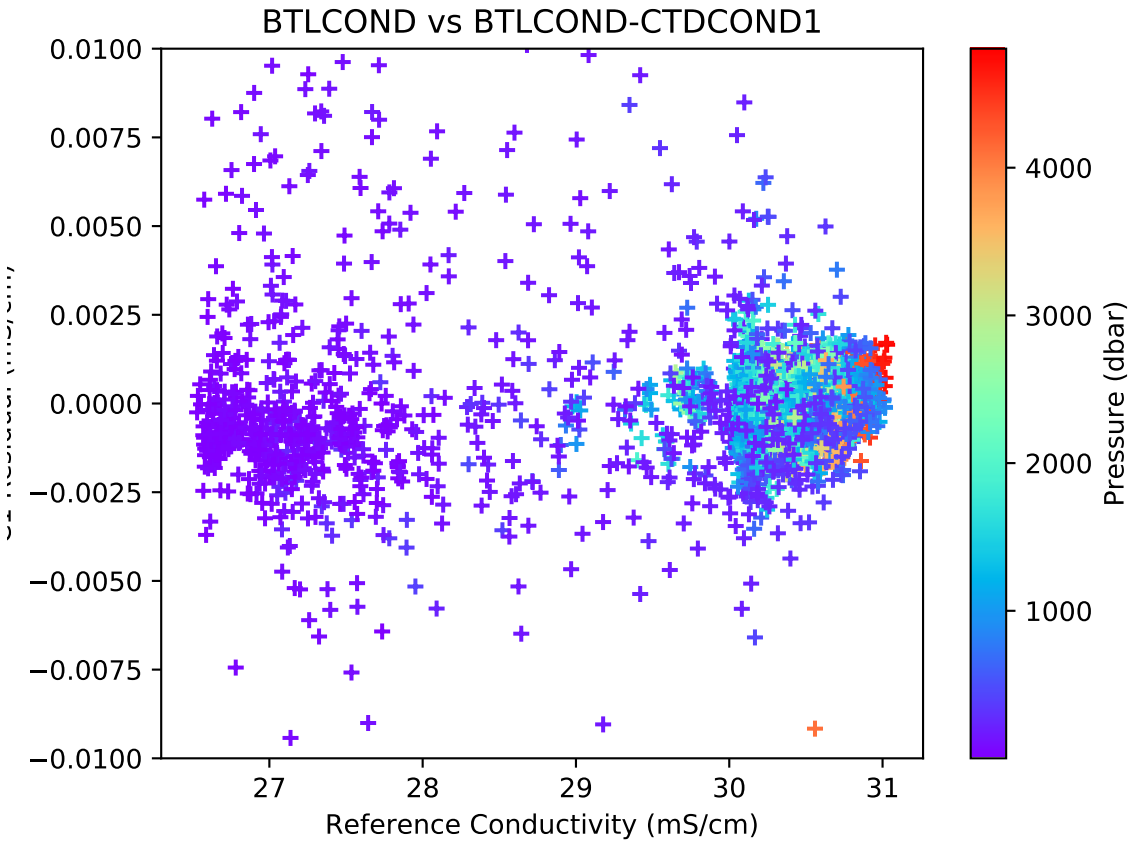


Fig. 4.23: Corrected C_{Bottle} - C1 by conductivity (-0.002 mS/cm $\leq$ BTLCOND-C1 $\leq$ 0.002 mS/cm).

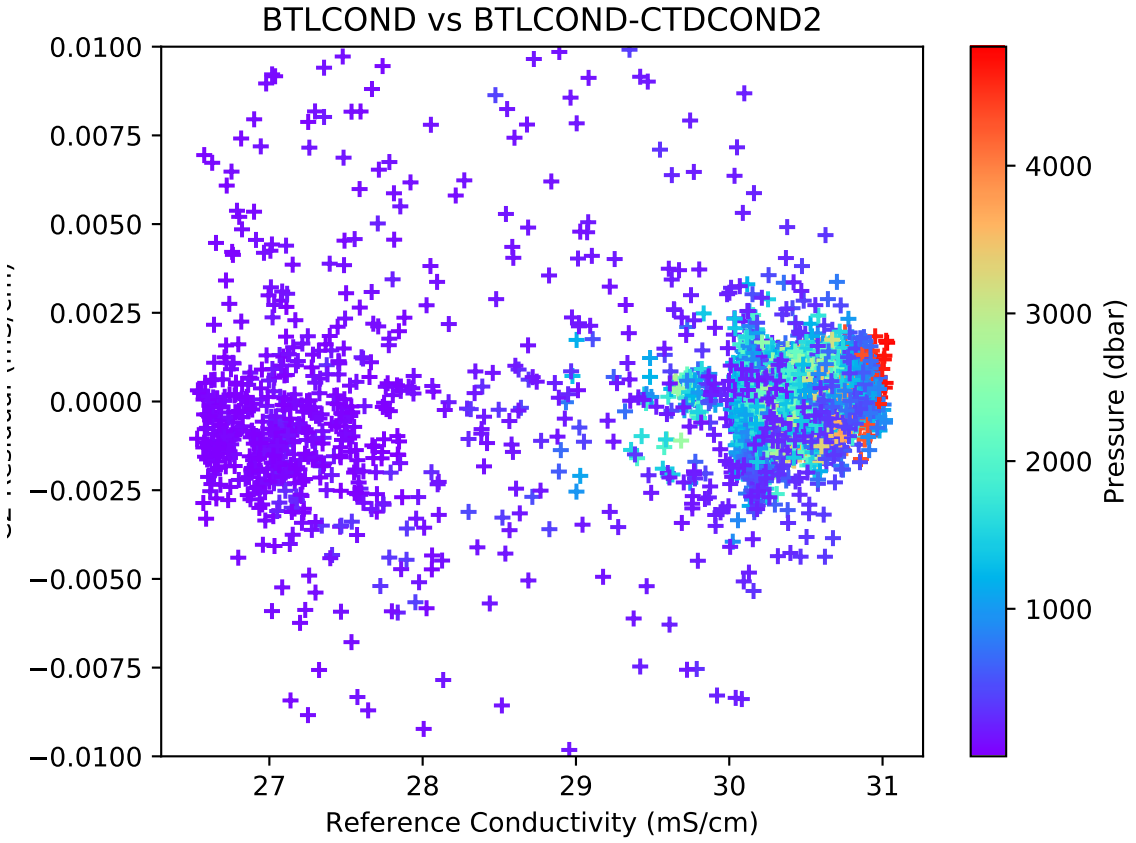


Fig. 4.24: Corrected C_{Bottle} - C2 by conductivity (-0.002 mS/cm $\leq$ BTLCOND-C2 $\leq$ 0.002 mS/cm).

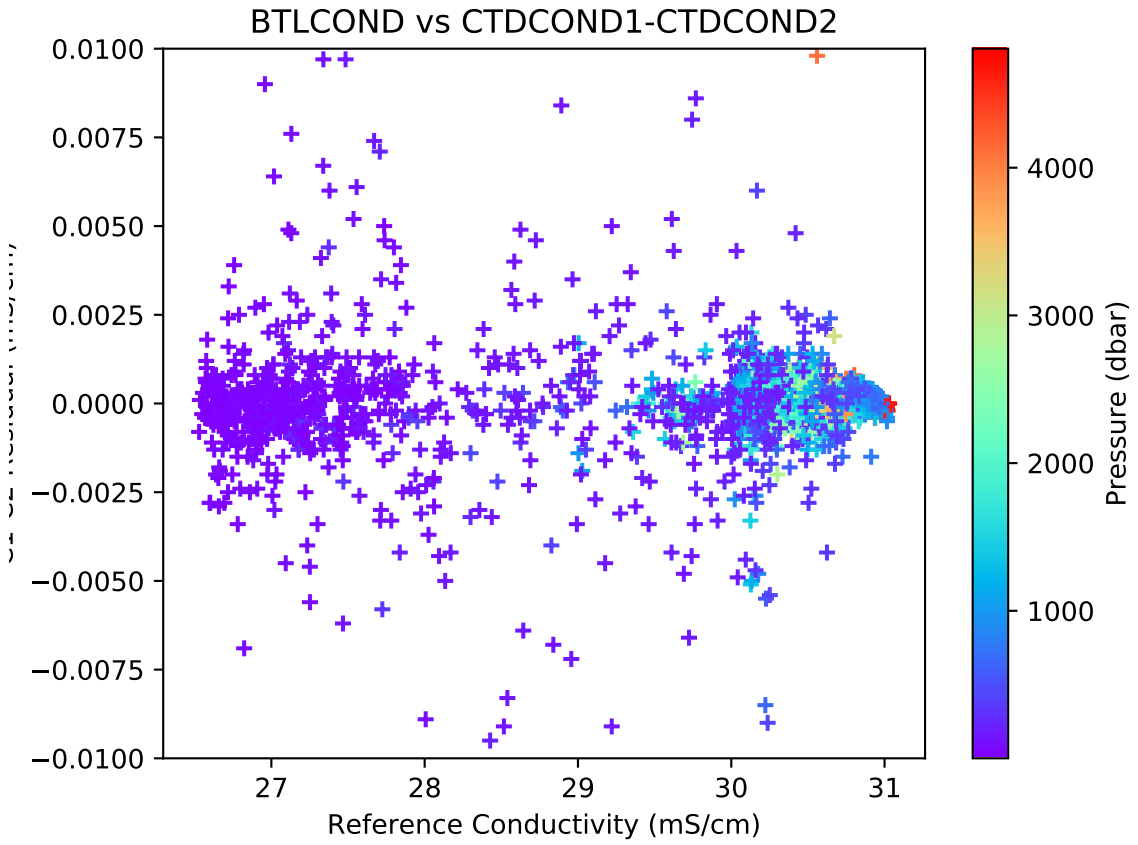


Fig. 4.25: Corrected C1-C2 by conductivity (-0.002 mS/cm $\leq$ C1-C2 $\leq$ 0.002 mS/cm).

residuals (where pressure $\geq$ 2000dbar) are $\pm$0.00155 mS/cm for BTLCOND-C1, $\pm$0.00142 mS/cm for SBTLCOND-C2, and $\pm$0.00086 mS/cm for C1-C2.

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

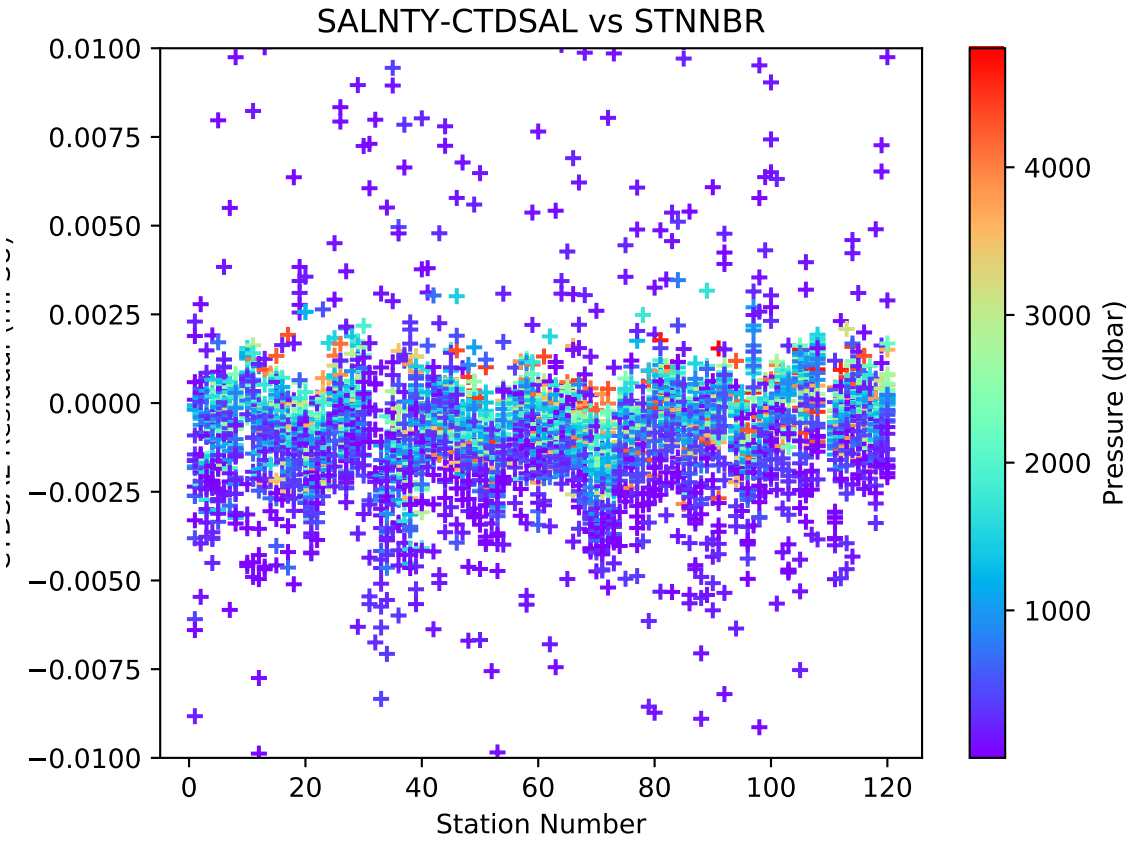


Fig. 4.26: Salinity residuals by station (-0.002 mPSU $\leq$ SALNTY-C1SAL $\leq$ 0.002 mPSU).

The 95% confidence limits for the whole water column differences are $\pm$0.0054 PSU for salinity-C2SAL. The 95% confidence limits for the deep salinity residuals (where pressure $\geq$ 2000dbar) are $\pm$0.00188 PSU for salinity-C2SAL.

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

- Bottle salinity analysis was complicated due to switching between two Autosals, leading to knock-on problems when attempting to calibrate conductivity against bottle salinity.

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

4.6 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.

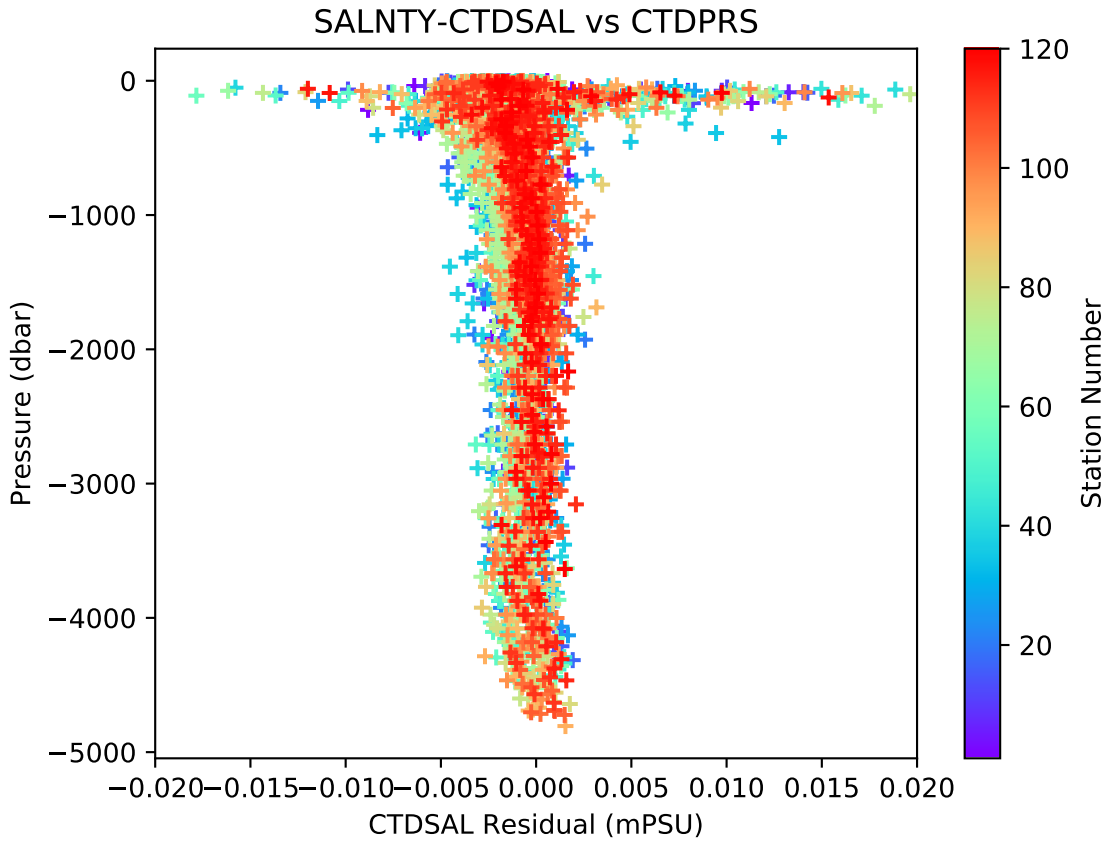


Fig. 4.27: Salinity residuals by pressure (-0.002 mPSU $\leq$ SALNTY-C1SAL $\leq$ 0.002 mPSU).

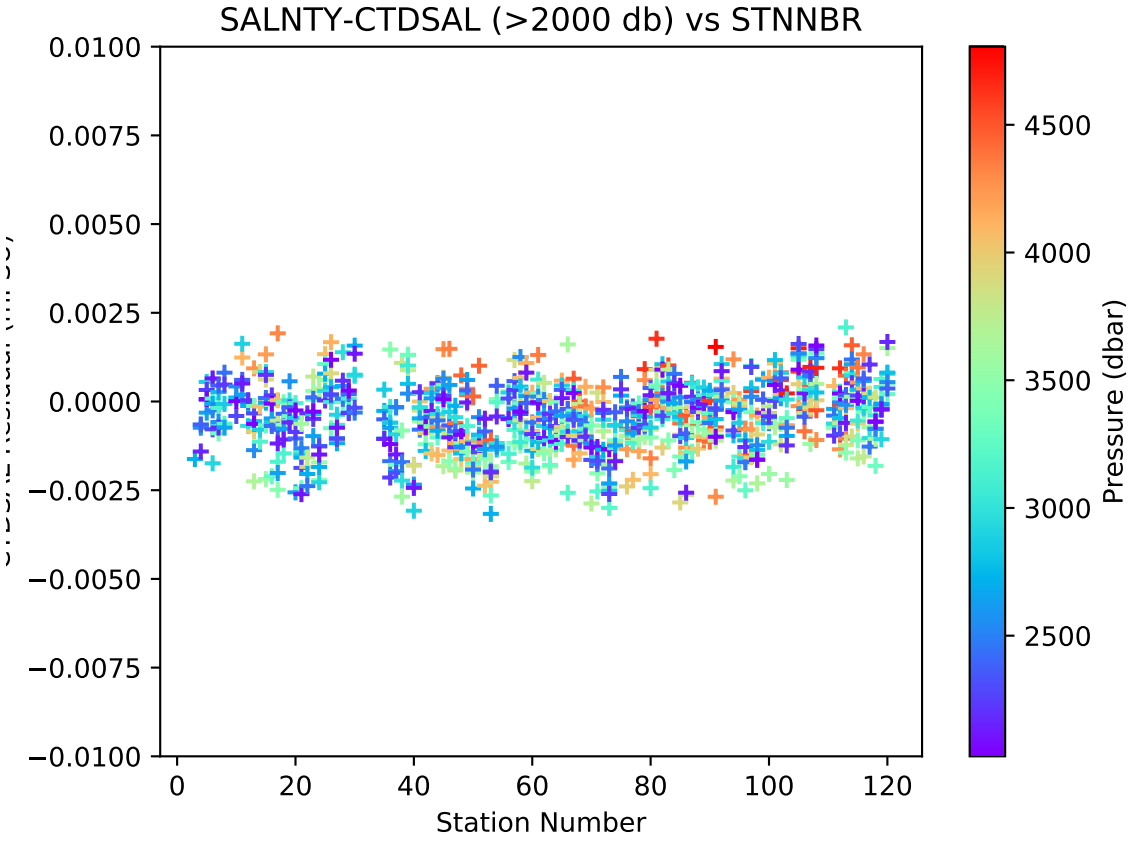


Fig. 4.28: Deep Salinity residuals by station (Pressure >= 2000dbar).

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 3.62 (µmol/kg) for all dissolved oxygen bottle data values and 1.15 (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.

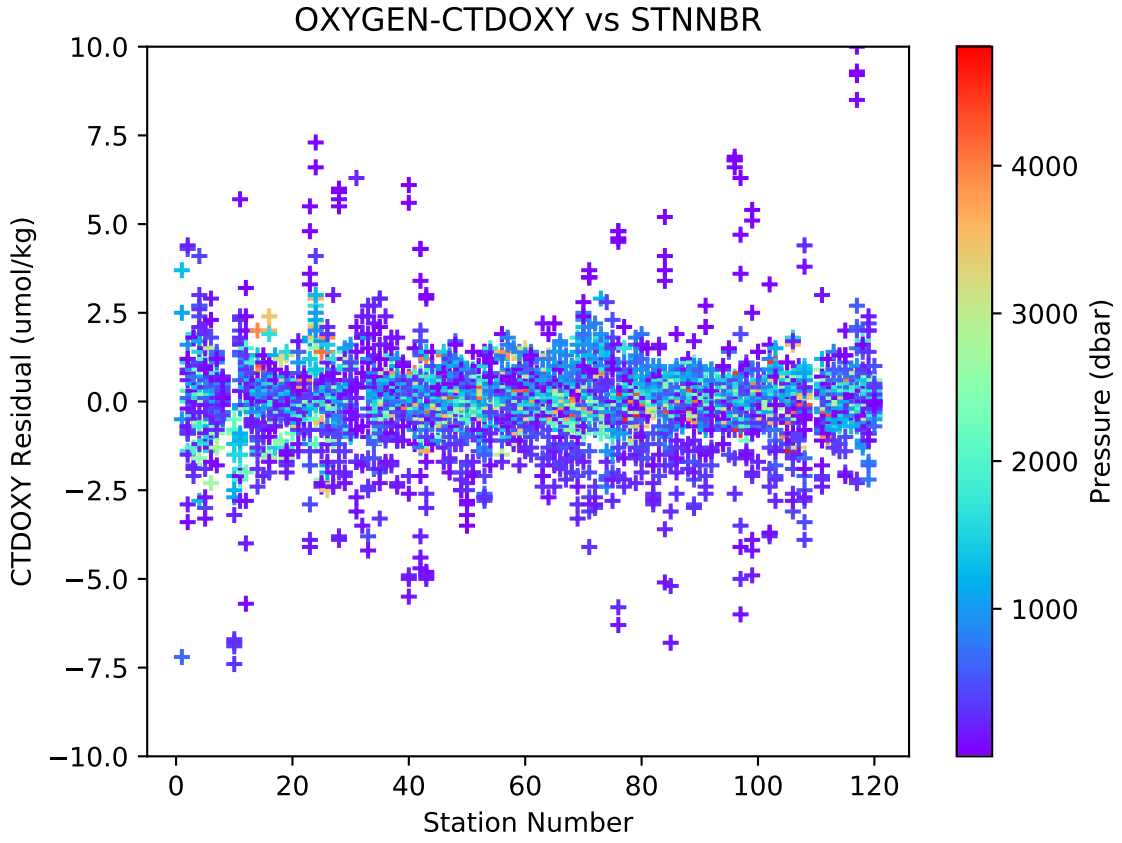


Fig. 4.29: O_2 residuals by station (-0.01 µmol/kg $\leq$ OXYGEN-BTLOXY $\leq$ 0.01 µmol/kg).

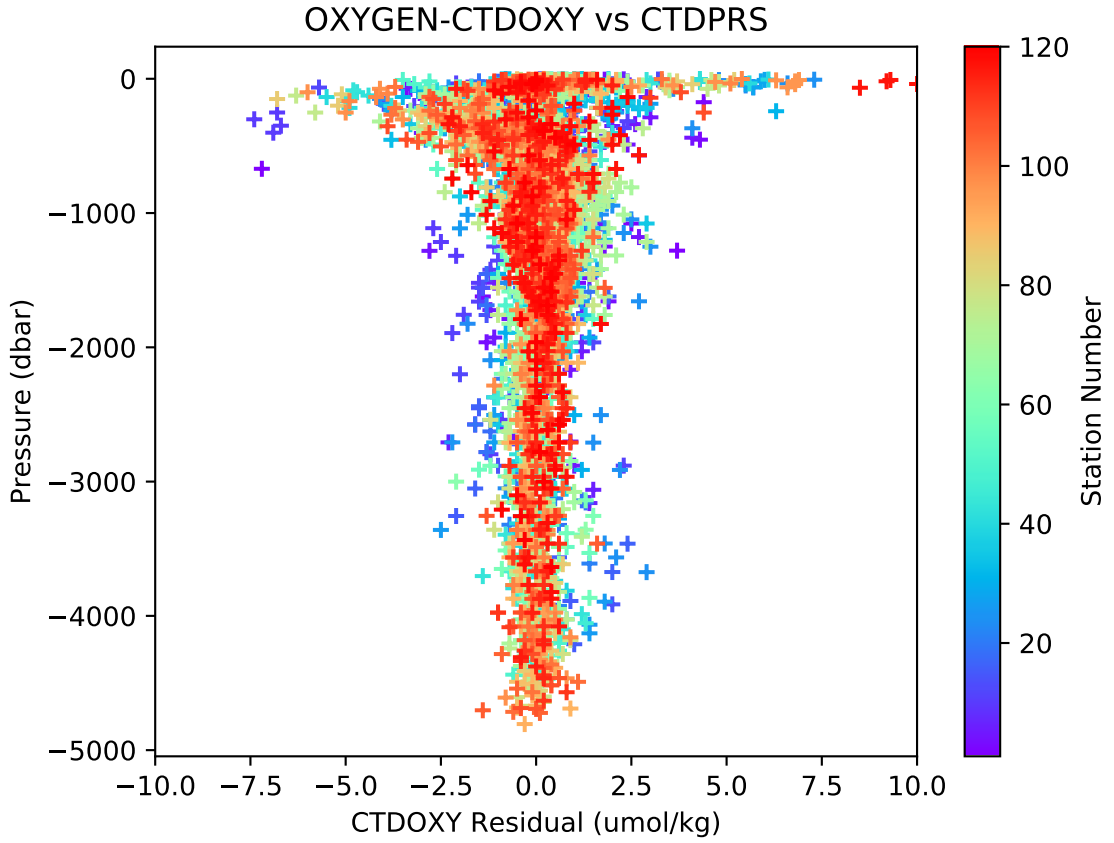


Fig. 4.30: O_2 residuals by pressure (-0.01 µmol/kg $\leq$ OXYGEN-BTLOXY $\leq$ 0.01 µmol/kg).

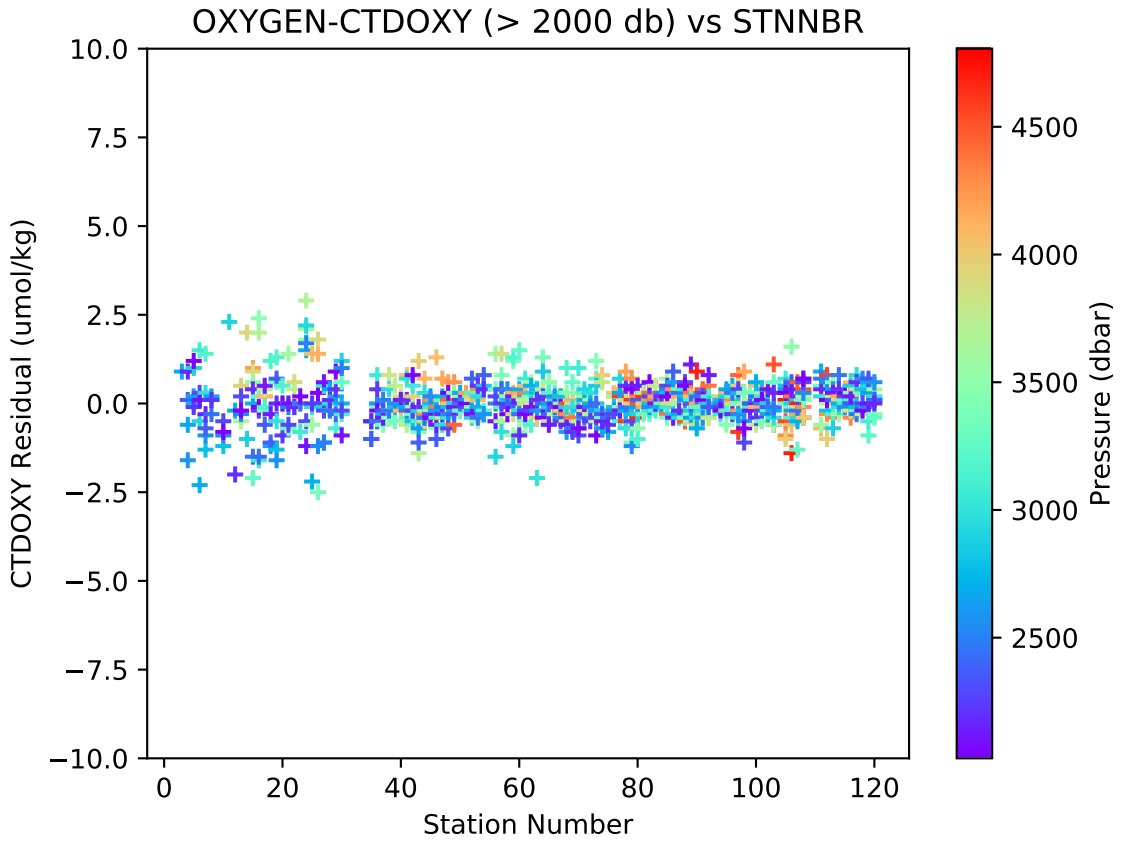


Fig. 4.31: Deep O_2 residuals by station (Pressure >= 2000dbar).

- Multiple stations had impacted SBE 43 oxygen data due to the pump not working leading to errant values. Values presented for those casts should all be considered as questionable.
- RINKO oxygen optode data has been nominally calibrated and presented in the bottle data file and ctd data files. See *RINKO Oxygen Optode* section for more detail.

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

FIVE

TRANSMISSOMETER

PI

- Wilf Gardner (*TAMU*)

Cruise Technician

- Joseph Gum

The following summarizes the air calibration and regular operation procedures for the CST-1803DR transmissometer.

5.1 Air Calibration

- Check that in air temperature and instrument temperature has been stable before starting calibration, and record air temperature
- Connect transmissometer to a pigtail or CTD for air calibration, and power up
- Remove protective red caps from windows
- Rinse lenses with DI water and tap dry with lab wipes
- Compare transmissometer readings with previous readings. If readings are substantially different, wash with slightly soapy water (2-3 drops of soap) or alcohol, then rinse with DI water and tap dry.
- Repeat rinsing and wiping procedure until voltage stabilizes, then record voltage in log
- Completely block light between two lenses, and record voltage
- Check that air temperature, unblocked voltage, and blocked voltage have been recorded

Great care must be taken to clean the transmissometer windows and get a stable reading in a couple of rinse and wipe cycles. The method used on S04P 2018 involved folding a Kimwipe neatly into a small square 1/8 the starting size of the rectangle, with no creases or fingerprints on the wiping surface. The lenses were rinsed with DI water then tapped dry, taking care to hold the Kimwipe at the corners. A new Kimwipe was then folded, soaked with ethanol or isopropyl alcohol, and then the lenses were tapped, taking care to use one side of the Kimwipe per lens. Each Kimwipe was discarded after one use to prevent reintroducing contaminants onto the lenses. Following this method a lens would have a reliable voltage in two to four cleanings.

One point of note is that a rinsing fluid of significantly different temperature than the transmissometer seemed to cause the reading to change by 0.1 to 0.3 volts. This forced the technician to wait for some period of time until the voltage reading stabilized. This change in reading might also be due to ship roll changing the atmosphere temperature around the transmissometer.

5.2 Daily Operations

Before a cast the CTD watchstanders would remove the red caps and rinse the windows with lightly soapy water, taking care to do this as close as possible to the cast to prevent the windows from drying. This was done to prevent bubbles from forming on the face of the windows. Post the windows were rinsed with DI water and the red caps were placed on the windows. At the end of the cruise the transmissometer was rinsed with fresh water before packing.

5.3 Calibration Results

Table 5.1: Calibration results for Transmissometer

Date	Time	Blocked Value (Volts)	Unblocked Value (Voltmeter)	Unblocked Value (CTD)	Air Temp	Remarks
16-Sep-16		0.008	4.813		21.6	Factory Calibration air
16-Sep-16			4.699		21.4	Factory Calibration water
28-Apr-17		0.009	4.829		25	TAMU Lab
4-Dec-17		0.009	4.805		21	TAMU Lab
12-Mar-18	2200 UTC	0.007		4.785	13.6	Pre test cast
16-Mar-18	0250 UTC	0.006		4.795	9.6	Pre-station 1 - changed cables
27-Mar-18	0231 UTC	0.007		4.79	7.6	Pre-station 23
4-Apr-18	0348 UTC	0.007		4.78	4.7	Pre-station 40
10-Apr-18	0239 UTC	0.007		4.763	6	Transit - Pre-station 54
15-Apr-18	0355 UTC	0.007		4.777	24.2	Transit -Pre-station 67 - heaters were on in transit
24-Apr-18	2317 UTC	0.007		4.768	8.9	Pre-station 89
29-Apr-18	2010 UTC	0.006		4.745	5.8	Pre-station 99 - temps may not be uniform due to water dump
3-May-18	0530 UTC	0.006		4.759	8.5	Pre station 109
9-May-18	1816 UTC	0.007		4.762	27	End of cruise - heaters were on in transit

CHAPTER

SIX

RINKO OXYGEN OPTODE

PIs

- James Swift
- Susan Becker

Analysts

- John Ballard (Calibration)
- Kenneth Jackson
- Joseph Gum

ODF has been using a RINKO oxygen optode as a second dissolved oxygen sensor on S04P 2018. The RINKO provides a redundant oxygen measurement to the SBE43 that is not plumbed, avoiding problems with plumbed line fouling. For S04P 2018 RINKO data has been fitted against bottle oxygen data, and has been reported in data files as CTDRINKO.

6.1 Calibration

- Model: ARO-CAV
- Serial: 0296
- Factory calibration: April 10, 2017
- Film No: 164312BA
- Factory DO coefficients: see factory calibration sheet

A two point calibration was performed prior, during, and after deployment on the 67 day repeat hydrography in the Southern Ocean. These calibrations produced three sets of calibration coefficients (G and H) to adjust factory calibration of dissolved oxygen raw voltage. The calibrations also provided an assessment of foil degradation over the course of the 125 station, 250-4800m, and -2 to -1.8 deg C deployment.

As per manufacturer (JFE Advantech Co., Ltd.) recommendation, 100% saturation points were obtained via bubbling ambient air in a stirred beaker of tap water about 30 minutes, removing air stone, then submersing the powered Rinko. Dissolved oxygen raw voltage (DOout), atmospheric pressure, and solution temperature were recorded for calculation of new oxygen sensor coefficients (G and H).

Zero point calibrations also followed general manufacturer recommendations. A sodium sulfite solution (25g in 500mL deionized water) was used for the pre-cruise calibration. For both the middle and post-cruise calibrations, ultra pure nitrogen gas was flushed through a plastic bag covering the sensor. Raw voltage (DOout), atmospheric pressure, and solution or air temperature were recorded, along with 100% saturation data, for calculation of coefficients (G and H).

An external temperature probe (Measurement Specialties 4600; accuracy +/-0.01 deg C) was used for middle and post-deployment calibrations. Rinko temperature (factory coefficients) was used for pre-cruise calibration. Mid-cruise comparison of Rinko temperature to 4600 probe yielded a difference of -0.02 deg C.

Generally, the Rinko III sensor appears to have performed as expected with no major problems or sharp drift throughout the deployment. An SBE 43 dissolved oxygen sensor was deployed simultaneously. Both oxygen sensor data sets were analyzed and quality controlled with winkler bottle oxygen data.

•	Date	G	H
Pre-deployment	02/08/18	-0.0327	1.0683
Mid-deployment	04/07/18	-0.7339	1.0332
Post-deployment	05/10/18	-1.4941	1.0298

6.2 Analysis

RINKO data was acquired, converted from volts to oxygen saturation, and then calculated for micromoles per kilogram. The resulting data was then fitted using the same oxygen calibration and fitting routines as for the SBE43. While the data in the deep looks acceptable, the data in the first 200 meters is badly fitted resulting in large erroneous values. More work will be needed to refine oxygen fitting, and while values might be flagged with 2, all RINKO values should be used with caution.

CHAPTER

SEVEN

SALINITY

PIs

- Susan Becker
- James Swift

Technicians

- John Calderwood
- Jeremiah Brower

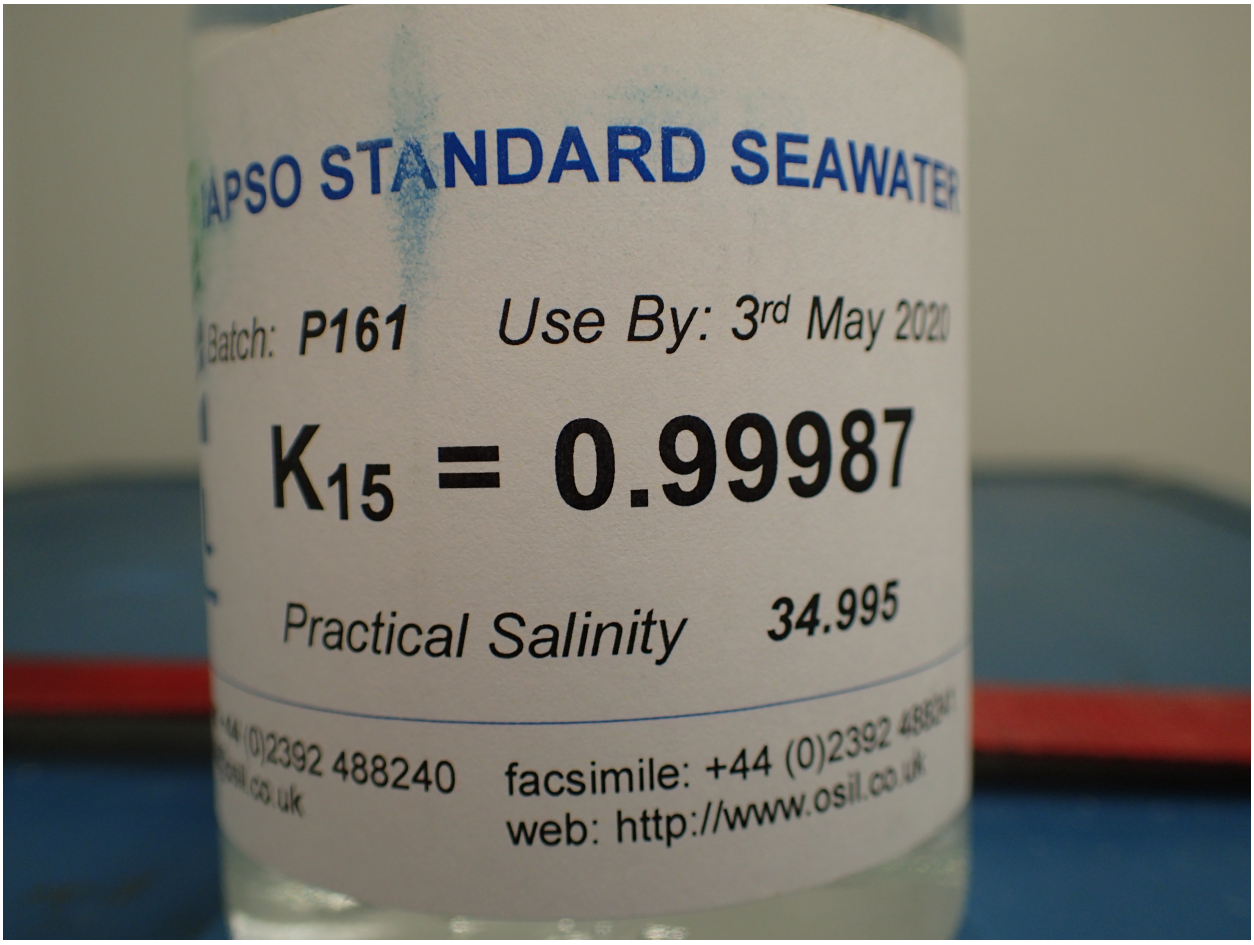
7.1 Equipment and Techniques

Two Guildline Autosals located in salinity analysis room, an 8400B (S/N 69-180) and an 8400A (S/N 57-396), were used for all salinity measurements. Both were serviced prior to NBP18-02/S04P in San Diego and sent with other equipment in January. The salinometer readings were logged on a computer using a LabView program developed by Carl Mattson. The Autosal water bath temperature was set to 21°C. The laboratory's temperature was set and maintained to 20°C. This is to ensure stabilize reading values and improve accuracy. Salinity analyses were performed after samples had equilibrated to laboratory temperature range of 20-21°C, usually 8 hours after collection. The salinometer was standardized for each group of samples analyzed (1 or 2 casts, up to 72 samples) using two bottles of standard seawater: one at the beginning and end of each set of measurements. The salinometer output was logged to a computer file. The software prompted the analyst to flush the instrument's cell and change samples when appropriate. Between runs the water from the last standard was left in the cell. For each calibration standard, the salinometer cell was initially flushed 2 times before a set of conductivity ratio reading was taken. For each sample, the salinometer cell was initially flushed at least 2 times before a set of conductivity ratio readings were taken.

IAPSO Standard Seawater Batch P-161 was used to standardize all casts.

7.2 Sampling and Data Processing

The salinity samples were collected in 200 ml Kimax high-alumina borosilicate bottles that had been rinsed at least three times with sample water prior to filling. The bottles were sealed with custom-made plastic insert thimbles and Nalgene screw caps. This assembly provides very low container dissolution and sample evaporation. Prior to sample collection, inserts were inspected for proper fit and loose inserts replaced to insure an airtight seal. Laboratory temperature was also monitored electronically throughout the cruise. PSS-78 salinity *[UNESCO1981]* was calculated for each sample from the measured conductivity ratios. The offset between the initial standard seawater value and its reference value was applied to each sample. Then the difference (if any) between the initial and final vials of standard seawater was applied to each sample as a linear function of elapsed run time. The corrected salinity data was then incorporated into the cruise database.


APSO STANDARD SEAWATER
Batch: P161
Use By: 3rd May 2020
K15 = 0.99987
Practical Salinity
34.995
facsimile: +44 (0)2392
web: http://www.osil.co.uk

7.3 Narrative

Autosal 69-180 was used to process samples from the first 16 stations. Communication errors between Labview and Autosal 69-180 occurred during processing of station 16's samples, causing the Labview software to lose connection with the Autosal. The LVasal software was updated to version 1.35c, but communication errors continued. The serial connection to the DGH board installed in the back of Autosal 69-180 had a wire work loose from its terminal block. Once the loose wire was found and re-installed, the serial feed from 69-180 worked correctly. Autosal 57-396 was used from station 18 to 120, and ended the cruise in good working order.

Autosal 57-396, being a model 8400A, appeared to be more unstable with its standard numbers between runs. On at least two occasions the standard number changed more than 10 units when measuring a standard for a single cast, with the casts on both sides of the impacted cast having the same standard value. On those casts the data was flagged as 3 or 4 as deemed appropriate. Some bottles of IAPSO standard were also suspected to be different from the stated value, requiring additional standards to be open and run before starting analysis of the cast. It is unclear whether the standards were bad, the autosal was reporting erroneous values, or some combination of both.

Due to communication issues during handoff six bottles were not sampled. Seven bottles were broken during sampling.

7.4 Standard Dial Experiment

To attempt corrections with the casts showing offsets in both salinity values and standard dial values on Autosal 8400A S/N 57-396, an experiment was run sampling IAPSO standard at different standard dial values. At the end of the cruise 12 standards were run with different standard dial values, where the values were chosen to constrain the values seen during the cruise. The standards were run from 400 to 450 and back to 400 to see if there was a difference in turning the standard dial versus standard dial down. Changing the standard dial seemed to show a linear change in conductivity ratio. While no standards were run as a standard, the value from the last autosal run is presented as a measure of autosal stability. The values sampled are presented below.

Std Value	Conductivity Ratio
440	1.99976 (Last run)
400	1.99947
410	1.99957
420	1.99965
430	1.99973
440	1.99978
450	1.99984
450	1.99991
440	1.99978
430	1.99971
420	1.99963
410	1.99954
400	1.99948

The values were compared to the runs with offsets to see if a linear offset would correct the data, such as station 93. Station 93 showed a good shape in the profile, but offset from the profiles seen on neighboring stations. Unfortunately, the offset did not entirely correct the data, resulting in the deep salinity values lower and outside the bounds of acceptable salinity than salinity values on neighboring stations. It is unsure what else could have caused the salinity value change. The impacted stations were still flagged as 4.

CHAPTER

EIGHT

NUTRIENTS

PIs

- Susan Becker
- James Swift

Technicians

- Susan Becker
- John Ballard

8.1 Summary of Analysis

- 4122 samples from 121 ctd stations
- The cruise started with new pump tubes and they were changed prior to stations 27, 54, and 87.
- 7 sets of nitrate, phosphate, and silicate Primary/Secondary standards were made up over the course of the cruise.
- 3 sets of Primary and 38 sets of Secondary nitrite standards were made up over the course of the cruise.
- The cadmium column efficiency was checked periodically and ranged between 97%-100%. A new column was put on if the efficiency fell below 97% or injected with air.

8.2 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]*.

8.3 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.

8.4 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.

8.5 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.

8.6 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.

8.7 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.

8.8 Standards and Glassware Calibration

Primary standards for silicate (Na2SiF6), nitrate (KNO3), nitrite (NaNO2), and phosphate (KH2PO4) were obtained from Johnson Matthey Chemical Co. and/or Fisher Scientific. The supplier reports purities of >98%, 99.999%, 97%, and 99.999 respectively.

All glass volumetric flasks and pipettes were gravimetrically calibrated prior to the cruise. The primary standards were dried and weighed out to 0.1mg prior to the cruise. The exact weight was noted for future reference. When primary standards were made, the flask volume at 20C, the weight of the powder, and the temperature of the solution were used to buoyancy-correct the weight, calculate the exact concentration of the solution, and determine how much of the primary was needed for the desired concentrations of secondary standard. Primary and secondary standards were made up every 7-10days. The new standards were compared to the old before use.

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

Standardizations were performed at the beginning of each group of analyses with working standards prepared every 10-12 hours from a secondary. Working standards were made up in low nutrient seawater (LNSW). One batch of LNSW was used on the cruise. It was collected and filtered prior to the cruise. 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

8.9 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.

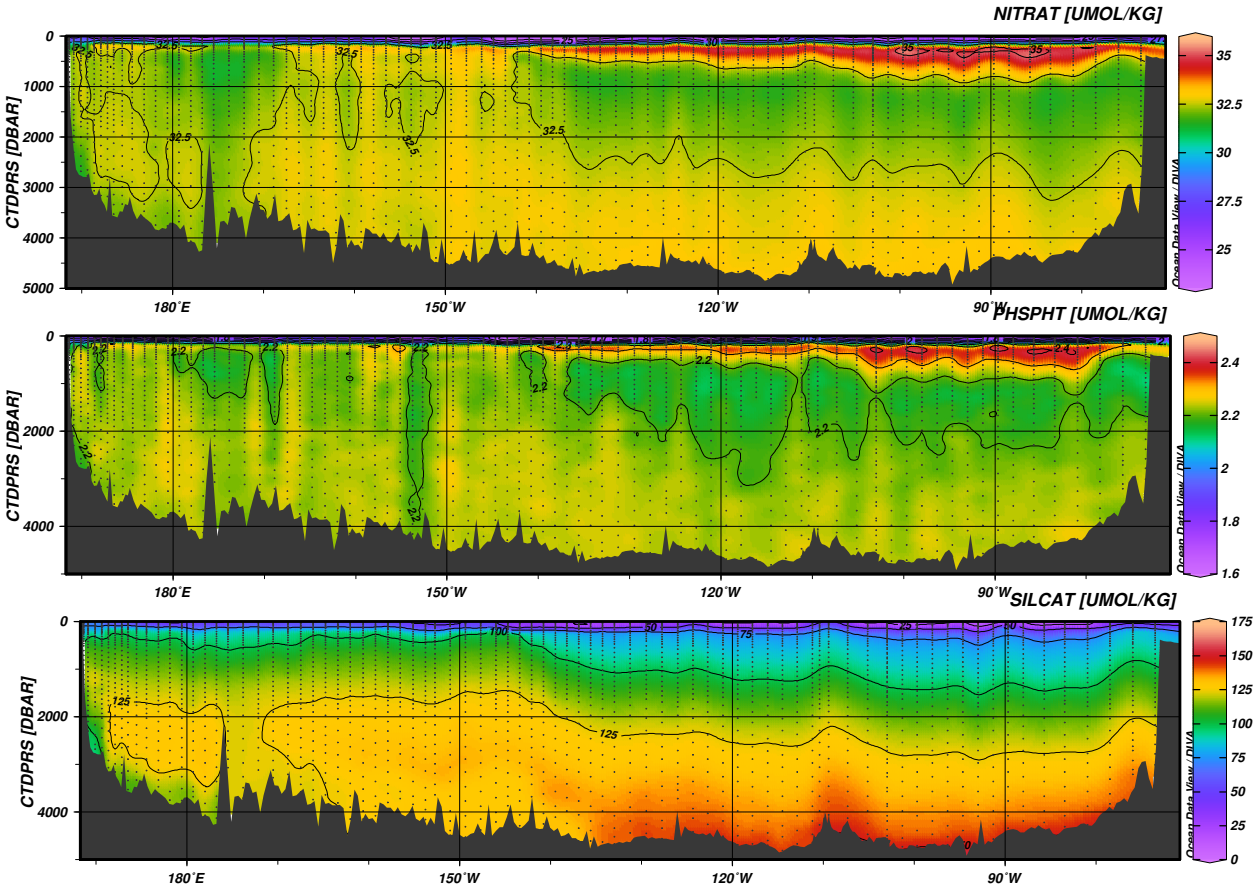
Parameter	Concentration (µM)	stddev
NO^3	31.69	0.135
PO_4	2.15	0.02
SIL	98.1	0.5

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 CF 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/l)	-	(µmol/l)
NO^3	44.68	0.17	44.46
PO_4	3.13	0.01	3.13
Sil	163.8	0.6	163.6
NO_2	0.09	0.01	0.07

8.10 Analytical Problems

No major analytical problems.


NITRAT [UMOL/KG]
CTDPRS [DBAR]
0
1000
2000
3000
4000
5000
180°E
150°W
120°W
90°W
35
32.5
30
27.5
25
Ocean Data View - DIVA
PHSPHT [UMOL/KG]
2.4
2.2
2
1.8
1.6
SILCAT [UMOL/KG]
175
150
125
100
75
50
25
0

CHAPTER

NINE

OXYGEN ANALYSIS

PIs

- Susan Becker
- James Swift

Technicians

- Andrew Barna
- Kenneth Jackson

9.1 Equipment and Techniques

Dissolved oxygen analyses were performed with an SIO/ODF-designed automated oxygen titrator using photometric end-point detection based on the absorption of 365nm wavelength ultra-violet light. The titration of the samples and the data logging were controlled by PC LabView software. Thiosulfate was dispensed by a Dosimat 665 buret driver fitted with a 1.0 ml burette. ODF used a whole-bottle modified-Winkler titration following the technique of Carpenter *[Carpenter1965]* with modifications by *[Culberson1991]* but with higher concentrations of potassium iodate standard approximately 0.012N, and thiosulfate solution approximately 55 gm/l. Pre-made liquid potassium iodate standards were run every day of station work (approximately every 3-4 stations), unless changes were made to the system or reagents. Reagent/distilled water blanks were determined with every standardization or more often if a change in reagents required it to account for presence of oxidizing or reducing agents.

9.2 Sampling and Data Processing

4138 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.

9.3 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.

9.4 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.

9.5 Narrative

Setup occurred in Hobart, Tasmania, Australia from 2018-03-06 to 2018-03-09, the date of departure. The oxygen analysis rig was setup and secured on the forward bench of the hydolab of the R/V Nathanial B. Palmer (NBP). Initial reagent batches of approximately 4l were made in port and the rig was checked out before departure.

During the week long transit from Tasmania to our first station off Antarctica, samples were taken from the uncontaminated seawater system every 4 hours in areas we had permission to sample in. These underway samples were stored for batch analysis all at once. A test station happened about midway though the transit, this was sampled and analyzed by one of the oxygen technicians for practice. These data are reported with the rest of the stations.

Station sampling and analysis went well, with only minor problems encountered. Around station 78 it was noticed that the gain on the detector box was almost at maximum, likely the cause of earlier high "blocked" voltages. The UV pen lamp was replaced, resulting in a lower needed gain. Additionally, the windows in the water bath were cleaned which resulted in a further reduction in needed gain. A single sample was lost due to the burette tip blocking the light path resulting in no findable end point.

The trends in thiosulfate normality were analyzed at the end of station work, three distinct trends were noticed. Batch 1 of thiosulfate (station 1 to 56) was stable around a single value. Batch 2 had a period of drift (station 57 to 85), then was stable around a value (station 86 to 120). The thiosulfate normality was smoothed (linear regression) in these three regions and the concentrations recalculated.

CHAPTER

TEN

DISSOLVED INORGANIC CARBON (DIC)

PIs

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

Technicians

- Andrew Collins (*UW*/*NOAA*/*PMEL*)
- Patrick Mears (*U Miami*/*NOAA*/*AOML*)

10.1 Sample collection

Samples for DIC measurements were collected from Niskin bottles into 310 ml borosilicate glass flasks using silicone tubing according to procedures outlined in the PICES Publication, Guide to Best Practices for Ocean CO2 Measurements. The flasks were rinsed three times and filled from the bottom with care not to entrain any bubbles, overflowing by at least one-half volume. The sample tube was pinched off and withdrawn, creating a 6 ml headspace, followed by addition of 0.12 ml of saturated HgCl2 solution in order to halt any biological activity. The sample bottles were then sealed with glass stoppers lightly covered with Apiezon-L grease and were stored at room temperature for a maximum of 12 hours.

10.2 Equipment

DIC analysis was performed via coulometry using two analytical systems (PMEL1 and PMEL2) simultaneously on the cruise. Each system consisted of a coulometer (CM5015-O UIC Inc) coupled with a Dissolved Inorganic Carbon Extractor (DICE). The DICE system was developed by Esa Peltola and Denis Pierrot of NOAA/AOML and Dana Greeley of NOAA/PMEL to modernize a carbon extractor called SOMMA (Johnson et al. 1985, 1987, 1993, and 1999; Johnson 1992).

The two DICE systems (PMEL 1 and PMEL 2) were set up in the dry lab onboard the RVIB Nathaniel B. Palmer.

10.3 DIC Analysis

In coulometric analysis of DIC, all carbonate species are converted to CO2 (gas) by addition of excess hydrogen ion (acid) to the seawater sample, and the evolved CO2 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 CO2 that enters the cell is determined by integrating the total change during the titration.

10.4 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, PMEL). 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 2.18 $\pm$ 1.31 µmol/kg for PMEL 1 and 5.32 $\pm$ 1.48 µmol/kg for PMEL 2. The consistently low offset on PMEL 2 can likely be explained by a slightly inaccurate pipette calibration. A post-cruise calibration will be performed, which should confirm this.

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 17.73 $\pm$ 4.3 and 21.11 $\pm$ 5.8 counts, respectively.

10.5 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 before sample analysis;
3. Duplicate samples from the same niskin were measured near the beginning; middle and end of each cell.

Each coulometer was calibrated by injecting aliquots of pure 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 ()#172) CRM value. The CRM certified value for this batch is 2039.06 µmol/kg.

The precision of the two DICE systems can be demonstrated via the replicate samples. Approximately 11.5% 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 0.67 µmol/kg - no major systematic differences between the replicates were observed.

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

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	1.002553	1.006788	27.5905 ml	2036.88, n=108	1.31	0.63
PMEL 2	1.004904	1.002426	26.4110 ml	2033.74, n= 86	1.48	0.72

10.6 Underway DIC Samples

Underway samples were collected from the flow thru system in the Hydro Lab during transit. Discrete DIC samples were collected approximately every 4 hours with duplicates every fifth sample. A total of 66 discrete DIC samples including duplicates were collected while underway. The average difference for replicates of underway DIC samples was 0.9 µmol/kg and the average standard deviation was 1.3.

10.7 Summary

The overall performance of the analytical equipment was good during the cruise. At the time of submission, our data includes 13 samples flagged as "questionable", and 2 samples flagged as "bad". In general, questionable values seemed to result from drift in the coulometer cell, which will be accounted for in post-cruise data quality control.

Including the duplicates, 3,905 samples were analyzed from 118 CTD casts for DIC, yielding a value for approximately 84% of the niskins tripped. The distribution of DIC with depth along the 2018 cruise track can be seen in Figure 1, while differences in DIC distributions observed between the 2011 and 2018 S04P occupations can be seen in Figures 2 and 3. The DIC data reported to the database directly from the ship are to be considered preliminary until a more thorough quality assurance can be completed shore side.

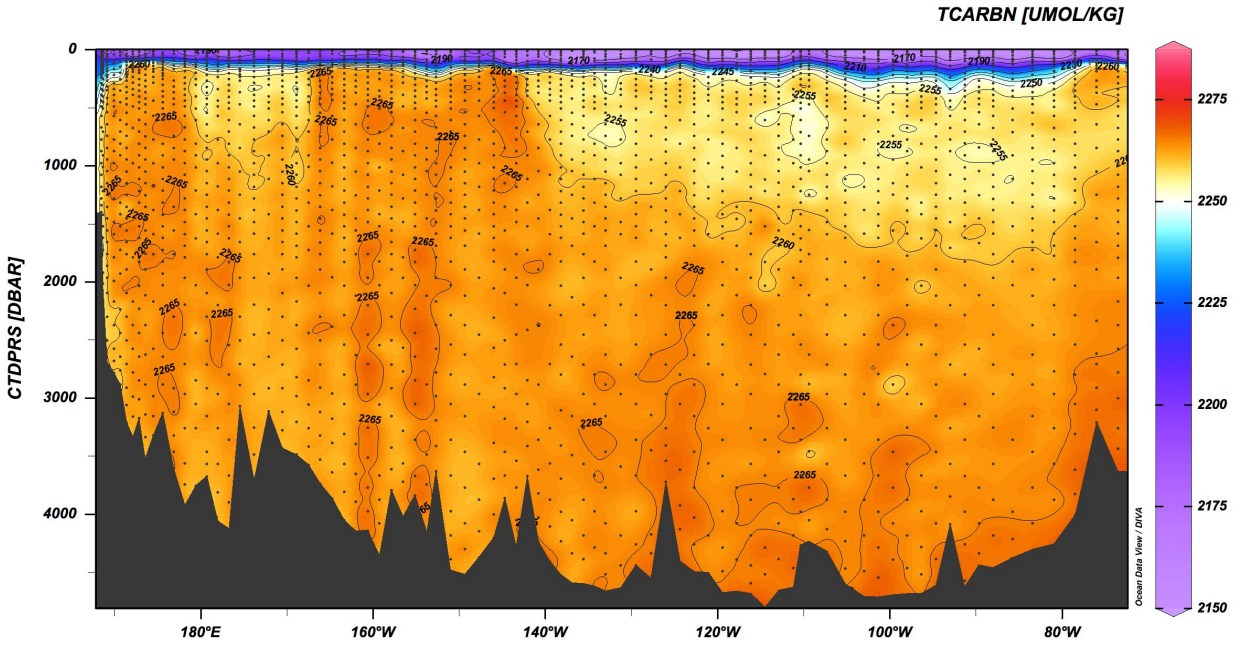


Fig. 10.1: Distribution of dissolved inorganic carbon measured during the 2018 GO-SHIP S04P research expedition.

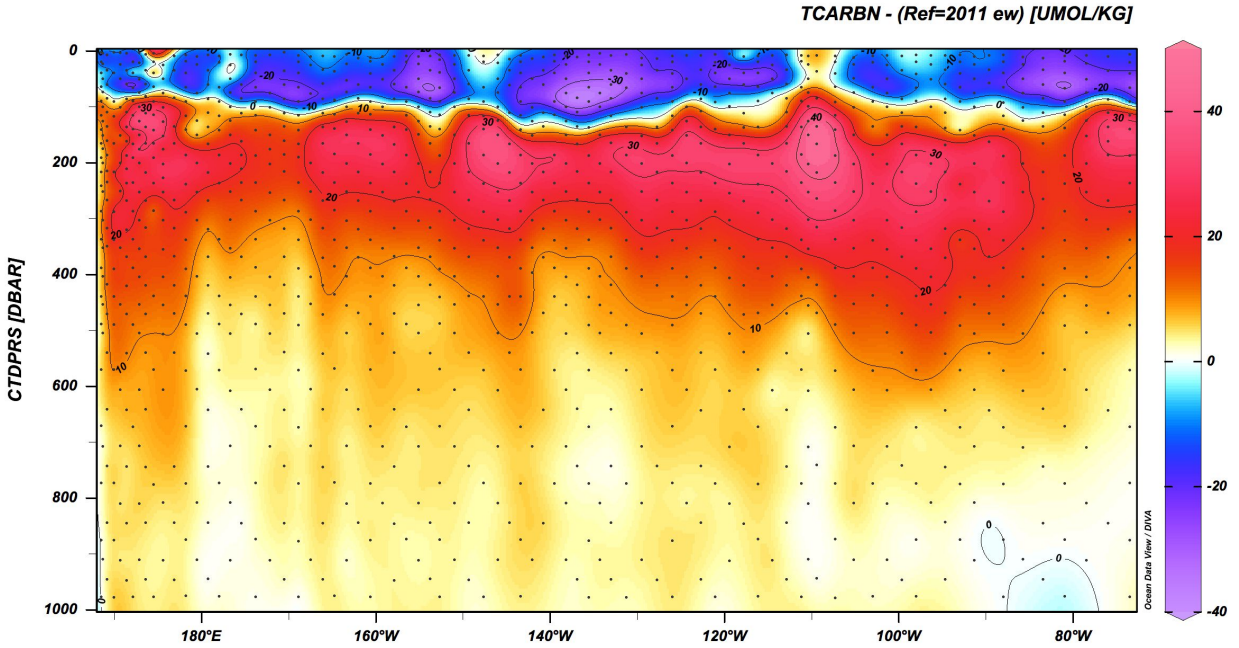


Fig. 10.2: Changes in the distributions of dissolved inorganic carbon in the upper 1000m measured during the 2018 S04P occupation compared to those measured during the 2011 S04P occupation.

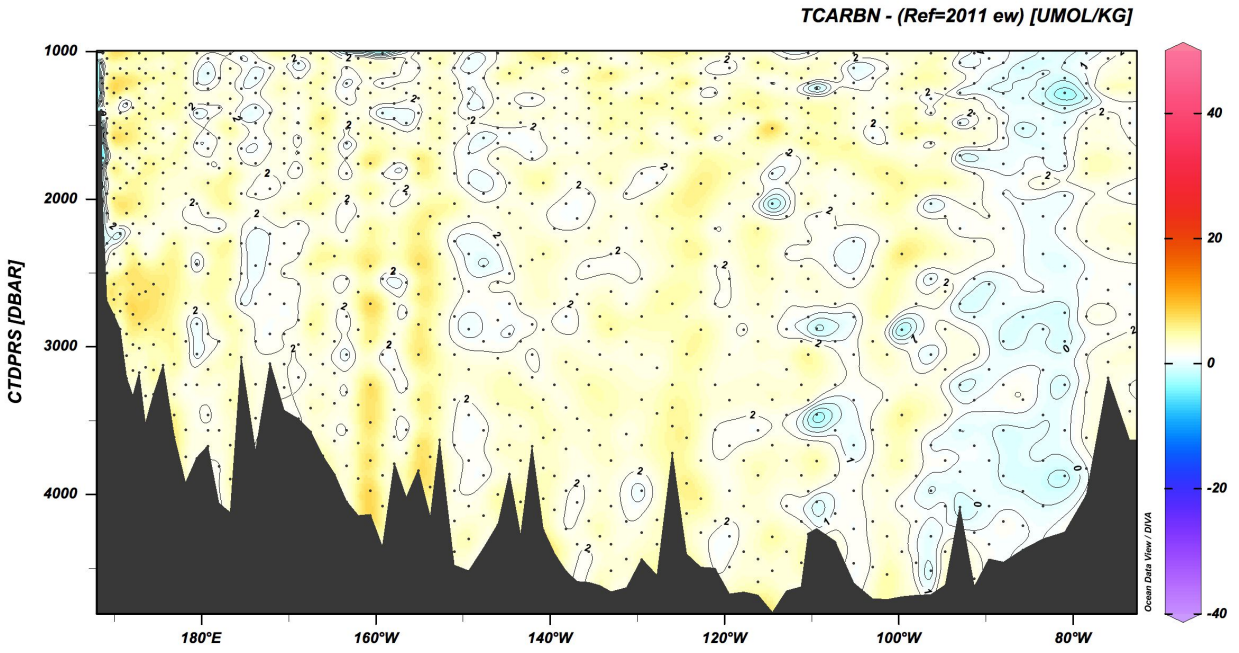


Fig. 10.3: Changes in the distributions of dissolved inorganic carbon below 1000m measured during the 2018 S04P occupation compared to those measured during the 2011 S04P occupation.

CHAPTER

ELEVEN

TOTAL ALKALINITY

PI

- Andrew G. Dickson – Scripps Institution of Oceanography

Technicians

- Manuel Belmonte
- Sarah Barnes

11.1 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.

11.2 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. The LabVIEW program then calculates the temperature of the sample dispensed. This calculated temperature is used to convert the sample volume to mass for analysis.

Seawater samples are analyzed using an open cell two-stage 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. The sample of seawater is first acidified to a pH between 3.4 and 4.0 with a single aliquot of standardized hydrochloric acid (~0.1 mol kg^{-1} HCl in ~0.6 mol kg^{-1} NaCl solution). The sample is then stirred for five minutes while air is bubbled into the sample 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 the five-minute period, the titration is continued until a pH of about 3.0 has been reached. 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.

11.3 Sample Collection

Samples for total alkalinity measurements were taken at all S04P Stations (1-120). Two Niskin bottles at each station were sampled twice for duplicate measurements. Using silicone tubing, the total alkalinity samples were drawn from Niskin bottles into 250 mL Pyrex bottles, making sure to rinse the bottles and Teflon sleeved glass stoppers at least twice before the final filling. A headspace of approximately 4.5 mL was removed and 0.05 mL of saturated mercuric chloride solution was added to each sample for preservation. After sampling was completed, each sample's temperature was equilibrated to approximately 20°C using a Fischer Scientific Isotemp® water bath.

11.4 Problems and Troubleshooting

The R/V IB Nathaniel B. Palmer is a fantastic research vessel. Our electrodes only occasionally appeared to pick up larger than expected interference from the lab's neighboring instruments or the ship itself. While breaking through thick ice there was an increase in this interference due to turbulence throughout the ship. Electrode plots could show increased electrode sensitivity over time. However, enough electrodes were brought on S04P so this never resulted in a bad measurement. Any unusual measurements (poor electrode plot / profile outlier) were always reran.

Near the start of S04P, low alkalinity values for reference material titrations required a Metrohm 876 Dosimat Plus to be changed. This changed the volume of acid being added to the titrations but due to careful calibration of the Metrohm 876 Dosimat Plus's delivery volume this did not affect the alkalinity titration's results.

Also near the start of S04P, Sample Delivery System B was changed due to a suspected shift in the volume being delivered. SDS A delivers 1 mL more than SDS B, but again due to careful calibration of both systems delivery volume this did not affect the alkalinity measurements. Additionally, throughout the cruise there were minor SDS glitches. Either the SDS would get stuck in a drawing command or dispensing command or the temperature probes would produce an obviously wrong temperature. Very few times did the system getting stuck in drawing or dispensing command cause samples to be lost, and erroneous temperatures were caught immediately. Furthermore, a leaky valve was discovered and although no measurements were affected because of the operators' quick responses, the valve was replaced to prevent any future samples from being lost.

11.5 Quality Control

Dickson laboratory Certified Reference Material (CRM) Batch 172 was used to determine the accuracy of the total alkalinity analyses on S04P. The total alkalinity certified value for this batch is:

- Batch 172 2217.40 $\pm$ 0.7 μmol/kg (32;16)

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

At least one reference material was analyzed at every S04P station, resulting in 455 reference material analyses. On S04P, the measured total alkalinity value for each batch is:

- Batch 172 2216.34 $\pm$ 1.59 mol kg-1 (455) [mean $\pm$ std. dev. (n)]

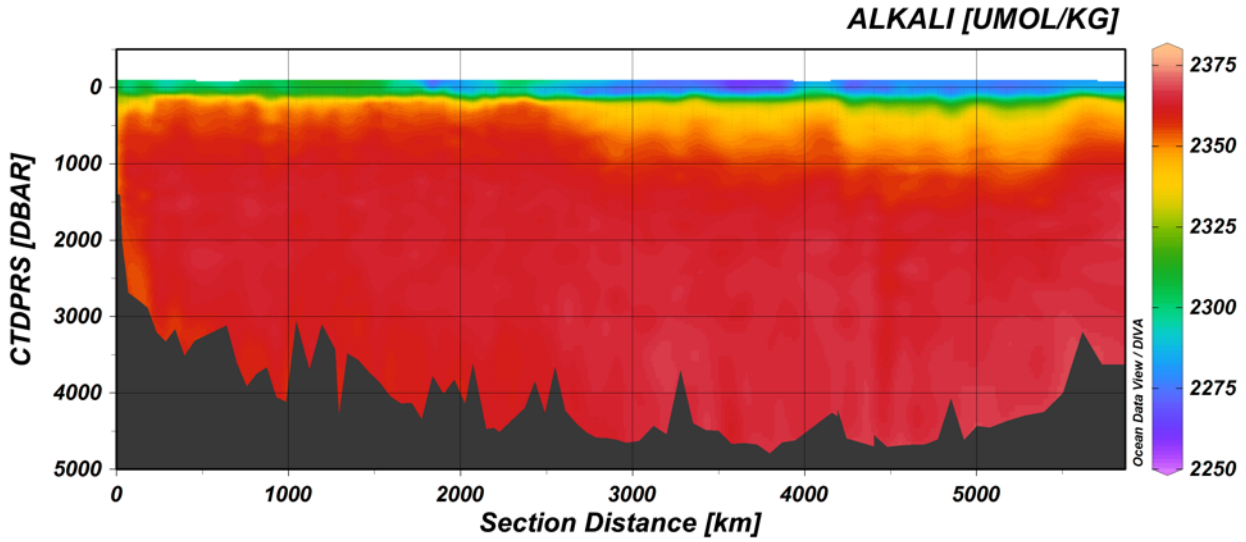
Two Niskin bottles were sampled twice at every station for duplicate analyses. The pooled standard deviation observed amongst duplicates measured on S04P is:

- 1.07 µmol kg-1 (234) [pooled std. dev. (n)] .

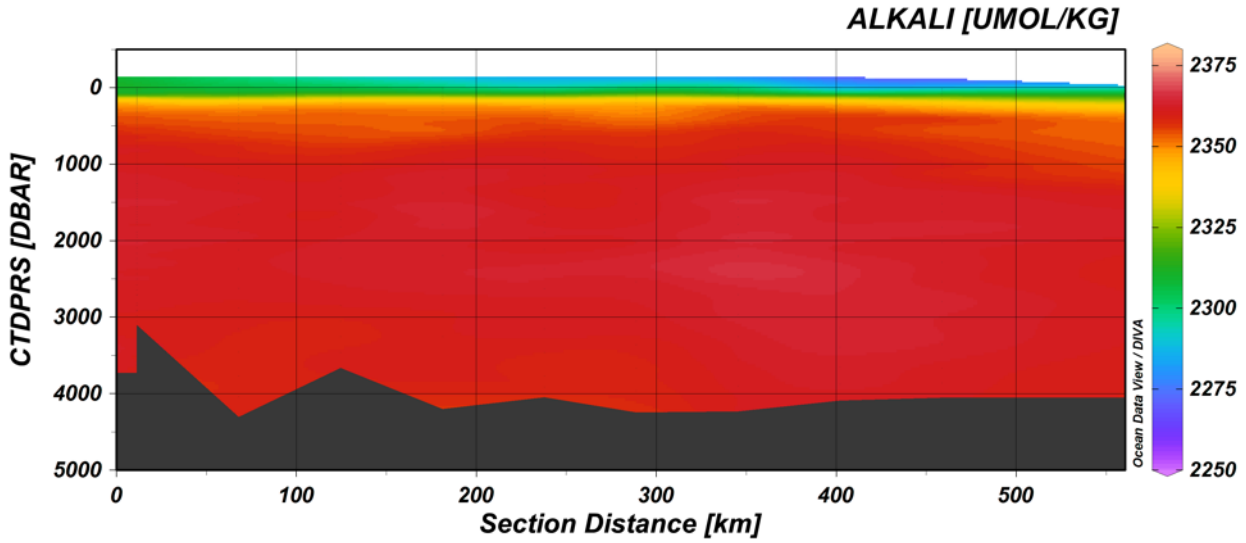
The total alkalinity measurements for each 2018 S04P station were compared to measurements taken from the neighboring 2018 S04P stations.

3502 total alkalinity values were submitted for S04P. The total alkalinity of the entire transect is shown as sectional figures in the attached Figures. Corrections have been made for Certified Reference Material measurement comparison

and also for the mercuric chloride additions. The correct sample volume still needs to be verified on land. Thus, the data submitted along with this report is to be considered preliminary.



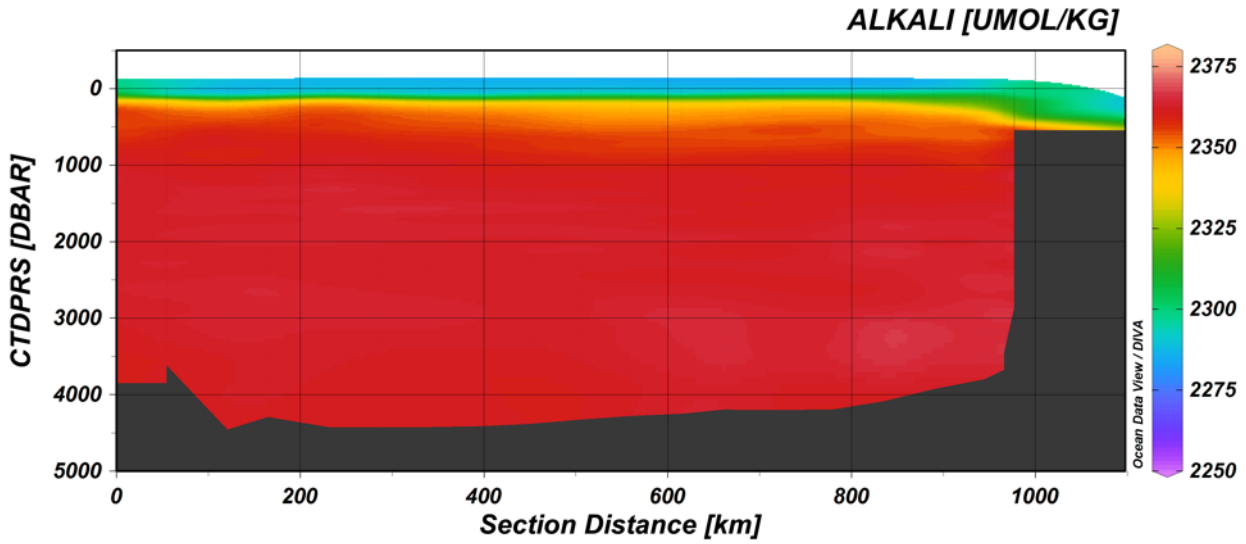
Section of total alkalinity along S04P 67° S (stations 1 - 120 except 10-17, 31-53, and 98-103).



Section of total alkalinity along S04P 170° W (stations 10-17).

Section of total alkalinity along S04P 150° W (stations 31-53).

Section of total alkalinity along S04P 103° W (stations 98-103).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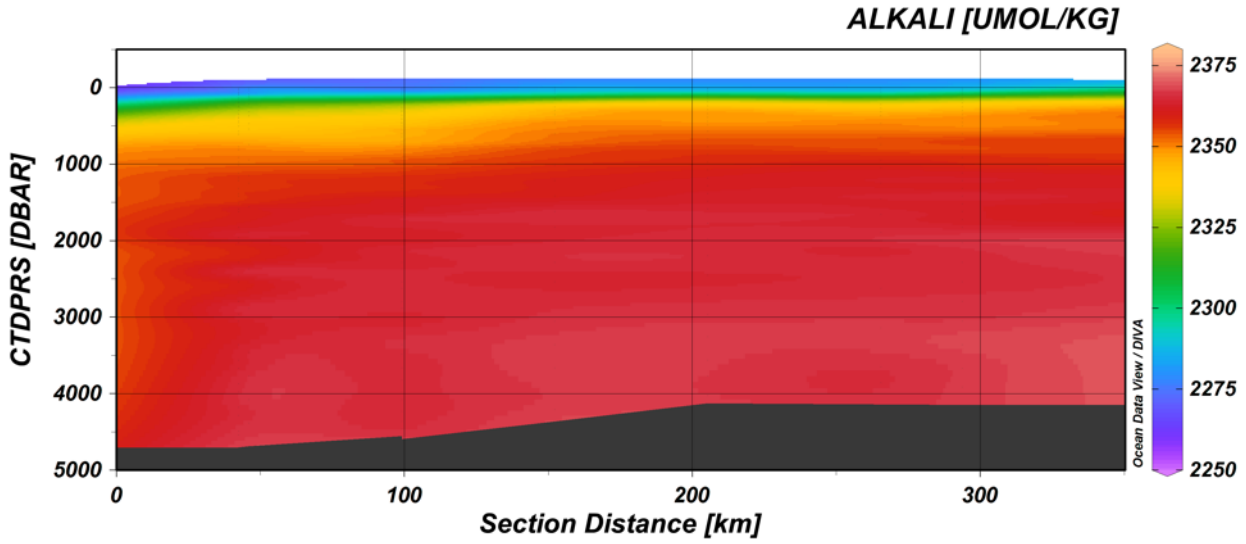
Ocean Data View / DIVA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CTDPRS [DBAR]
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Section Distance [km]
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2275
2250
Ocean Data View / DIVA

CHAPTER

TWELVE

DISCRETE PH ANALYSES (TOTAL SCALE)

PI

- Dr. Andrew Dickson

Technicians

- May-Linn Paulsen

12.1 Sampling

Samples were collected in 250 mL Pyrex glass bottles and sealed using Teflon-sleeved glass stoppers held in place by rubber bands. 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 (HgCl2) using an Eppendorf repeating pipettor. 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, two duplicate samples were collected from all stations for quality control purposes.

12.2 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 (Abase) 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. The salinity data was later corroborated by shipboard measurements.

12.3 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 5 batches were used during the cruise. The pHs of these batches was adjusted with 0.1 M solutions of HCl and NaOH (in 0.6 M NaCl background) to approximately 7.85, measured with a pH meter calibrated with NBS buffers.

The indicator was obtained from Prof. Eric Achterberg at GEOMAR-Helmholz Centre for Ocean Research (Kiel), and was purified using the flash chromatography technique described by Patsavas et al., 2013. *[Patsavas2013]*.

12.4 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:

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

12.5 Problems and Troubleshooting

Many of the samples had 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). Efforts were made to reduce bubble formation by verifying all pump fittings were tight, and periodically flushing the system with air or isopropanol, followed by thorough flushing with junk seawater.

Bubbles also occasionally formed in the water bath that controls the measurement temperature. In one instance, an extremely large bubble in the tubing stopped the circulation of water around the 10-cm cell and caused a sudden drop in temperature. This occurred as the room temperature changed drastically (also observed in total alkalinity temperature measurements), the reason for the room temperature change is not known. This appeared to affect the pH of one sample, which deviated from a typical profile and was flagged as questionable in the preliminary data. Room temperature and water bath tubing was checked periodically following this incident.

There were occasionally problems with the rubber bands slipping off the bottle stoppers, potentially causing de-gassing of the samples prior to the analysis, although the extent to which degassing could have happened is not known. The rubber band slipping off would also happen occasionally while the samples were temperature-equilibrating in the water bath, and sometimes the stopper would pop off from the sample expanding. The samples to which this happened did not appear to have an anomalous pH when compared to deeper and shallower samples from the same station.

One bottle broke prior to analysis, resulting in the loss of data for one sample.

Our HgCl2 dispenser would sometimes partly clog due to the cold temperatures in the Baltic Room causing the volume of HgCl2 dispensed into some of the samples to vary slightly, although no effect on the pH was detected. When this happened, the pipette tip was thoroughly rinsed with de-ionized water.

12.6 Standardization/Results

The precision of the data was assessed from measurements of duplicate analyses, replicate analyses (two successive measurements on one bottle), certified reference materials (CRMs) from Batch 172 (provided by Dr. Andrew Dickson, UCSD). CRMs were measured twice a day over the course of the cruise.

The overall precision determined from duplicate analyses was ±0.0017 (n=207). The overall precision determined from replicate analyses was ±0.0027 (n=207). Additionally, 418 measurements were made on 112 bottles of Certified Reference Materials, which were found to have a pH of 7.8306 ±0.002 (n=418) and a within-bottle standard deviation of ±0.0005 (n=103).

The precision statistics for P06W are:

Duplicate precision	± 0.0017 (n=207)
Replicate precision	± 0.0027 (n=207)
B172	7.8306 ± 0.002 (n=418)
B172 within-bottle SD	± 0.0005 (n=103)

3492 pH values were submitted for S04P 2018. 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. 12.1.

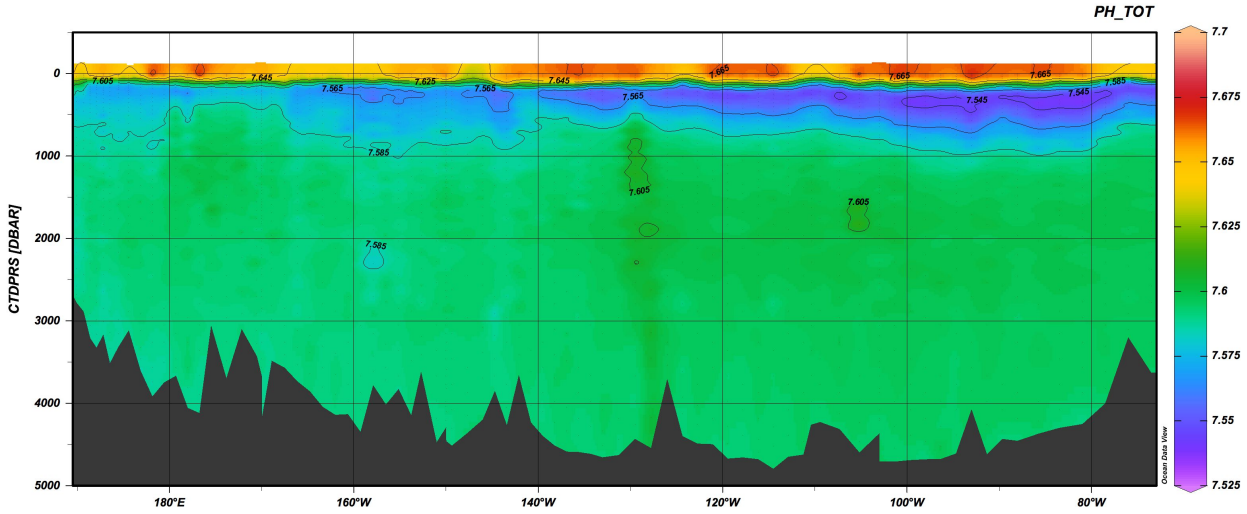


Fig. 12.1: Section of pH on the total scale along S04P (all the stations along the 67 line, not including the south-ward excursions). The data were DIVA-gridded, and a few contours are shown.

CHAPTER

THIRTEEN

CHLOROFLUOROCARBON (CFC), SULFUR HEXAFLUORIDE (SF6), AND NITROUS OXIDE (N2O)*

PI

- Mark J. Warner, University of Washington (warner@u.washington.edu)

Co-PI

- William Smethie, Columbia University – Lamont-Doherty Earth Observatory

Samplers and Analysts

- Mark J. Warner, University of Washington
- Eugene Gorman, Lamont-Doherty Earth Observatory
- Max Rintoul, Australian National University

* Note that N2O measurements are a Level 3 measurement. The concentrations were measured on the same water samples collected for the Level 1 CFC/SF6 measurements. The N2O analysis is still under development. Please contact the PI for any use of these data.

13.1 Sample Collection

Samples for the analysis of dissolved CFC-11, CFC-12, SF6, and N2O were collected from approximately 2460 of the Niskin water samples during the expedition. When taken, water samples for CFC analysis were the first samples drawn from the 10-liter bottles. Care was taken to co-ordinate the sampling of CFCs with other samples to minimize the time between the initial opening of each bottle and the completion of sample drawing. In most cases, dissolved oxygen, dissolved inorganic carbon, and pH samples (and 3He when sampled) were collected within several minutes of the initial opening of each bottle. To minimize contact with air, the CFC samples were collected from the Niskin bottle petcock into 250-cc ground glass syringes through plastic 3-way stopcocks. The syringes were stored in large ice chest in the laboratory at 3.5° - 6°C until 30-45 minutes before analysis to reduce the degassing and bubble formation in the sample. At that time, they were transferred to a water bath at approximately 28°C in order to increase the stripping efficiency.

13.2 Equipment and Technique

Concentrations of CFC-11, CFC-12, SF6, and N2O in air samples, seawater and gas standards were measured by shipboard electron capture gas chromatography (EC-GC). This system from the University of Washington was located in a portable laboratory on the heli-deck. Samples were introduced into the GC-EC via a purge and trap system. Approximately 200-ml water samples were purged with nitrogen and the compounds of interest were trapped on a Porapak Q/Carboxen 1000/Molecular Sieve 5A trap cooled by an immersion bath to -60°C. During the purging of the

sample (6 minutes at 220 ml min-1 flow), the gas stream was stripped of any water vapor via a Nafion trap in line with an ascarite/magnesium perchlorate dessicant tube prior to transfer to the trap. The trap was isolated and heated by direct resistance to 175°C. The desorbed contents of the trap were back-flushed and transferred onto the analytical pre-columns. The first precolumn was a 40-cm length of 1/8-in tubing packed with 80/100 mesh Porasil B. This precolumn was used to separate the CFC-11 from the other gases. The second pre-column was 13 cm of 1/8-in tubing packed with 80/100 mesh molecular sieve 5A. This pre-column separated the N2O from CFC-12 and SF6. Three analytical columns in three gas chromatographs with electron capture detectors were used in the analysis. CFC-11 was separated from other compounds by a long column consisting of 36 cm of Porasil B and 150 cm of Carbograph 1AC maintained at 90°C. CFC-12 and SF6 were analyzed using a column consisting of 2.33 m of molecular sieve 5A and 1.5 m of Carbograph 1AC maintained at 80°C. The analytical column for N2O was 30 cm of molecular sieve 5A in a 120°C oven. The carrier gas for this column was instrumental grade P-5 gas (95% Ar / 5% CH4) that was directed onto the second precolumn and into the third column for the N2O analyses. All three detectors were run at 300°C.

The analytical system was calibrated frequently using a standard gas of known gas composition. Gas sample loops of known volume were thoroughly flushed with standard gas and injected into the system. The temperature and pressure was recorded so that the amount of gas injected could be calculated. The procedures used to transfer the standard gas to the trap, precolumns, main chromatographic columns and EC detectors were similar to those used for analyzing water samples. Three sizes of gas sample loops were used. Multiple injections of these loop volumes could be made to allow the system to be calibrated over a relatively wide range of concentrations. Air samples and system blanks (injections of loops of CFC-free gas) were injected and analyzed in a similar manner. The typical analysis time for samples was 740 sec.

13.3 Atmospheric Sampling

For atmospheric sampling, a ~100 meter length of 3/8-in OD Dekaron tubing was run from the portable laboratory to the bow of the ship. A flow of air was drawn through this line to the main laboratory using an Air Cadet pump. The air was compressed in the pump, with the downstream pressure held at ~1.5 atm. using a back-pressure regulator. A tee allowed a flow (100 ml min-1) of the compressed air to be directed to the gas sample valves of the CFC/SF6/N2O analytical system, while the bulk flow of the air (>7 l min-1) was vented through the back-pressure regulator. Air samples were generally analyzed when the relative wind direction was within 50 degrees of the bow of the ship to reduce the possibility of shipboard contamination. The pump was run for approximately 30 minutes prior to analysis to insure that the air inlet lines and pump were thoroughly flushed. The average atmospheric concentrations determined during the cruise (from a sets of 4 or 5 measurements analyzed when possible) were 224.0 +/- 2.9 parts per trillion (ppt) for CFC-11 (n=47), 504.7 +/- 4.7 ppt for CFC-12 (N=47), 9.2 +/- 0.6 ppt for SF6 (N=28), and 325.1 +/- 2.6 parts per billion for N2O (N=18). Note that a larger aliquot was required for higher precision N2O analysis, and this higher aliquot resulted in SF6 peak areas outside the range of the calibration curve used for seawater samples. No air samples were collected after May 5th due to the bow mast (and air inlet) becoming entirely ensconced in ice.

13.4 Summary

Concentrations of the CFCs in air, seawater samples and gas standards are reported relative to the SIO98 calibration scale (Cunnold, et. al., 2000) *[Cunnold2000]*. Concentrations in air and standard gas are reported in units of mole fraction in dry gas, and are typically in the parts per trillion (ppt) range for CFCs and SF6 and parts per billion (ppb) for N2O. Dissolved CFC concentrations are given in units of picomoles per kilogram seawater (pmol kg-1), SF6 in femtomoles per kilogram seawater (fmol kg-1), and N2O in nanomoles per kilogram seawater (nmol kg-1). CFC concentrations in air and seawater samples were determined by fitting their chromatographic peak areas to multi-point calibration curves, generated by injecting multiple sample loops of gas from a working standard (UW WRS 32399) into the analytical instrument. Full-range calibration curves were run at the beginning and end of the cruise, as well as during long transits/weather delays when possible. Single injections of a fixed volume of standard gas at one atmosphere were run much more frequently (at intervals of 2 hours) to monitor short-term changes in detector sensitivity. The SF6 peak was often on a small bump on the baseline, resulting in a large dependence of the peak area

on the choice of endpoints for integration. Estimated accuracy is +/- 3%. Estimated limit of detection is 1 fmol kg-1 for CFC-11, 2 fmol kg-1 for CFC-12 and 0.05 fmol kg-1 for SF6.

The efficiency of the purging process was evaluated by re-stripping water samples and comparing the residual concentrations to initial values. These re-strip values were less than 1% for CFC-11 and essentially zero for CFC-12 and SF6. For N2O, the re-strip values were complicated by the apparent production of N2O within the re-stripped sample within the sparging chamber for a subset of the samples. Based on the re-strips of numerous samples where the stripper blank was low and relatively constant, the mean values were approximately 5%.

On this expedition, based on the analysis of over 50 duplicate samples (i.e two samples collected from the same Niskin), we estimate precisions (1 standard deviation) of 0.67% or 0.0014 pmol kg-1 (whichever is greater) for dissolved CFC-11, 1.26% or 0.0023 pmol kg-1 for CFC-12 measurements, 0.032 fmol kg-1 or 3.5% for SF6, and 1.06% or 0.18 nmol kg-1 for N2O.

13.5 Analytical Difficulties

The major analytical challenge for this voyage was the sensitivity of the electron capture detector used for the measurement of SF6 and CFC-12 to changes in atmospheric pressure. The peak area of an injection of one large sample loop of the increased by approximately 4% per decrease of 1 mb in atmospheric pressure. In addition the baseline shifted upwards and was very sensitive to the motion of the ship. At atmospheric pressures below 970 mb, the broad plateau on which the SF6 peak eluted became a broad peak with the SF6 peak on the downslope. In rough seas, it was difficult to separate the smaller SF6 peaks from the broader peaks associated with the ship roll. For most of the analyses during these periods, any peak within a time window (74 to 80 sec) was identified as SF6 with endpoints manually chosen. In most of these instances, the reported low-level SF6 concentrations are flagged as questionable (flag 3).

13.6 Surface Saturations of the Dissolved Gases

Analyst

- Max Rintoul

The O2, CFC-11, CFC-12, SF6, and N2O concentration values obtained from the surface bottles were used to calculate the surface saturation of each gas.

Of all gases measured, only N2O was consistently supersaturated (saturation > 100%) at the ocean's surface (Figure above). The other gases were primarily slightly undersaturated, with O2 consistently being the closest to saturation. The CFC-12 saturations were similar to, but displayed less variance than, the CFC-11 saturations, while the much greater variance in SF6 values makes comparisons between the saturations of SF6, CFC-11 and CFC-12 difficult. The marked difference in the variation of O2 and the other gases likely stems from the different technique used to measure the O2 concentrations.

The observed gas saturations can be explained by considering a simple model of mixed layer of the surface ocean (Figure above). At the surface of this layer, gas exchange occurs between the atmosphere and the ocean. If this exchange was the only process affecting the saturation of gases in the surface ocean, over time the system would approach thermodynamic equilibrium, with all gases having saturations of 100%. The deviation of the saturation values from 100% likely results from a gas flux occurring along the mixed layers lower boundary driven by mixing and upwelling. The concentration of CFC-11, CFC-12, SF6 and O2 decline exponentially with depth (Figure below) and hence the water introduced along the lower boundary of the mixed layer is undersaturated, resulting in the entire layer becoming slightly undersaturated with respect to these gases.

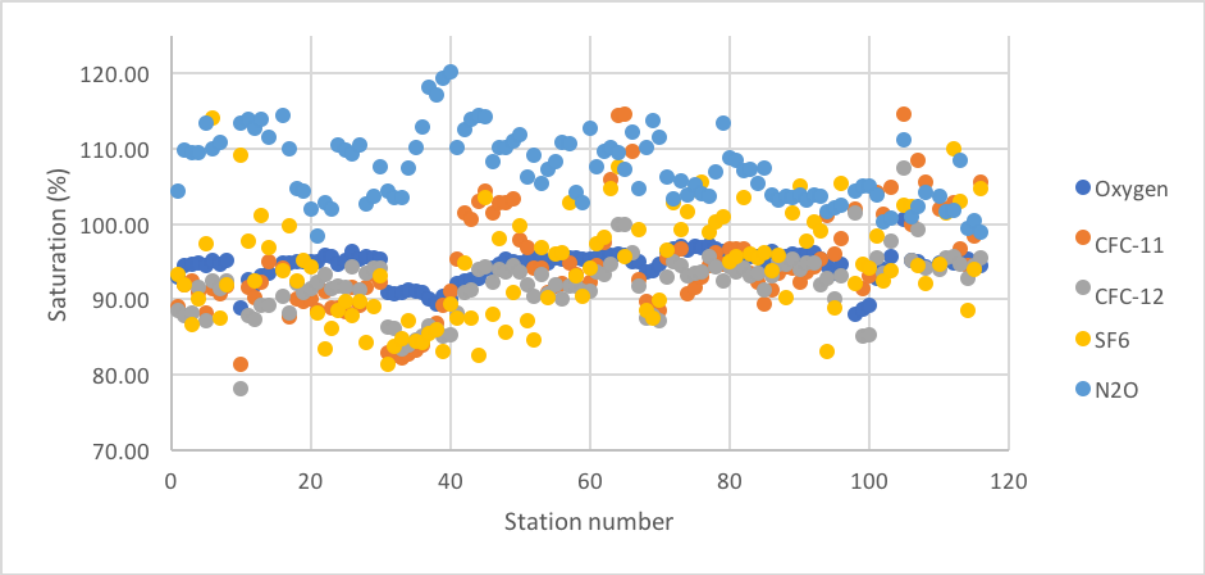


Fig. 13.1: Surface saturations of O2, CFC-11, CFC-12, SF6 and N2O.

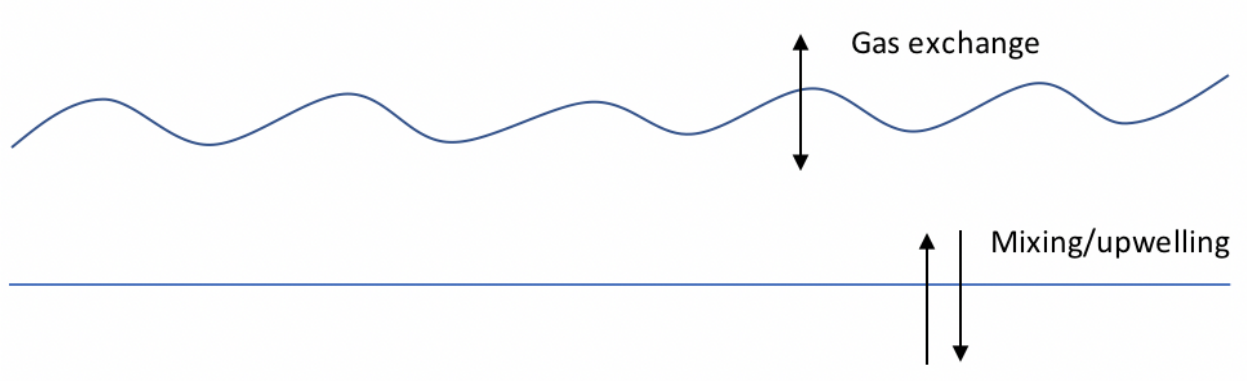


Fig. 13.2: Simple model of gas fluxes into and out of the mixed layer.

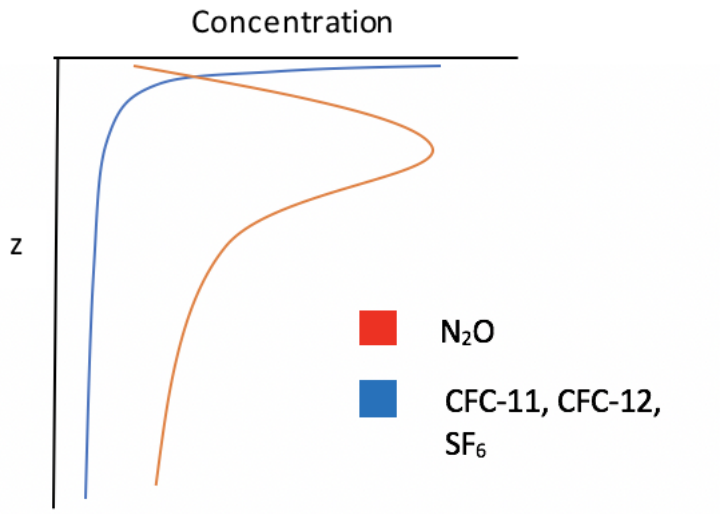


Fig. 13.3: Idealised concentration profiles of various gases with depth.

Upwelling of deeper waters into the mixed layer also accounts for the observed supersaturation of N2O. Unlike CFC-11, CFC-12, SF6 and O2, N2O is produced in the ocean by nitrogen fixers, with such production occurring beyond the mixed layer. In areas and times of high productivity, such as the Southern Ocean in summer, N2O is rapidly consumed as it is a source of bioavailable nitrogen, however beyond the photic zone primary production decreases dramatically, allowing N2O concentrations to build up and for the water below the mixed layer to become supersaturated. The mixing of this supersaturated water into the mixed layer is likely responsible for the observed supersaturation of the surface.

At greater depths N2O production also diminishes, resulting in the concentration profile shown in the figure immediately above. The gas saturations calculated for stations 35-40 lend further credence to the theory that upwelling and mixing have a notable impact on gas saturation values in the surface ocean. These stations were performed in areas of relatively thick sea ice which would prevent gas exchange occurring between the surface ocean and atmosphere. If upwelling and mixing continues to occur it would be expected that the gas saturations of CFC-11, CFC-12, SF6 and O2 would be lower than in the open ocean, while N2O would be higher. While this is observed most strongly between stations 35 to 40, the O2 saturation in particular was also noticeably lower between stations 10 to 14 and 98 to 100. These stations were conducted in regions of high, but not complete, ice cover in which gas exchange between the ocean and atmosphere continued to occur, albeit at a reduced rate. A similar trend was also observed in the open ocean stations 68 and 70. As there was nothing limiting gas exchange between the surface ocean and atmosphere in these locations, this may indicate a region of stronger upwelling or the presence of a shallower mixed layer.

The higher saturation of O2 is likely a result of photosynthesis occurring within the mixed layer. This would also help explain the low oxygen saturation at ice bound stations, as the limited light filtering though the ice would limit primary production. The difference in saturations between CFCs, SF6 and O2 may be further enhanced by the different gas saturations below the mixed layer. The production of CFCs and SF6 began fairly recently and so these gases unlikely to have become as pervasive below the mixed layer as O2, which has been present for a significantly greater period of time. As a result, the O2 saturation of the ocean below the mixed layer is likely greater than the saturation of either CFCs or SF6, hence mixing and upwelling of deeper water would cause a smaller decrease in the surface saturation of O2 than it would on the other gases. As CFC production preceded SF6 production, it might be expected that the CFC saturation values would be greater than those of SF6, however the variation in the calculated SF6 surface saturations prevents this assertion from being made with any confidence.

CHAPTER

FOURTEEN

NITRATE δ^{15}N AND δ^{18}O

PIs

- Gerald Haug (Max-Planck Institute of Chemistry)
- François Fripiat (Max-Planck Institute of Chemistry)

Samplers

- Taimoor Sohail
- Bingkun Luo

Samples for Nitrate δ15N and δ18N were taken by the CTD-watch (Taimoor Sohail and Bingkun Luo) for Haug and Fripiat. A total of 1896 30 ml plastic bottles were used to collect 20 ml samples according to the protocol provided.

- The sample bottles came stored in annotated postal boxes (31x21.5x7 cm); with the annotation corresponding to the labels of the bottles inside; e.g. MPI 2016 Haug SO 01970 to 03866.
- The container with the empty sample bottles and documentation was kept in the forward bio-lab. Usually before the return of the CTD to the deck, but sometimes afterward, the 36 bottle plastic rack was filled with the empty bottles.
- Seawater was taken directly from the Niskin bottles. Sample bottles were rinsed 3 times with seawater from the Niskin prior to sampling. Each 30 ml sample bottle was filled with approximately 20 ml of seawater.
- After 36 bottles were filled they were placed in their corresponding postal boxes and placed directly in the dark in a -20°C freezer.
- The sample ID's, Niskin bottle numbers and date were recorded on the log sheet provided. After all sampling was complete this log sheet was converted to the electronic version, also provided.

The original sample plan asked for 52 stations x 36 bottles sampling every third station. Assuming 30 nm spacing (except near boundaries) this would provide ~90 nm spacing. As station spacings were increased over the course of the cruise due to weather delays, the sampling resolution was increased, first to 2:3:2 from station 54, and then to every station from station 105 till the end of the transect at station 120.

Note that Bottles 3814 to 3866 were not sampled as the ship diverted to Punta Arenas for a medical emergency.

Table 14.1: List of sample boxes and corresponding stations sampled. Latitude and longitude ranges correspond to the first and last station sampled in that box, respectively.

Box Latitude	ID Start Longitude	ID End	Stations
1 -70.4507 to -69.6653	1970 168.4729 to 169.9072	2023	1 - 4

Continued on next page

Table 14.1 – continued from previous page

Box Latitude	ID Start Longitude	ID End	Stations
2 -69.6653 to -70.496	2024 169.9072 to -170.0017	2077	4 - 11
3 -70.496 to -69.0064	2078 -170.0017 to -170.0002	2131	11 - 14
4 -69.0064 to -67.0023	2132 -170.0002 to 175.5832	2185	14 - 20
5 -67.0023 to -66.999	2186 175.5832 to 179.4227	2239	20 - 23
6 -66.999 to -66.9997	2240 179.4227 to -172.1528	2293	23 - 29
7 -66.9997 to -75.2647	2294 -172.1528 to -147.4598	2347	29 - 35
8 -75.2647 to -74.9995	2348 -147.4598 to -150.1162	2401	35 - 38
9 -74.9995 to -71.9904	2402 -150.1162 to -149.9658	2455	38 - 44
10 -71.9904 to -70.5	2456 -149.9658 to -149.9987	2509	44 - 47
11 -70.5 to -67.0001	2510 -149.9987 to -168.8821	2563	47 - 54
12 -67.0001 to -67.0002	2564 -168.8821 to -166.1342	2617	54 - 56
13 -67.0002 to -66.9995	2618 -166.1342 to -159.2655	2671	56 - 61
14 -66.9995 to -66.9983	2672 -159.2655 to -155.1439	2725	61 - 64
15 -66.9983 to -67.0002	2726 -155.1439 to -147.685	2779	64 - 69
16 -67.0002 to -66.9995	2780 -147.685 to -144.6988	2833	69 - 71
17 -66.9995 to -66.9987	2834 -144.6988 to -138.2009	2887	71 - 76
18 -66.9987 to -67.0013	2888 -138.2009 to -134.3021	2941	76 - 79
19 -67.0013 to -67.0001	2942 -134.3021 to -126.0023	2995	79-84
20 -67.0001 to -67.0014	2996 -126.0023 to -122.7131	3049	84-86
21 -67.0014 to -67.0011	3050 -122.7131 to -114.4999	3103	86-91
22 -67.0011 to -67.001	3104 -114.4999 to -111.2144	3157	91-93
23 -67.001 to -68.0023	3158 -111.2144 to -105.1588	3211	93-97
24 -68.0023 to -69.7477	3212 -105.1588 to -102.9768	3265	97-98
25 -69.7477 to -67.9997	3266 -102.9768 to -102.9985	3319	98-102
26	3320	3373	102-105

Continued on next page

Table 14.1 – continued from previous page

Box Latitude	ID Start Longitude	ID End	Stations
-67.9997 to -67.4996	-102.9985 to -101.3294		
27 -67.4996 to -67.5012	3374 -101.3294 to -98.0007	3427	105-107
28 -67.5012 to -67.4994	3428 -98.0007 to -96.3293	3481	107-108
29 -67.4994 to -67.3004	3482 -96.3293 to -92.9992	3535	108-111
30 -67.3004 to -67.0996	3536 -92.9992 to -89.6713	3589	111-113
31 -67.0996 to -67.0004	3590 -89.6713 to -83.4641	3643	113-116
32 -67.0004 to -66.54143	3644 -83.4641 to -80.58336	3697	116-117
33 -66.5414 to -66.4194	3698 -80.5833 to -75.5959	3751	117-119
34 -66.4194 to -66.3597	3752 -75.5959 to -73.2998	3805	119-120
35 -66.3597	3806 -73.2998	3859	120
36 –	3860 –	3866	–

CHAPTER

FIFTEEN

DISSOLVED ORGANIC CARBON AND TOTAL DISSOLVED NITROGEN

PI

- Craig Carlson (UCSB)

Technician

- Cole Hansell

On-Shore Technicians

- Keri Opalk
- Elisa Halewood

Support NSF

15.1 Project Goals

The goal of the DOM project is to evaluate dissolved organic carbon (DOC)) concentrations along the S04P zonal transect (67°S to 75°S & 168°E to 70°W).

15.2 Sampling

Over the course of the S04P cruise, DOC was sampled at every other station (with few exceptions where multiple stations in a row were sampled for DOC), in alignment with the full profile casts of DIC, Alkalinity, and pH. DOC was sampled at 64 stations of the total 120 stations. At the start of the cruise, DOC sampled 30 unique Niskins ranging the full depth of the water column, with a single duplicate randomly selected for a total of 31 samples collected per cast. Starting at station 12, when it was established we would be skipping stations inaccessible due to ice, DOC sampled 31 unique Niskins with a single duplicate randomly selected for a total of 32 samples collected per cast. At station 102, when further weather delays substantially reduced the total number of expected stations, DOC sampled all 36 Niskins with a single duplicate randomly selected for a total of 37 samples collected per cast. In total 2052 individual DOC samples were collected.

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

To avoid contamination, gloves were used when handling all sampling equipment and clean lab surfaces were used for processing samples. After each station, all equipment used for sampling was rinsed with 10% hydrochloric acid and soaked in DI water in preparation for the next station.

All samples were rinsed 3 times with about 5 mL of seawater and collected into 40 mL glass EPA vials. 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.

Samples were fixed with 50 µL of 4N hydrochloric acid and stored upright at -1.5°C on board. Samples were never frozen. Samples were shipped back to UCSB for analysis via high temperature combustion on Shimadzu TOC-V or TOC L analyzers.

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.

15.3 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]*).

15.4 DOC calculation

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

15.5 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.

15.6 TDN calculation

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

CHAPTER

SIXTEEN

CARBON ISOTOPES IN SEAWATER (14/13C)

PI

- Ann McNichol (WHOI)
- Robert Key (Princeton)

Technician

- Cole Hansell
- Ribanna Dittrich
- Chanelle Cadot

16.1 Project Goals

In the upper water column, the goal is to adequately measure the distribution to estimate the penetration of bomb-produced 14C and quantify the 13C decrease due to the influx of anthropogenic CO2. While the vast majority of bomb-14C will be confined to the upper 1000m of the water column, we are also looking to document the penetration of bomb-produced 14C in abyssal waters near deep water formation regions.

16.2 Sampling

A total of 502 samples were collected from 20 stations along the S04P transect (67°S -75°S & 168°E to 70°W). The North-South transects of 168°E -174°E, 170°W, 150°W, 103°W were prioritized in sampling due to their proximity to the continental shelf (See figure for the visualized station plan). The East-West approach of 70°W was planned to be sampled, however due to a medical emergency NSF advised for an immediate departure to Punta Arenas resulting in unexecuted stations along this approach. 12 stations sampled 31 of 36 Niskin bottles with a focus on deep abyssal water, while 5 available Niskins in the upper water column were skipped. A random duplicate was taken at these 12 stations. The other 9 stations sampled 18 of 36 Niskins, where only the top 1500-2000m of the water column was sampled.

Samples were collected in 500 mL airtight glass bottles. The first 50mL was used to rinse the tygon tubing. Then the flasks were rinsed 2 times with seawater from the specified 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, nitrile 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 secured in AMS crates inside an onboard walk-in cooler set at 10°C. Samples were shipped to WHOI for analysis.

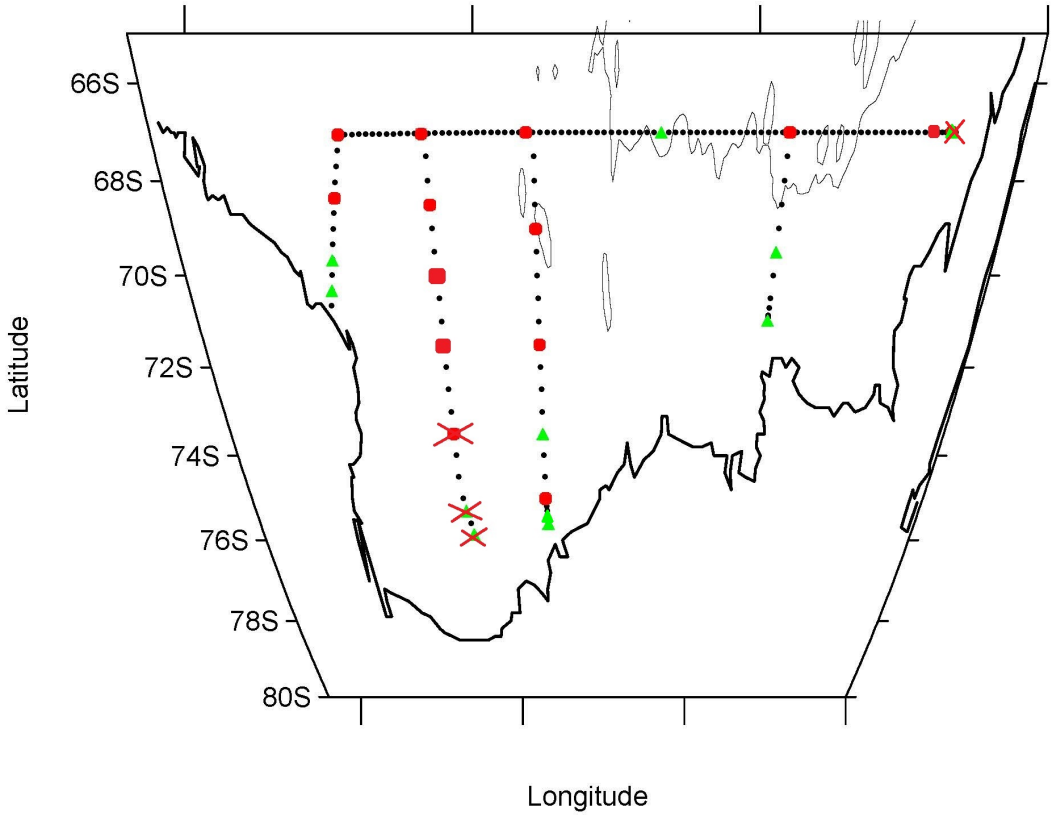


Fig. 16.1: An updated station plot for 14C sampling along the S04P cruise. Red rectangles represent full profile casts, where 31 Niskins were sampled. Green triangles represent stations where only the upper water column (1500-2000m) was sampled. Stations crossed out in red represent stations that were originally planned to be sampled but were cancelled for varying reasons.

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 Δ14C 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

SEVENTEEN

MICROBIAL REMINERALIZATION

PI

- Craig Carlson (UCSB)

Technician

- Cole Hansell

On-Shore Technicians

- Keri Opalk
- Elisa Halewood

Support NSF

17.1 Project Goals

To observe surface microbes utilization/transformation of carbon that is available to them over a long duration of time by measuring microbial growth and total organic carbon (TOC).

17.2 Sampling

Four microbial remineralization experiments were conducted over the course of the S04P zonal transect (67-75°S & 168°E to 70°W). Collection locations were selected based on spatial and timing separation. At each collection site, 9L of surface water were collected from an underway line. 4.5L were filtered using a Georig 142mm filter holding a 0.22µm filter into a designated 8L carboy. Using a Georig 142mm filter holding a 1.2 µm filter, 1.5L were filtered into a separately designated 8L carboy. The 0.22µm and 1.2µm filtered waters were combined and mixed well. 2L were dispensed into a 2L biotainer. Using a positive pressure system, where filtered air displaces the water in the bottle, eighteen 40mL combusted EPA glass vials were filled to serve as parallels to test for bottle effect within the incubation containers (2L biotainers). The remaining 4L of mixed filtered water were equally dispensed into two 2L biotainers. Incubations were stored in a dark, -1.5^{0}C walk in cooler. Duplicate TOC samples were taken from each biotainer, and 3 of 18 parallel vials were sacrificed at 6 separate timepoints (T-0, T-3, T-7, T-14, T-21, T-28). Duplicate flow cytrometry (FCM) samples were taken from each biotainer, with a duplicate also taken from the 3rd parallel vial (only at overlapping TOC collection points), at 12 separate timepoints (T-0, T-1, T-2, T-3, T-4, T-5, T-6, T-7, T-10, T-14, T-21, T-28; where bold represents overlapping collection points with TOC collection) (See table for sampling scheme).

Table 17.1: Sampling scheme for microbial remineralization experiments. Duplicates are denoted by xx and triplicates are denoted by xxx. Rows marked with * represent timepoints where both FCM and TOC measurements were taken.

Time (days) TOC- Biotainer B	Parallel TOC vial FCM- Biotainer A	FCM- 3rd TOC vial FCM- Biotainer B	TOC- Biotainer A
T-0* xx	xxx xx	xx xx	xx
T-1	 xx	 xx	
T-2	 xx	 xx	
T-3* xx	xxx xx	xx xx	xx
T-4	 xx	 xx	
T-5	 xx	 xx	
T-6	 xx	 xx	
T-7* xx	xxx xx	xx xx	xx
T-10	 xx	 xx	
T-14* xx	xxx xx	xx xx	xx
T-21* xx	xxx xx	xx xx	xx
T-28* xx	xxx xx	xx xx	xx

Sampling scheme for microbial remineralization experiments. Duplicates are denoted by xx and triplicates are denoted by xxx. Yellow boxes represent timepoints where both FCM and TOC measurements were taken.

TOC samples were collected in 40mL EPA vials from each 2L biotainer using a positive pressure system. TOC samples were fixed with 50 µL of 4N hydrochloric acid and stored upright at -1.5°C on board. TOC samples were never frozen.

FCM samples were initially collected in 14mL falcon tubes from each 2L biotainer using a positive pressure system. Under a fume hood, 50µL of 8% Paraformaldehyde was added to 2mL cryovials followed by 1.95mL of sample water which were dispensed from the falcon tubes into the cryovials. FCM samples were mixed and stored at room temperature for 30 minutes before being stored in a -80^{0}C freezer.

To avoid contamination, nitrile gloves were used when handling all sampling equipment and clean lab surfaces were used for processing samples. Prior to each experiment, all equipment used for sampling was rinsed with 10% hydrochloric acid and rinsed with DI water. Containers used for collecting, storing, and transporting sample seawater were rinsed 3 times with sample water prior to use (8L carboys, 2L biotainers, 14mL falcon tubes). TOC samples were rinsed 3 times with about 5 mL of seawater.

EPA glass 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.

TOC samples were shipped back to UCSB for analysis via high temperature combustion on Shimadzu TOC-V or TOC L analyzers. FCM samples were shipped back to UCSB for analysis.

CHAPTER

EIGHTEEN

δ18O ISOTOPES

PIs

- Lynne Talley (SIO)
- Nicholas Beaird (OSU)
- Fiamma Straneo (SIO)
- Yves Plancherel (Oxford)

Samplers

- Lauren Ferris
- Amir Barkhordary

Samples for δ18O were taken by the CTD watch for Talley. A total of XX poly-seal screw cap vials were used to collect XX ml samples according to the protocol provided.

- The empty sample vials were stored in annotated boxes (i.e. "Box 2") within a metal cabinet in the Bio Lab. A paper copy of the δ18O sample log was kept in the forward Dry Lab, and an electronic copy of the sample log was maintained in the "Science" drive of the ship's network.
- Before return of the CTD Rosette to deck, sample vials (5 to 10 per cast) were prepared with tape labels, around the circumference of the vial, with the station number and sample number (i.e. "Station 36, Bottle 109"). The "Bottle number" on the label is the δ18O sample number, not the Niskin bottle # or intended depth. The prepared vials were placed in the provided foam holder. The bottle numbers to be used on the cast were written into the sample log.
- For each sample, the Niskin bottle # was obtained from a sample cop who read them from the previously prepared sample log (ii). Seawater was taken directly from the Niskin bottles as described:
  - Retrieve the empty vial from the foam holder. Unscrew the cap from the vial. Fill the vial with seawater from the identified bottle on the rosette. Re-cap, shake the vial, uncap, and empty the seawater onto the cap to rinse.
  - Fill the vial nearly to the top (not overflowing but nearly full).
  - Tighten the cap and place the vial back into the foam holder.
- After sampling, the foam rack with filled samples was taken back to the Bio Lab, where sample vials were dried with paper towels and allowed to come to ambient room temperature. After warming, the caps were re-tightened and wrapped with vinyl electrical tape (around the neck of the vial) to prevent loosening.
- The samples were documented in the paper and identical electronic δ18O sample logs with the following information: Sample, Station, Cast, Niskin, UTC Date (i.e. "Bottle 111, Station 36, Cast 1, Niskin 26, 03 Apr 2018").

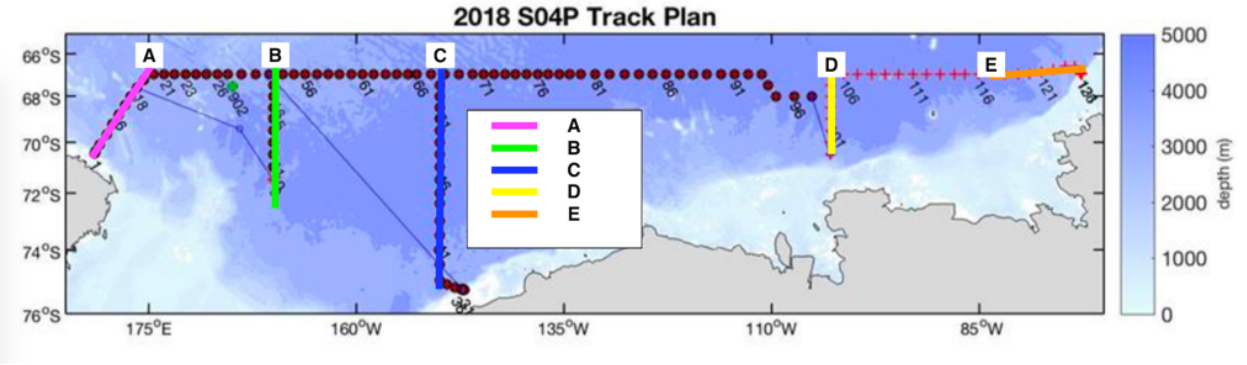


Fig. 18.1: The sampling plan for d18O on S04P 2018.

The sampling plan focused on five shelf-ward excursions from the 67S line (below).

Some of these meridional sections were truncated before reaching the shelf due to ice and weather conditions and a medical situation. The table below summarizes the sampling.

Excursion LAT	Station LON	δO18 Start Date	δO18 End Depth (m)
A -70.45	1 168.47	1 17-Mar-18	10 1391.5
A -70.36	2 168.63	11 17-Mar-18	20 1993.1
A -69.67	4 169.91	21 17-Mar-18	30 2744.7
A -68.81	6 171.39	31 18-Mar-18	40 3167.7
A -68.01	8 172.82	41 18-Mar-18	48 3128.7
B -71.01	10 -170	49 21-Mar-18	58 3995.8
B -70.5	11 -170	59 22-Mar-18	68 4032.5
B -69.5	13 -170	69 22-Mar-18	78 4183.4
B -68.5	15 -170	79 23-Mar-18	88 4139.9
C -75.28	31 -147.1	89 2-Apr-18	94 543.3
C -75.29	32 -147	95 2-Apr-18	98 285.7
C -75.26	34 -147.28	99 2-Apr-18	107 2047.3
C -75.21	36 -148.19	108 3-Apr-18	116 3403.5
C -75	38 -150.12	117 3-Apr-18	125 3749.1
C -74.02	40 -150.11	126 4-Apr-18	134 4030
C -73.02	42 -150.05	135 5-Apr-18	142 4141.4
C -71.99	44 -149.97	143 5-Apr-18	150 4188.5
C -71	46 -150	151 6-Apr-18	158 4263
C -69	50 -150	159 7-Apr-18	167 4362.6
C -67	68 -149.36	168 17-Apr-18	176 4443.6
D -69.5	99 -102.92	177 30-Apr-18	185 4081.6
D -68.96	100 -103	186 30-Apr-18	194 4068.1
D -68	102 -103	195 1-May-18	203 4485.7
E -66.9	117 -80.97	204 7-May-18	212 4188.7
E -66.8	118 -78.48	213 8-May-18	220 4019.8
E -66.7	119 -75.99	221 8-May-18	229 3217.7
E -66.6	120 -73.5	230 9-May-18	269 3647.6

CHAPTER

NINETEEN

RARE EARTH ELEMENTS (REES)

PI

- Yves Plancherel

Sampler

- Yves Plancherel

A total of 945 REEs samples were taken from 50 stations (Figure 1) during S04P making this section one of the most heavily sampled REEs section ever sampled to date (with P18-2016). This REEs sample set also constitutes the first transect in the Pacific sector of the Southern Ocean and the first sections across the Ross Sea, increasing the total number of REE samples from that area by a factor >10. The southernmost station occupied was station 31, in the eastern Ross Sea. Vertical resolution varied slightly from station to station, especially for shelf stations, but for typical stations comprise 21 samples, oscillating between odd and even Niskin bottles, with more samples taken near the top, the bottom and in the oxygen minimum.

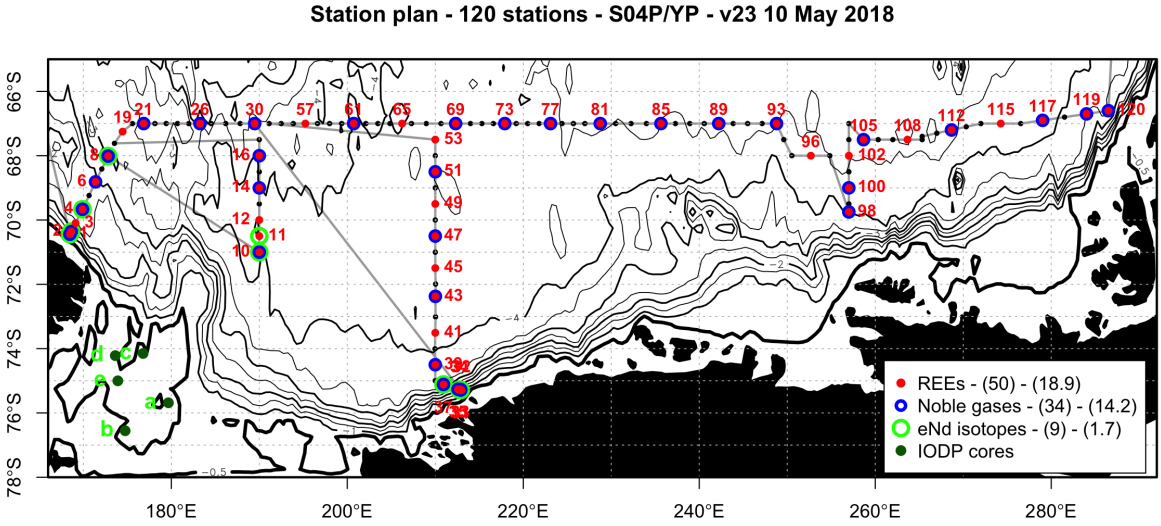


Fig. 19.1: Station location for REE, neodymium isotopes and noble gases. The first number in parenthesis in the legend shows the number of station, the second number is the average number of samples per station. The IODP core sites that the eNd samples taken here are meant to support are shown in dark green.

19.1 Sampling

Samples were drawn from Niskins with acid-cleaned (3M HCl) 60ml PP syringes and ¼" acid-cleaned silicone tubing equiped with a PP Luer slip syringe fitting. New syringes and filters were used for every 4-5 samples to reduce cross-contamination and due to syringe deterioration. After flushing the tubing for a few seconds, a ~30ml aliquot was taken into the syringe. The plunger was then fully opened and the syringe was shaken before ejecting 25ml from the syringe. A 0.45um PP Whatman Puradisc filter was connected to the syringe and the remaining 5ml were used to sample-rinse the filter. After this systematic sample rinse, 60ml were drawn into the syringe and syringe-filtered into prelabelled acid-cleaned 60ml LDPE bottles. Bottles were dried with a Kimwipe and the stopper sealed with Parafilm. All samples were then stored in Ziploc bags in the dark.

To minimize contamination, all sampling material was kept in plastic bags until sampling and nitrile gloves were worn at all times when manipulating REE equipment. Samples were collected either directly after Alkalinity or after DOC. The lab workbench was covered in plastic, which was cleaned regularly with DI water and a Kimwipe. Anything left on the counter was stored in a plastic bag, which was taped to the wall and tied shut, opened only to access content.

CHAPTER

TWENTY

NEODYMIUM ISOTOPES (END)

PI

- Tina van de Flierdt

Sampler

- Yves Plancherel

A total of 15 eNd samples were taken, from 9 stations (Figure 1), all of them as close to the continental shelf as possible, in the Ross Sea. The goal of these samples is to support interpretation of IODP cores taken on the Ross Sea shelf 2 months prior to SO4P and help constrain eNd variability of Ross Sea Bottom Water. Samples were taken from the bottom-most Niskin bottle, the top most, or close to the oxygen minimum.

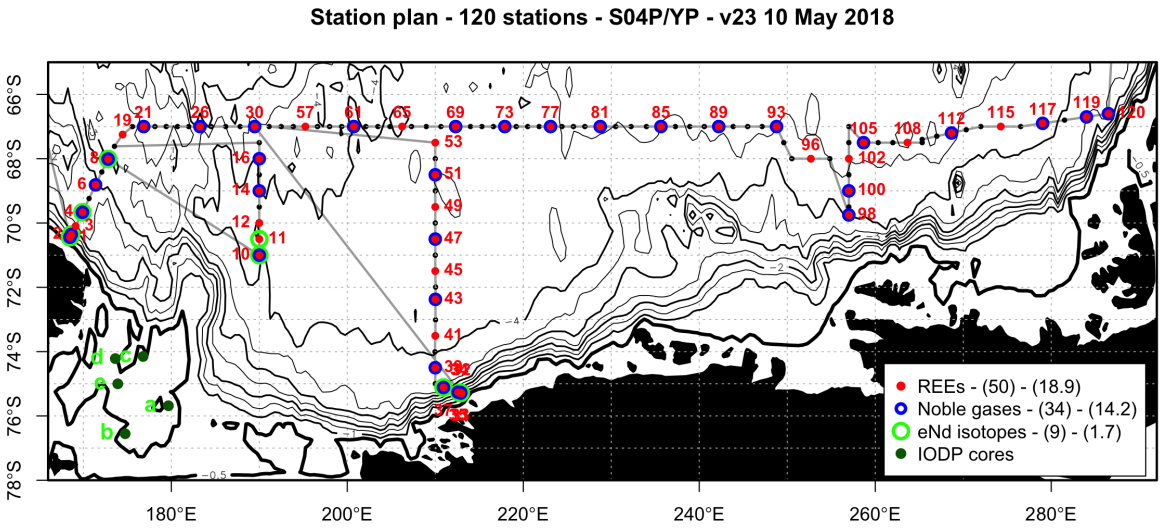


Fig. 20.1: Station location for REE, neodymium isotopes and noble gases. The first number in parenthesis in the legend shows the number of station, the second number is the average number of samples per station. The IODP core sites that the eNd samples taken here are meant to support are shown in dark green.

20.1 Sampling

eNd samples were collected last, or from dedicated Niskin bottles. Silicone tubing was connected to the Niskin and fitted with an Acropak 0.22um cartridge filter. Air was first purged from the line and the filter and the filter was then flushed with sample for about 20 seconds. Two filter cartridges were used: one for "shallow" samples and one for "deep samples". The samples were collected in 4L acid-cleaned cubitainers. Upon collection, which took less than 10 minutes per sample, the cubitainers where sealed with parafilm and stored in the dark at room temperature.

CHAPTER

TWENTYONE

NOBLE GASES

PI

- Nicholas Beaird
- Fiamma Straneo

Samplers

- Yves Plancherel
- Lauren Ferris
- Bingkun Luo

A total of 482 noble gases samples were taken, from 34 stations (Figure 1). This is ~200 fewer than the previous occupation of SO4P 2011. Typically, 15 samples were taken from each station, but this number varies somewhat depending on station location.

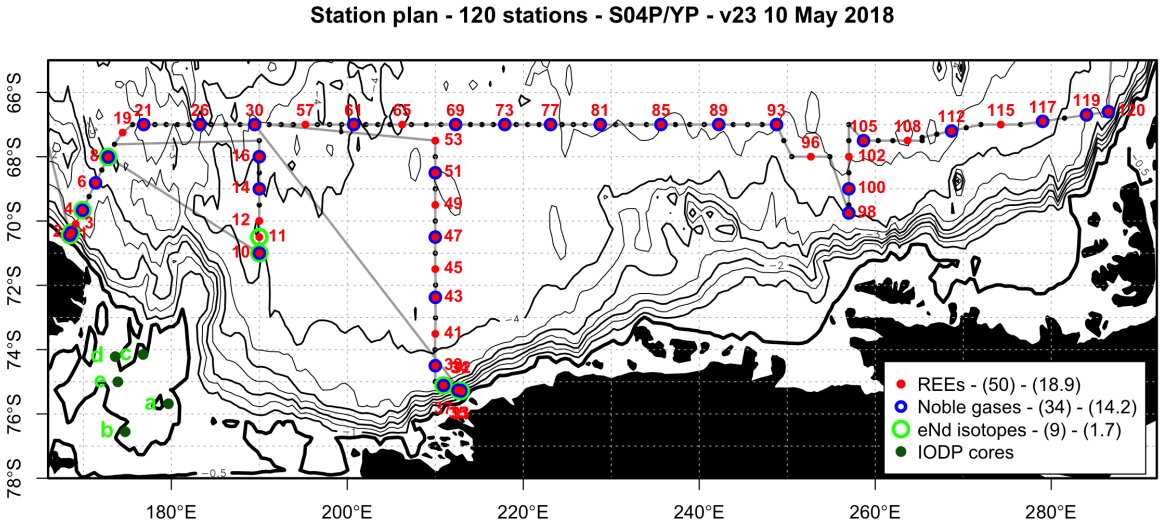


Fig. 21.1: Station location for REE, neodymium isotopes and noble gases. The first number in parenthesis in the legend shows the number of station, the second number is the average number of samples per station. The IODP core sites that the eNd samples taken here are meant to support are shown in dark green.

21.1 Sampling

The copper tube used was 5/8" dehydrated refrigeration copper tubing from Cambridge-Lee Industries Inc., supplied in 50ft rolls. All rolls were kept in their shipping boxes and stored in the air-conditioned and low humidity bio-analytical lab in order to limit corrosion and exposure risk.

The copper tubes were rolled out and cut into 30" sections less than 1.5 hours before sampling. Each tube sections was flattened slightly with the Pana press so that after sampling and sealing (cold welding), each sample could be re-rounded in order to create a small headspace allowing for expansion of the seawater after warming.

Copper tubes were connected to the Niskins using Tygon tubing fitted with a small silicon tubing adaptor at the nipple end. Tubing is attached to both ends of the copper tube, with the inlet tube coming in the bottom of the copper tube and outlet at the top. Water was drawn through the copper tube while knocking the tube with a thumper to remove bubbles from the inside of the tubes. After all bubbles had been cleared, the 2 plastic clamps were closed and the Tygon disconnected from the Niskin (closing the outlet clamp first). Hydraulic jaws operating at 9000 psi supplied with 80 psi of compressed air from the ship's air line, were used to cold-weld the copper tubes shut. Immediately after sealing, the tubes were re-rounded with the Pana press to create the expansion space. All samples were then rinsed with fresh water, dried with a paper towel, wrapped in bubble wrap and stored at room temperature in Bio-Analytical Lab.

CHAPTER

TWENTYTWO

LADCP

PI

- Dr. Andreas Thurnherr

Cruise Participants

- Manuel Othon Gutierrez Villaneuva
- Rachel Lekanoff

Full depth Lowered Acoustic Doppler Current Profiler (LADCP) velocities were sampled on every CTD station by Manuel Othon Gutierrez Villanueva (MOGV) and Rachel Lekanoff (RL). MOGV performed the on-board preliminary Quality Control (QC) and processing of each cast using the LDEO_IX routines for MATLAB. After the processing, the processed files and plots were sent for inspection to Andreas Thurnherr and Bruce Huber at Lamont-Doherty Earth Observatory (LDEO).

22.1 LADCP Configuration

Two ADCP instruments were affixed to the Rosette using custom brackets: the Upward Looking (UL) instrument was mounted above the Niskin bottle 14 and the Downward Looking (DL) instrument was mounted below the Niskin bottles 04 and 06. A rechargeable battery was also installed in the Rosette below the bottles 31-33 to supply power to both instruments during the full length of the cast.

The UL instrument used in this cruise was a 300 kHz Teledyne RDI WHM300 (sn: 12734). The DL instrument was a 150 kHz Teledyne RDI WHM150 (sn: 19394). The two instruments were configured to record velocity data at 8 m bin with staggered pinging to avoid previous ping contamination. The battery was a DeepSea Power & Light SB-48V/18A (sn: 01283).

A magnetometer was installed inside the UL instrument to provide an independent source of pitch, roll and heading measurements. These data will be used for post-processing the on-board processed casts. The magnetometer started (stopped) taking measurements once the rechargeable battery was connected (disconnected) from both instruments. A Teledyne RDI star cable was installed to connect both instruments to the battery and deck/communication cables using three extension cables.

While the Rosette was in the Baltic Room (BR) resting between stations, two deck (communication) serial cables extended from the dry lab to the BR. The serial cables connected to a MacMini Desktop computer in the dry lab using a USB Serial Port Adapter. A power supply was connected to one of the deck cables in the dry lab to provide additional power while the data were being downloaded from the instruments. The power supply was disconnected once the data download finished and was not used when programming the ADCPs before each cast. Between casts a second cable connected the battery on the Rosette to the battery charger located in the Aft Dry Lab. Once the data download was complete, the battery was fully charged. The battery voltage was measured before each cast and before charge. The MacMini Desktop computer was synced to the ship´s clock server via the ship network system.

22.2 Problems and Setup Warnings

- Test Cast 901: UL (DL) instrument was programmed as the master (slave) instrument. Configuration changed to DL (UL) as the master (slave) instrument after this cast. Star cable failed, unable to connect to both instruments after the cast. Star cable replaced by a spare.
- CTD Station 002: CTD pumps stopped working when they froze. Rosette was brought back on deck and pumps were allowed to warm while the ADCPs continued to sample. Rosette was re-deployed once the pumps had unfrozen.
- CTD Station 003: Data download from ADCPs failed. Star cable failed. Raw files were individually downloaded from each instrument bypassing the star cable, i.e. connecting the deck cables directly to each instrument. The star cable was not replaced due to the short transit between stations.
- CTD Station 004: Only the UL instrument was programmed. Data were downloaded without using the star cable.
- CTD Station 005: Only the UL instrument was programmed. Data were downloaded without using the star cable. Star cable was replaced by a spare after data were downloaded.
- CTD Station 006: Only the DL instrument was programmed.
- CTD Station 007: Only the DL instrument was programmed.
- CTD Station 008: Both instruments were programmed.
- CTD Station 009: Cast aborted due to bad weather. Station cancelled.
- CTD Station 016: One extension cable burnt and lost a dummy plug. Extension cable was replaced and data was downloaded successfully.
- CTD Station 020: Battery charger did not fully charge the battery before the cast. Nevertheless, the battery in the Rosette had enough voltage to last the full cast.
- CTD Station 023: MacMini clock desynched from ship´s server. The computer´s clock was synced again.
- CTD Station 031: No BT data available.
- CTD Station 050: Charger was not able to charge battery. Faulty extension cable from the battery charger was replaced.
- CTD Station 058: Station cancelled due to bad weather.
- CTD Station 066: Cast was done before planned position due to icebergs drifting towards the ship.
- CTD Station 095: During the upcast, winch was stopped to avoid ice floes. CTD wire was badly angled under the ship.
- CTD Station 098: After the cast, computer was not able to connect to instruments. USB Serial adapter was swapped by a spare. Data download was successful.
- CTD Station 104: Cast aborted at 146 m due to ship's heave causing large tension spikes.
- CTD Station 117: Problems while connecting to both instruments before the cast. Only the UL instrument was programmed. USB serial adapter had problems but was disconnected and connected to the computer. Communications were fine afterwards.

22.3 Data Processing and Quality Processing

The DL ADCP data from the DL instrument had a bad orientation switch during the entire S04P cruise, reporting its orientation as upward facing. After the data were downloaded, MOGV corrected the raw orientation data from the

DL instrument using the perl-based editPD0 utility from Thurnherr's ADCP Acquire Tools. Once the raw file was corrected, the correct zmax (maximum depth) and zend (end depth) values were recalculated with the mkProfile tool and logged in on the corresponding LADCP cast sheet.

MOGV processed the ADCP data from both instruments daily using the MATLAB-based LDEO IX Processing software. Additional data were obtained from the os38nb Shipboard ADCP (SADCP) processed using UH DAS software. To obtain the final velocity profile Conductivity, Temperature and Depth (CTD) 1 Hz raw data were used. LDEO IX plots and log files included processing warnings such as GPS issues, large compass deviations and/or large shear-inverse solution differences. Plots and files were individually inspected for signs of anomalies such as Rosette rotation, tilt, biased shear, agreement between the unconstrained LADCP velocities and ADCP data, beam strength and range, bin residuals and quality of Bottom Track (BT) data and Rosette position relatively to ship´s position. Processed files and plots of each cast were emailed to Andreas Thurnherr and Bruce Huber on daily basis. Raw data (CTD, LADCP and SADCP) were sent to Andreas Thurnherr when suspicious profiles were detected.

Figure 1 shows the preliminary velocity results: zonal (U) and meridional (V) for the 4 southward transects. In general, maximum values reached ~0.5 m/s. Relatively strong northward flows are found on the 103o W leg. Also, a bottom intensified northward flow was observed near the shelf break on the 175o E transect. Figure 2 shows the U and V velocity components and along the main track. Mid-depth and near-bottom intensified northward flows (0.40 m/s) were observed.

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

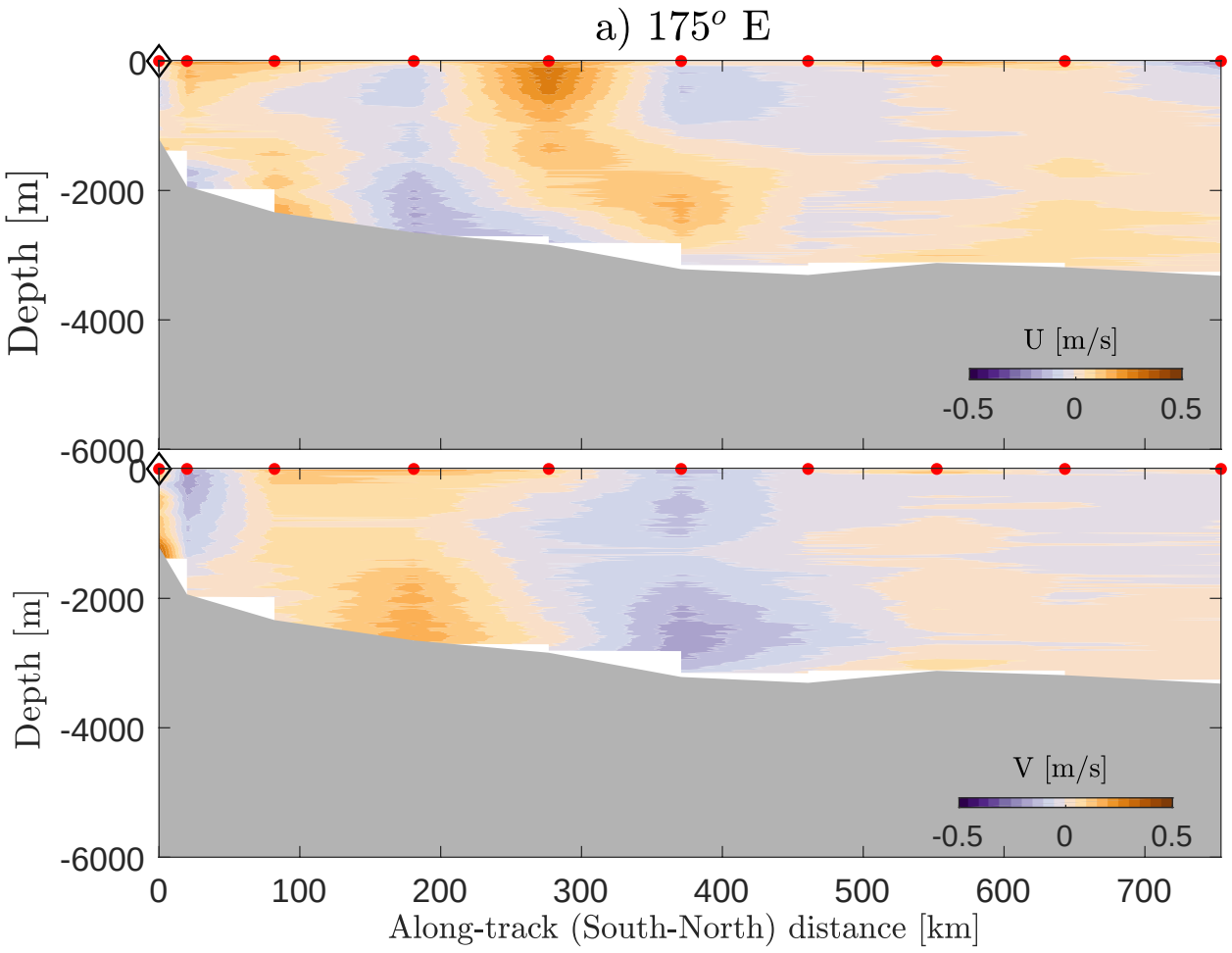


Fig. 22.1: Zonal (U) and meridional (V) velocity transects for the south-north legs along 175E. Colored markers indicate CTD station position and open black markers show the position of the southernmost station along the transect.

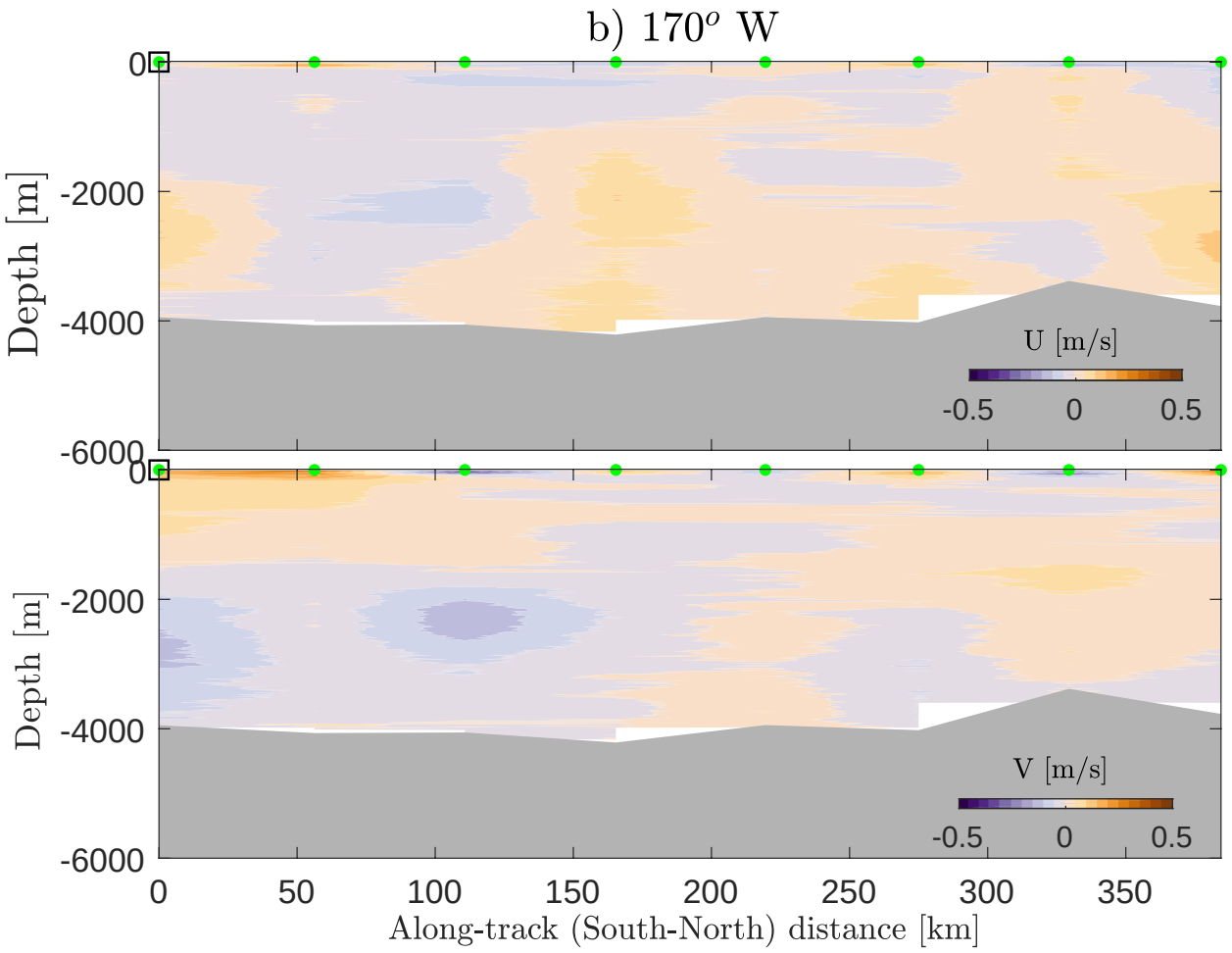


Fig. 22.2: Zonal (U) and meridional (V) velocity transects for the south-north legs along 170W. Colored markers indicate CTD station position and open black markers show the position of the southernmost station along the transect.

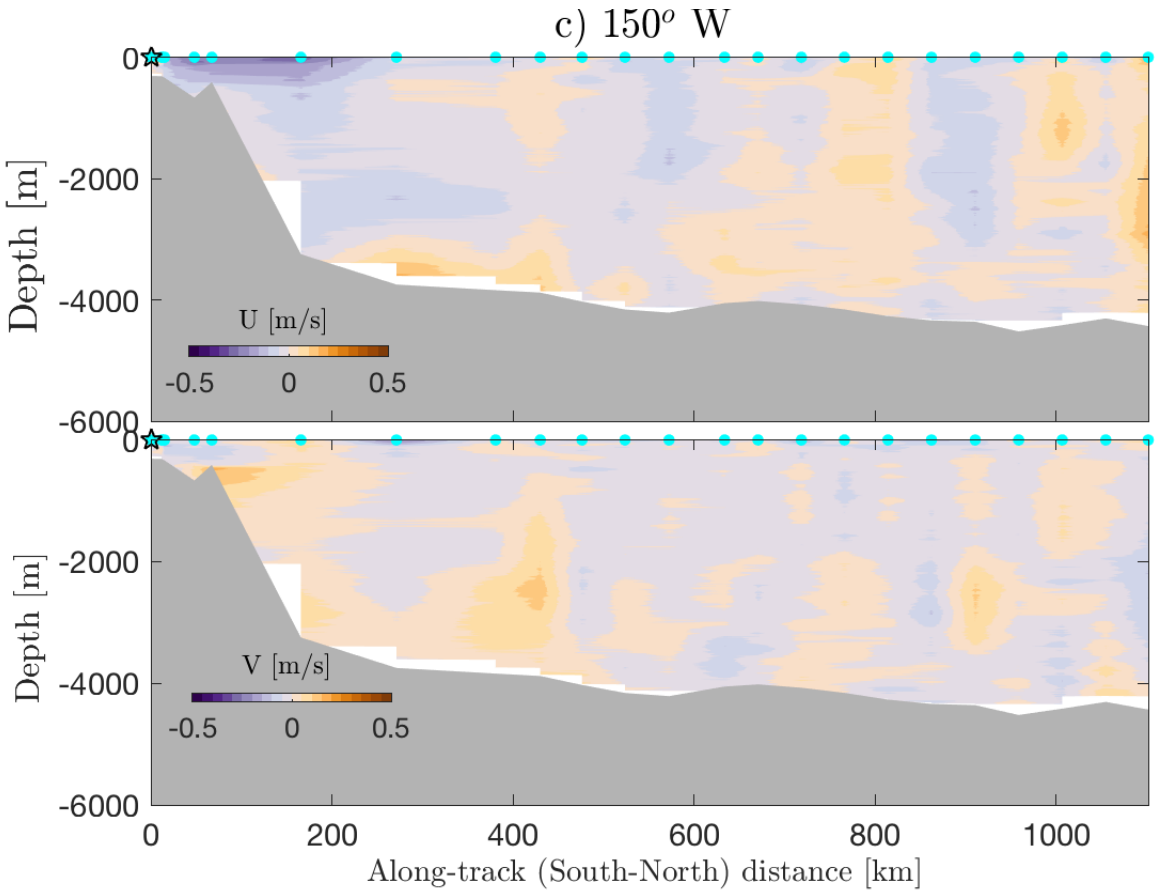


Fig. 22.3: Zonal (U) and meridional (V) velocity transects for the south-north legs along 150W. Colored markers indicate CTD station position and open black markers show the position of the southernmost station along the transect.

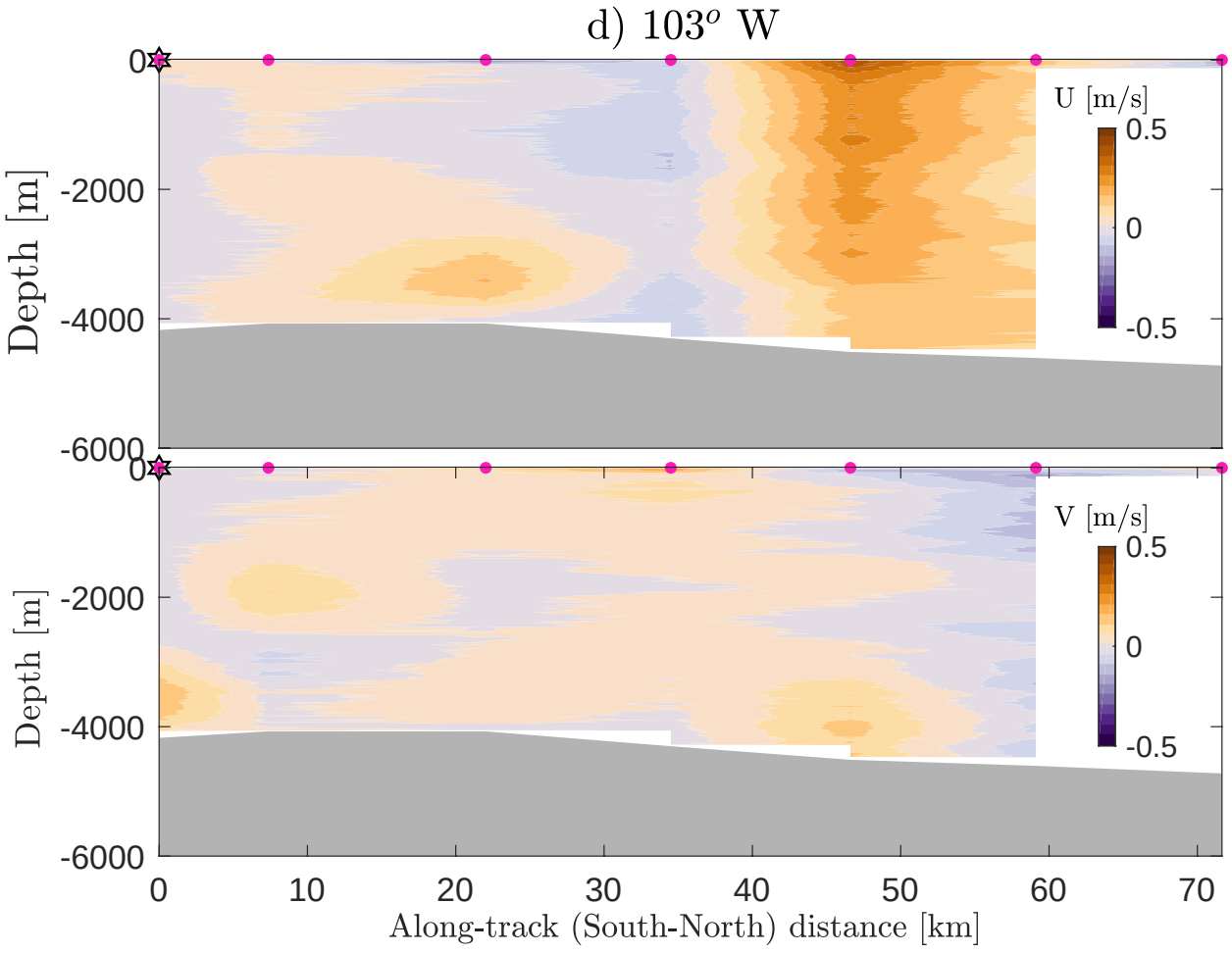


Fig. 22.4: Zonal (U) and meridional (V) velocity transects for the south-north legs along 103W. Colored markers indicate CTD station position and open black markers show the position of the southernmost station along the transect.

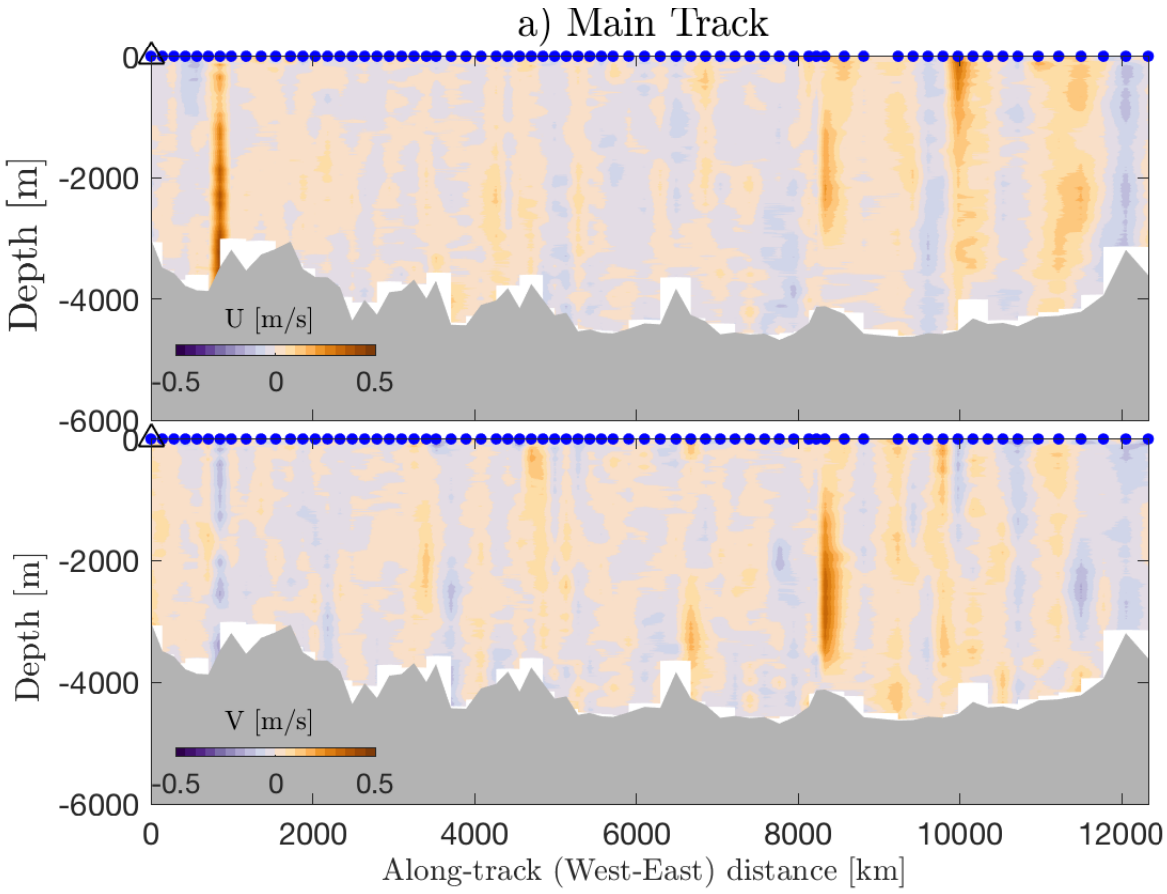


Fig. 22.5: Along track Zonal (U) and meridional (V) velocity transects for the west-east main track. Colored markers indicate CTD station position and open black markers indicate the position of the southernmost station in each transect (right panel).

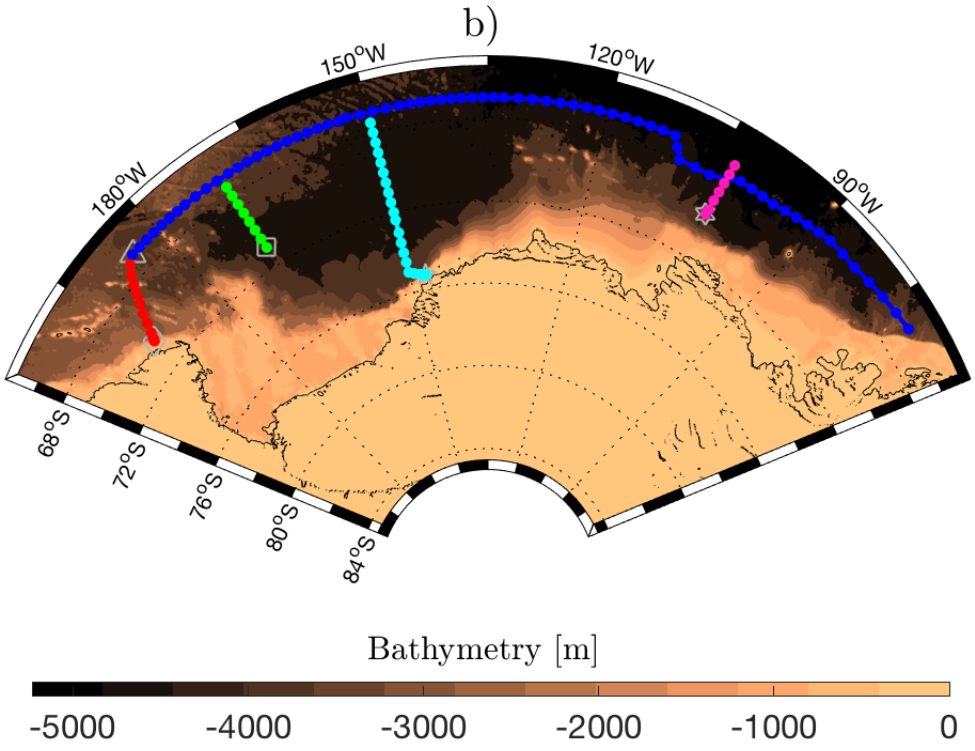


Fig. 22.6: Map showing the S04P cruise track. Black line indicates the coastline.

CHAPTER

TWENTYTHREE

UNDERWATER VISION PROFILER 5 HD (UVP)

PI

- Andrew McDonnell

Cruise Participant

- Rachel Lekanoff

23.1 System Configuration and Sampling

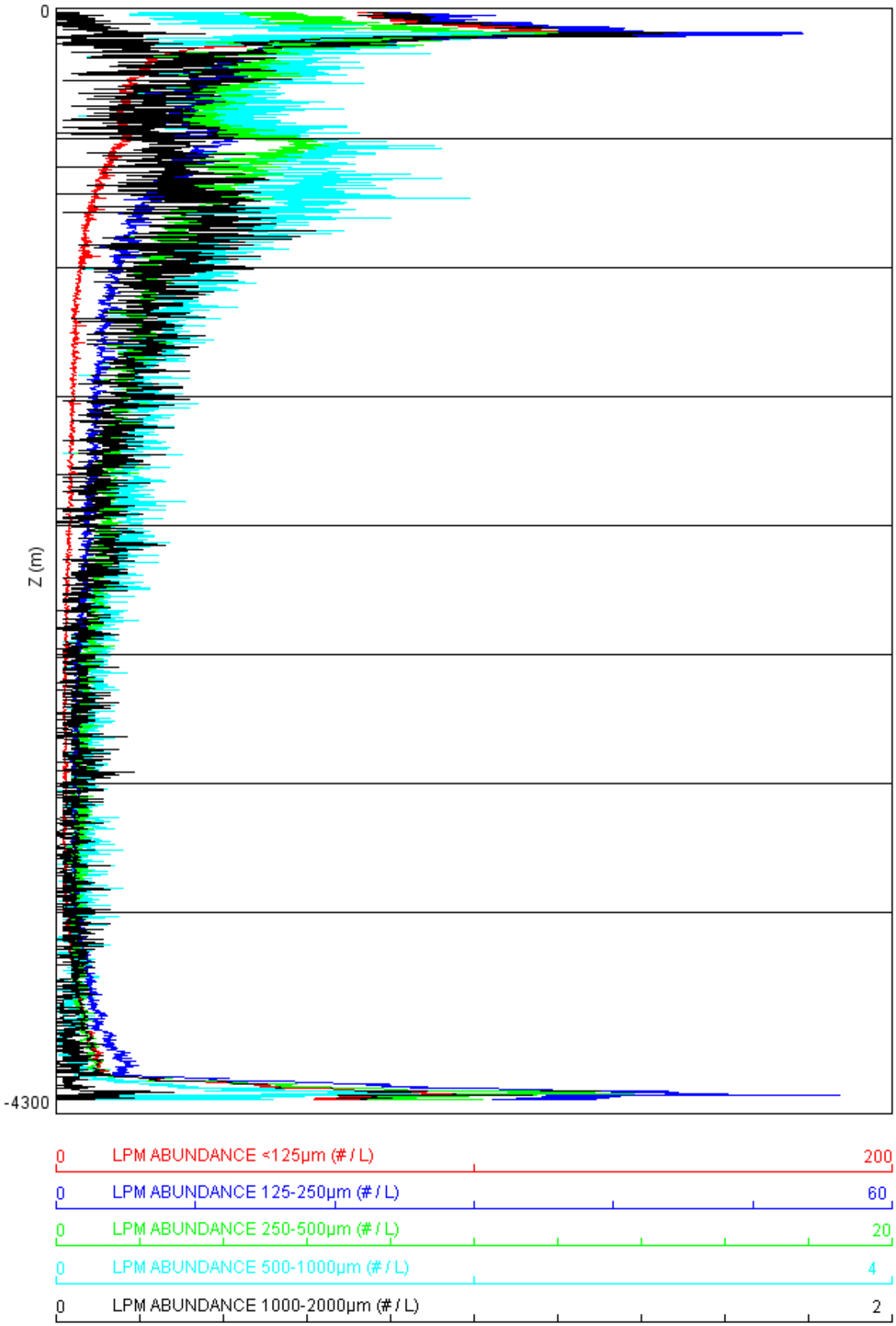
The Underwater Vision Profiler 5 (UVP5) HD serial number 207 was programmed, mounted on the rosette, and charged. The UVP5 is outfitted with a High Definition 4 Mp camera with an acquisition frequency of up to 20 Hz. This optical imaging device obtains in situ concentrations and images of marine particles and plankton throughout the water column, capturing objects sized ~100 μm to several cm in diameter. The camera of the UVP5 HD is different from the previous non-HD version, but the operations are identical for both. The instrument and data processing are described in Picheral et al., 2010 *[Picheral2010]*. A typical station had high particle abundance in the upper few hundred meters of the water column and just above the seafloor. Some stations had secondary maxima of particle concentrations between 500 and 1000 m.

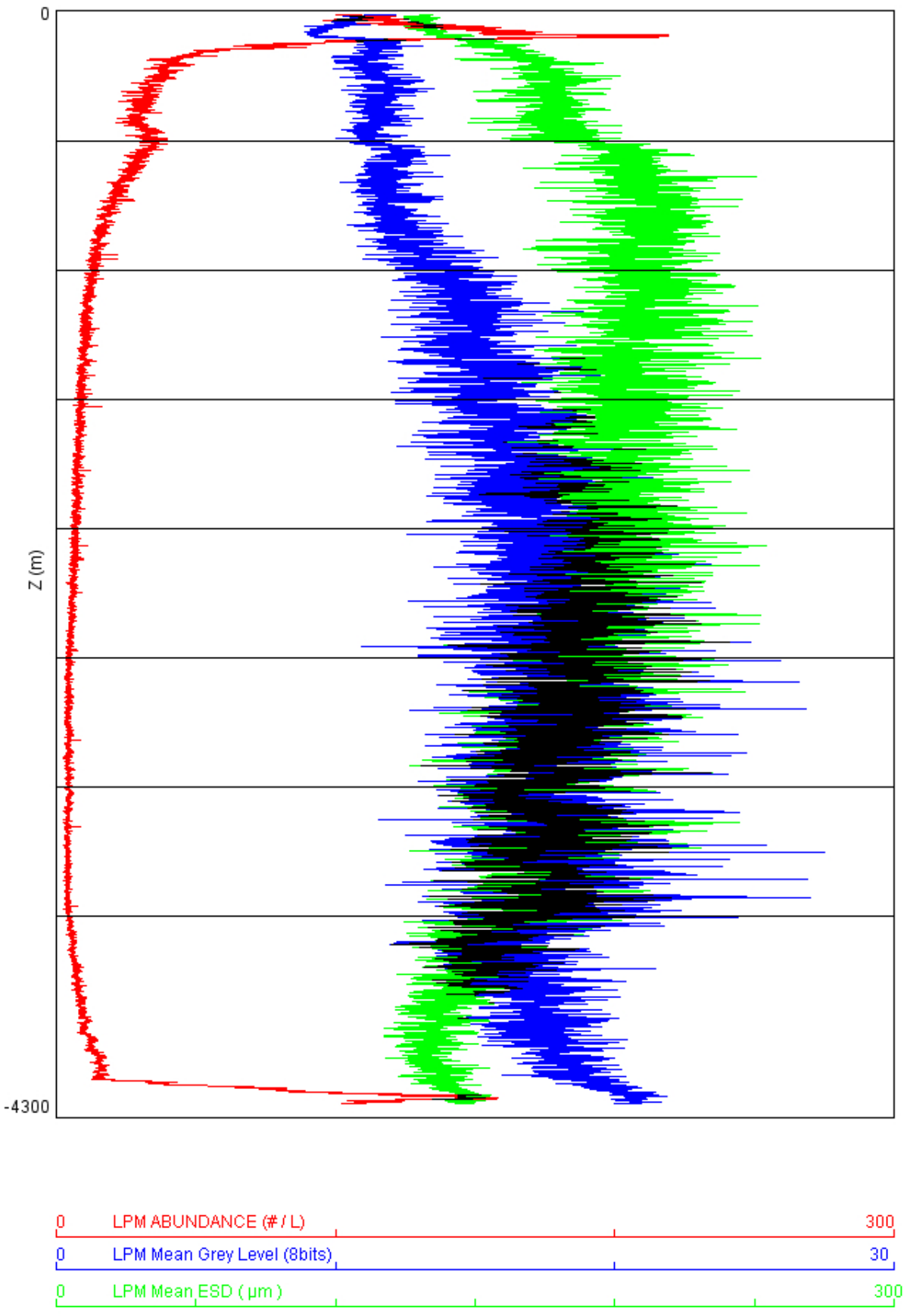
23.2 Figures

23.3 Problems

Station 2 is missing due to operator error. At stations 4, 6, 7, and 8 the UVP5 was not turned on due to the lithium ion battery not charging. After some troubleshooting, it was determined that the charging unit inside the UVP5 deck box had been disconnected either by shipping agents or Australian customs agents. After reconnecting the charger, the UVP5 battery was able to charge and then operated as expected. At stations 45, 46, and 47, the UVP5 was kept off due to problems with the UVP5 software. The manufacturer of the UVP5, Hydroptic, was consulted for assistance with troubleshooting. Their instructions included accessing the UVP5 via remote desktop connection and removing the password from the UVP5's Hydroptic account. After following their instructions, the UVP5 successfully acquired data and was able to communicate with the custom Hydroptic laptop for downloading and processing data.

23.4 Reference


0
Z (m)
-4300
0 LPM ABUNDANCE <125µm (# / L) 200
0 LPM ABUNDANCE 125-250µm (# / L) 60
0 LPM ABUNDANCE 250-500µm (# / L) 20
0 LPM ABUNDANCE 500-1000µm (# / L) 4
0 LPM ABUNDANCE 1000-2000µm (# / L) 2
Project : sn207_2018_s04p / Stn Id : 075
Profile Id (cast) : s074
Start (UTC) : 20180419 13:22:17


0
Z (m)
-4300
0 LPM ABUNDANCE (# / L) 300
0 LPM Mean Grey Level (8bits) 30
0 LPM Mean ESD (µm) 300
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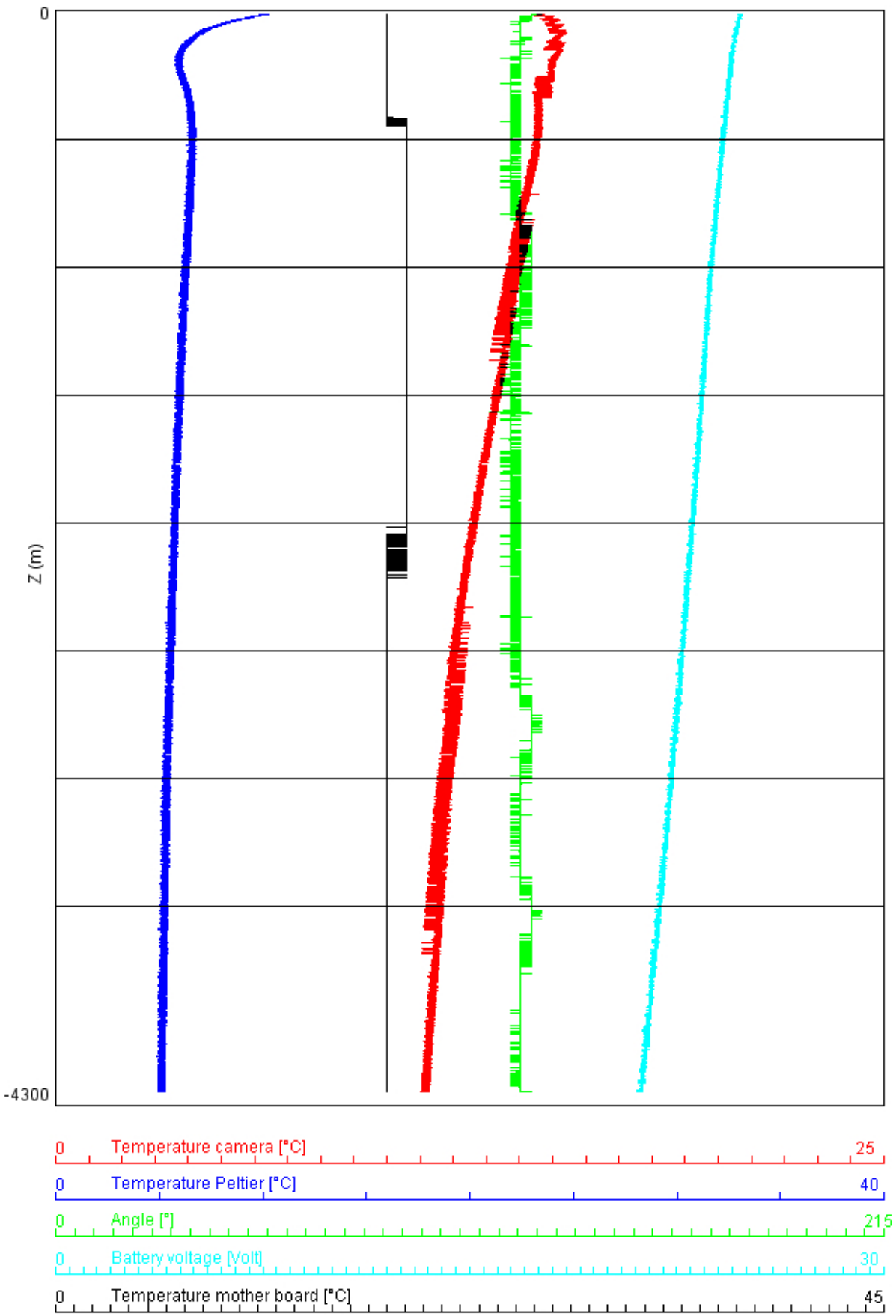
Start (UTC) : 20180419 13:22:16


0
Z (m)
-4300
0 Temperature camera [°C] 25
0 Temperature Peltier [°C] 40
0 Angle [°] 215
0 Battery voltage [Volt] 30
0 Temperature mother board [°C] 45
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Profile Id (cast) : s074
Start (UTC) : 2018041 91:32:21

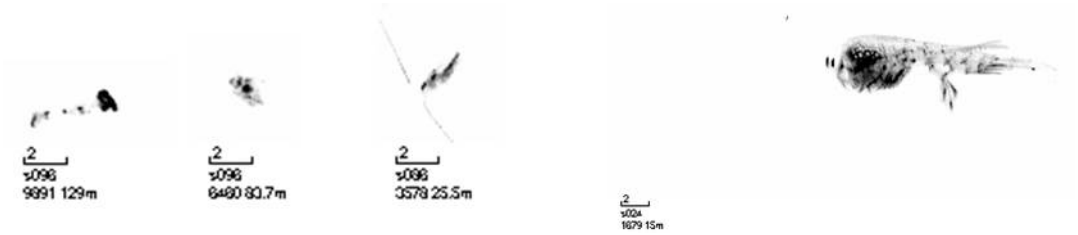

Fig. 23.2: Examples of particle and plankton images captured by the UVP5HD and processed by custom software. The scale bar indicates 2 millimeters. Station number, image number for that cast, and depth at which the image was captured are also given in the image.

CHAPTER

TWENTYFOUR

FLOAT DEPLOYMENTS

Cruise Participant Leads

- Ellen Briggs
- Chanelle Cadot

During 2018 S04P a total of 18 profiling floats were deployed, which were part of several programs: 6 SOCCOM biogeochemical, 5 FSU MRV ALTO, 5 CSIRO Argo, and 2 APL EM-APEX profiling floats. There was an effort to co-deploy floats from the different programs at the same coordinates particularly for the SOCCOM and FSU floats.

Ellen Briggs and Chanelle Cadot were responsible for overseeing all float deployments as well as recording and communicating the deployment details to the various PIs of the programs. The ASC marine technician on watch was the lead for the actual deployment of the floats and all back deck operations. The CTD watchstanders assisted with float preparation and deployment when available. Rick Rupan (UW) prepared and tested all of the applicable profiling floats during the port call in Hobart, Australia prior to departure on 2018 S04P.

In typical operation, profiling floats descend to 2000 m and collect data as they ascend to the surface. Onboard measurements include temperature, salinity and pressure for all the float varieties and additional velocity measurement for the EM-APEX floats and additional biogeochemical measurements for the SOCCOM floats. Data from the 2000 m to surface profile are then sent to shore via satellite, using an antenna located at the top of the float. The floats then descend to a parking depth of 1000 m and drift for a programmable length of time (typically 10 days) with the ocean currents at this depth and then repeat the cycle by again heading down to 2000 m and collecting data on the ascent back to the surface.

In the following, the specific deployment details of each float program are discussed.

24.1 SOCCOM floats

PIs

- Steve Riser
- Ken Johnson
- Lynne Talley

Six 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. Its goal is to deepen our knowledge of the processes that regulate the carbon export in the Southern Ocean in addition to expanding the existing observing system for heat and freshwater (i.e. Argo floats). So far, SOCCOM has 111 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.

The SOCCOM floats deployed on 2018 S04P are also equipped with ice avoidance software to prevent the float from colliding with sea ice at the surface. If the float measures colder than -1.79°C in the upper 30 m the float immediately descends to park depth and continues its normal cycle until it reads 2 consecutive measurements greater than -1.79°C near the surface at which point the float will surface and transmit its stored data via satellite.

Before the deployment of each float, the fluorometer/backscatter and the NO3- sensors were carefully cleaned using DI water, pre-moistened lens wipes, and lens paper. 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 and no sea ice present (not including icebergs) or an upper water column temperature greater than -1.7°C. After the CTD cast, the ship steamed approximately 1 nm away from the station location and then slowed to 1 knot for the float deployment. The floats were deployed by stringing a line through the stability ring of the float and slowly lowering the float over the side of the ship timing the release of the line with the swell. Each deployment occurred on the starboard side, stern, while the ship was steaming at 1 knot.

Samples for HPLC and POC analyses were taken from the Niskin bottles, tripped as duplicates, at the surface and at the depth corresponding to the chlorophyll maximum. These samples were filtered shipboard and will be sent to the U.S., where NASA (HPLC) and UCSB (POC) groups will perform the analyses. Full-depth samples of other ocean properties (salts, pH, DIC, nitrate, oxygen) were collected and analyzed by the different groups on board, as part of a validation process of the floats' sensors. In particular, pH samples were collected and analyzed by personnel from SIO, Dickson lab; DIC samples by personnel from AOML and PMEL; oxygen, nitrate and salinity samples by the ODF group at SIO.

5 of the 6 floats have reported their first profiles and their sensors are working well. Float 12768 was deployed under conditions of slushy ice at the surface and it is likely that the ice avoidance software was activated, thus keeping the float from surfacing and transmitting its data. It is likely this float will stay under ice cycling until next austral Spring when the ice melts and the float can surface to transmit its stored data.

As part of an outreach initiative, the SOCCOM project also partners with teachers and classrooms across the country through a program called 'Adopt-a-Float' to engage elementary to secondary aged students with lead scientists on the significance of the Southern Ocean and climate change research. As part of the program, selected schools are given the opportunity to name a profiling float, follow its deployment, and later track the float as it collects biogeochemical observations. The 6 SOCCOM floats on 2018 S04P were decorated with drawings depicting their given name and the deployments were documented with pictures, videos, and blogposts to be shared with the schools that adopted the float.

The float ID, location, date, station number, and depth of the float deployments are indicated in the table below along with the Adopt-a-Float program name and communication confirmation. An asterisk marks the SOCCOM floats that were co-deployed with floats from other programs.

Table 24.1: Summary of the deployment details of the six SOCCOM floats

Float ID	Lat	Lon	Date (UTC)	Station	Depth	Adopt a Float Name	Confirm (Y/N)
12768*	-71.01	-170.002	3/21/18 19:50	10	4000	Floating Falcon	N
12398*	-67.617	173.521	3/25/18 22:17	18	3470	MVESuperSeal	Y
12701*	-66.998	-173.67	3/29/18 07:22	28	3650	Thunderbird-Martlet	Y
12758	-69	-150.011	4/7/18 18:12	50	4362	Tidal Wave	Y
12754	-66.997	-149.283	4/17/18 21:35	68	4443	Griffin-Eagle	Y
12787*	-66.999	-129.469	4/22/18 04:42	82	4362	Southern Ocean Spy (SOS)	Y

24.2 FSU floats

PI

- Kevin Speer

5 MRV ALTO profiling floats from FSU were deployed on 2018 S04P. These floats have the core Argo temperature, salinity, and pressure sensors.

Prior to deployment, the FSU floats needed to be activated by swiping a magnet in the 'activation region' on the float indicated by a reset sticker. The floats were enclosed in bio-degradable cardboard boxes and there was a small window through which the activation region could be accessed. Plastic covered the box, deployment harness, and water release mechanism. To activate a FSU float it was first brought outside and secured in the best unobstructed location for sending a signal to be picked up by satellite. A hole was then cut in the outer plastic covering the window in the cardboard box. Then the reset sticker was located and the provided magnet was placed on the sticker and deliberately swiped. Tape was then used to repair the hole in the plastic and the float remained outside for 24 hours or until communication was received on land via satellite. Once the float was activated, there were 5 days until the float embarked on deployment mode unless it was re-activated by an additional magnet swipe.

Several problems were encountered while trying to activate these floats. First, the activation region was not properly positioned in the window provided in the cardboard box. The reset sticker was well out of sight and half under support cardboard that could not easily be moved and in some cases needed to be cut away. One of the floats had rotated which required cutting a much larger hole in the cardboard box to rotate the float to expose the activation region. Another float (11036) did not activate after numerous attempts so the float was fully removed from the box and swiped by the magnet in a much larger area not indicated by the reset sticker which finally did the trick. Being the Southern Ocean the weather was too extreme some days to reasonably access the floats outside and carry them up and down icy stairs. It was too cold for the tape to adhere to the plastic outer covering and precipitation did penetrate through to the box. Despite all of these problems all of the floats were properly activated in the end.

These floats were deployed in their original bio-degradable cardboard boxes (with the outer plastic covering removed) in order to reduce the possibility of incurring any damage to the float during deployment. 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. The water release mechanism failed to release (likely because the water was too cold) during the deployment of the first 2 floats after more than 5 minutes of soaking so it was decided for the remaining floats to instead cut one strap of the harness to allow the float, still inside the box, to slide free from the harness and drift away from the ship. Float 11036 had to be completely removed from its box in order to be activated, as outlined above, so it was deployed by stringing a line through its deployment collar and lowering it over the side of the ship.

Deployments were done after the completion of the CTD station nearest to the requested deployment location, immediately after the ship had turned, and begun its course to the next station and had reached a speed of approximately 1 knot. Deployment details including float ID, location, date, station, depth, and communication confirmation are listed in the Table below. An asterisk marks the FSU floats that were co-deployed with floats from other programs.

Table 24.2: Summary of the deployment details of the five FSU MRV ALTO floats

Float ID	Lat	Lon	Date (UTC)	Station	Depth	Confirm (Y/N)
11038*	-71.001	-170.002	3/21/18 20:07	10	4000	Y
11035*	-67.617	173.534	3/25/18 22:08	18	3470	Y
11037*	-67.617	173.528	3/25/18 22:13	18	3470	Y
11039*	-66.999	-173.812	3/29/18 07:16	28	3650	Y
11036	-67	-160.643	4/12/18 14:56	60	4070	Y

24.3 CSIRO floats

PI

- Steve Rintoul

5 Argo profiling floats from CSIRO were deployed during 2018 S04P, and have the core Argo temperature, salinity, and pressure sensors. These floats were intended to be deployed in their original bio-degradable cardboard boxes that were secured with a connected to a water release mechanism (a metal cylinder) at the bottom. Due to failure of similar water release mechanisms on the first 2 FSU floats it was decided to deploy the CSIRO floats without the harness and box. The floats were removed from their boxes, and a deployment line strung through the stability ring of the float was used to gently lower the float into the water in time with the swell at the stern, starboard side of the ship.

Deployments were done after the completion of the CTD station nearest to the requested deployment location, immediately after the ship had turned, and begun its course to the next station and had reached a speed of approximately 1 knot. Deployment details including float ID, location, date, station, depth, and communication confirmation are listed in the Table below.

Table 24.3: Summary of the deployment details of the five CSIRO floats

Float ID	Lat	Lon	Date (UTC)	Station	Depth	Confirm (Y/N)
8148	-67.003	175.57	3/26/18 11:22	20	3085	Y
8149	-67	-179.293	3/27/18 13:58	24	3616	Y
8150	-67	-168.882	4/10/18 16:13	54	3438	Y
8151	-67.006	-163.384	4/12/18 09:00	58	3980	Y
8152	-66.998	-156.517	4/13/18 12:04	63	3957	Y

24.4 EM-APEX floats

PI

- James B. Girton

2 EM-APEX floats that collect profiles of velocity, temperature, salinity, and pressure were deployed on 2018 S04P. These floats also include an ice guard, which consists of a carbon-fiber pole that reaches 20 cm above the CTD allowing for measurements close to the ice and a custom collar that allows the float to rotate through the water column.

Prior to deployment the floats were prepared by replacing the pressure fit electrode caps and pre-filling the bladder with water by dunking the float cowling in a bucket of water. The starboard side mid-ship A-frame was used to deploy the float. A harness fitted with a pin was adjusted to the center of gravity of the float so it could be lifted horizontally and not damage its rotation collar. The float was then lifted and lowered over the side of the ship using the A-frame until the float reached the water surface. A line attached to the pin was then pulled to release the float from the harness and the harness and pin were recovered. The ship then slowly accelerated in the opposing direction of the float until the float was clear of the ship. The floats were deployed without any problems via the mid-ship starboard A-frame, but it should be noted that the stern A-frame may have been a more preferable option on the RVIB NB Palmer, depending on the sea state, to deploy the float further away from the ship.

Both deployments were carried out immediately after the CTD cast at the specified location without changing ship position. The floats were both successfully deployed, with no issues. Float ID, date, time, location of the deployment, CTD cast associated with the deployments, depth, and float communication confirmation are reported in the Table below. An asterisk marks the EM-APEX floats that were co-deployed with floats from other programs.

Table 24.4: Summary of the deployment details of the two EM-APEX floats

Float ID	Lat	Lon	Date (UTC)	Station	Depth	Confirm (Y/N)
6624	-66.999	-131.261	4/21/18 19:55	81	4556	Y
6479*	-67	-129.504	4/22/18 04:23	82	4362	Y

CHAPTER

TWENTYFIVE

DRIFTER DEPLOYMENTS

PI

- Rick Lumpkin (*AOML*)
- Shaun Dolk (*AOML*)

20 drifters were deployed on S04P 2018 for the Global Drifter Program. Alison Macdonald and Ellen Briggs oversaw the deployment of the drifters and the CTD watchstanders of each shift and the UVP student carried out the deployment. Secondary assistance was provided by ASC Marine Technicians.

The deployments occurred after the completion of the CTD cast at the station that was closest to the planned deployment location. Two drifters were deployed at each location within 30 seconds of each other after achieving a minimum ship speed of 1 knot. The simple deployment process involved: (1) removing the plastic wrapping from the drifter; (2) carrying the drifter to the back or O1 deck; (3) deploying the drifter off the stern on starboard side, after reaching at least 1 knot ship speed; (4) recording the deployment details including drifter ID, time, latitude, and longitude. Ellen Briggs, Chanelle Cadot or Alison Macdonald sent the deployment details to Shaun Dolk at AOML. The Table below lists the details for each deployment.

Table 25.1: Deployment details for the 20 drifters

Drifter ID	Date (UTC)	Lat	Lon	Station	Depth
65333790	3/27/18 07:12	-67	-179.427	23	3696
65334790	3/27/18 07:12	-67	-179.427	23	3696
65253040	3/28/18 04:22	-67	-176.732	26	4059
65252010	3/28/18 04:22	-67	-176.732	26	4059
65253050	3/29/18 07:12	-67	-173.816	28	3650
65253020	3/29/18 07:12	-67	-173.816	28	3650
65250050	3/30/18 00:35	-67	-170.51	30	3383
65250040	3/30/18 00:35	-67	-170.51	30	3383
65336420	4/10/18 22:54	-67	-167.501	55	3521
65333780	4/10/18 22:54	-67	-167.501	55	3521
65336530	4/11/18 12:19	-67	-164.736	57	3802
65250070	4/11/18 12:19	-67	-164.736	57	3802
65334530	4/12/18 07:49	-67	-162.025	59	4079
65333890	4/12/18 07:49	-67	-162.025	59	4079
65251020	4/12/18 12:07	-67	-159.26	61	4283
65336570	4/12/18 22:09	-67	-159.26	61	4283
65251010	4/13/18 12:07	-66.997	-156.516	63	3958
65252060	4/13/18 12:07	-66.997	-156.516	63	3958
65336560	4/16/18 09:02	-67.058	-150.967	before 67	4406
65335480	4/16/18 09:02	-67.058	-150.967	before 67	4406

CHAPTER

TWENTYSIX

STUDENT STATEMENTS

26.1 Ribanna Dittrich

My name is Ribanna Dittrich and I am Ph.D. student at the University of Edinburgh. My Ph.D. is about dissolved organic matter at the West Antarctic Peninsula which is why I was absolutely thrilled to hear about the opportunity to go down to Antarctica as part of the GO-SHIP team and potentially conduct some experiments on board the ship.

I am now a CTD watchstander for the day shift aka the dinner club. Our team consists of Lauren, Taimoor and myself and for the night shift, there are Chanelle, Bingkun and Amir. Together, we have been responsible for the safe deployments of all CTD casts (120 in total). The cruise has been a very exciting experience for me. The people are

wonderful and good fun to work with which is important on such a long cruise. We got to experience the Southern Ocean in all its glory: Rough and stormy seas that kept us from doing science on the one hand, and wonderful, indescribable landscapes of sea ice and icebergs with penguins, seals and humpback whales on the other hand. The routine work as a CTD watchstander consists of preparing the CTD rosette for deployment and deploying it from the CTD console – we are in direct contact with the winch controller and the marine tech and observe all sensors and the tension on the wire on screens so that we can interfere if necessary. We are in constant communication with the marine tech so that we can make quick decisions if conditions change. After the CTD comes back onboard, different samples are taken for different parameters to be measured. My sampling jobs are either for alkalinity or radiocarbon, depending on who needs me. Within our shift, we have a well-working rotation system so that none of us ever gets bored of doing the same task over and over again. So every now and then one of us also happens to be the sample cop – making sure that everyone fills the correct sampling bottle from the correct Niskin bottle in the correct order. But we also get to help out the techs when adjustments need to be made to the Niskin bottles, or the wire needs to be cut. Overall, this is a great experience which showed my once more how important and valuable observational data is for oceanographic research, especially down here in the Southern Ocean.

26.2 Taimoor Sohail

My name is Taimoor Sohail and I am a PhD candidate in Earth Sciences at The Australian National University. I primarily conduct modelling studies of the Southern Ocean, so I never expected to be on a research cruise conducting observational fieldwork! I applied to be part of the S04P leg of the GO-SHIP project with the hopes of learning more about the work and processes that go behind observational work. Little did I know, that innocuous application would result in a life-changing experience with the best ship-mates I could ask for.

I was accepted to be a CTD Watchstander and, with much trepidation, embarked on a 69 day journey from Hobart to Punta Arenas. I was placed with two other watchstanders in the day shift, Lauren and Ribanna, and found that we were fast friends. As the ship ventured South to Antarctica, we settled into our various roles. The responsibilities of a watchstander are large (that's why there's three of us!). We prepare the rosette for deployment, fire Niskin bottles as the rosette rises from the depths, and help to collect seawater samples for analysis. With 120 stations completed over the course of the cruise, needless to say we got good at our jobs. I also got a crash course in Ocean Data View, an invaluable tool for biological and chemical oceanographers, from the Co-Chief scientist, Ellen, and learned a lot about ensuring high-quality observational data from our in-house data analyst, Joseph. Overall, I gained a unique insight into how observational data is collected, how it is ensured the data is accurate, and finally how it can be interpreted. As an ocean modeller, this knowledge forms a critical part of my understanding, and will hopefully pave the way for future research connections.

This experience was much more than an avenue for professional growth. During the course of the trip, we saw scores of Adelie and Emperor penguins, crushed through feet of sea ice, and saw seals and pods of whales. Through this shared experience, I got to know my fellow ship-mates and formed life-long friendships. Being in one of the most remote places in the world, I gained a broader perspective on life and realised just how untameable nature can be. The S04P GO-SHIP Cruise has been a life-changing experience in more ways than one, and I can't wait to come back to Antarctica and do it all over again!

26.3 Lauren Newell Ferris

My name is Lauren Ferris and I am a PhD student in physical oceanography. When I first talked to Alison (chief-scientist) half a year ago, I felt incredibly lucky to be given this opportunity. Now into 60+ days at sea in the Southern Ocean, I can say that I never imagined that I would learn so much on GO-SHIP S04P. I am a CTD watchstander on the day shift with Ribanna and Taimoor. Together with the night shift (Chanelle, Bingkun, and Amir), we were responsible for 120 CTD casts. My favorite part of this experience was being part of the "full stack" of this process (to use a programming term). It entailed working closely with the marine technicians, winch operators, data analyst, and chief scientists. Each one of them had a different perspective on the CTD operations and a unique angle on the cast.

Fig. 26.1: Wrestling on a survival suit before joining marine technician Tony in the Baltic Room for a CTD cast. (Photo by MOG Villanueva)

A cast begins with stringing up the Niskin bottles and their closing valves, cleaning optical sensors, turning on winch data feed and switching off Multi-beam bathymetric logging (since it would be a bit of a nightmare to analyze hours of bathymetry data in the same spot). The day shift (aka "Dinner Club) has a system. Ribanna strings bottles separately (since she is lightning-fast) and Taimoor and I "tag-team" for efficiency. Casts take 4-8 hours, depending on sea state. The winch operates more slowly during rough weather to avoid tension spikes and artificial overturns due to ship heave. It also operates more slowly during deep casts due to the immense tension of having more than 4500m of heavy metal wire in the ocean. During the cast, we communicate with the day shift marine technician (Tony) and winch operators (Lauro, Louie, Domingo) to relay depths and deliberate about weather considerations. When the CTD is recovered, sampling begins! All of the watchstanders take salt samples. I sample for helium, oxygen isotopes, and alkalinity. Ribanna does radiocarbon and alkalinity. Taimoor does nitrogen isotopes and alkalinity. There is also "sample cop" who is effectively an air traffic controller, directing samplers to Niskin bottles and ensuring that properties are sampled in the correct order (i.e. CFCs, then helium, then oxygen, then inorganic carbon species, organic carbon species, etc.). The Dinner Club rotates through sampling jobs to make sure that every cast stays interesting.

Perhaps my favorite part of S04P was being trapped on a ship with unbelievably knowledgeable scientists, technicians, and crewmembers. Tony taught us about "wire forensics", after which both the marine technicians (Tony and Jennie) led us through removing hundreds of meters of worn winch wire. (The wire used for S04P had some interesting issues that resulted in us having to remove wire on a fairly regular basis). Electronics technician Barry was always up for me barging into his shop asking for an explanation about what he was currently fixing. Data analyst Joseph taught me how to inspect and replace Niskin bottles, and about the extensive process of scrutinizing reference-quality hydrographic data. Ellen taught us Ocean Data View and Alison provided advice on incorporating bathymetry into data analysis. I also learned from the ECO crew, who were kind about my affinity to spend hours on end (while off-shift, of course) on the bridge. As an ocean engineer by training, I have been quite excited about the infrastructure and operation of the ship. The crewmembers told me about iceberg avoidance, selecting a course through sea ice, the ship's dynamic positioning system, and maritime industry, etc.

More than anything, I have gained an appreciation for the difficulty of collecting and scrutinizing hydrographic data in an environment such as the Southern Ocean. Prior to this cruise, it was simple for me to write a quick script to search through a few gigabytes of CTD data, derive a few physical parameters, and automatically plot them.... without ever considering the laborious and exhaustive process of acquiring reference-quality data! In particular, with the frequent and intense storms that we experienced on S04P, I have also learned that the ocean doesn't always cooperate with the science goals. As I am in the planning stage of my PhD research, this is a critical lesson that I will take home with me and incorporate into both my project and professional career.

26.4 Bingkun Luo

My name is Bingkun Luo and I am a Ph.D. student from RSMAS/Meteorology and Physical Oceanography Program at University of Miami. I am a CTD watch stander on the night shift with Chanelle and Amir. Thanks for Alison and Ellen give me this opportunity to participate this 67-days cruise. I think this cruise is awesome! We did 120 CTD casts and collected lots of samples!

I am a night shift person. It is very quiet at night and I enjoy the peaceful night to let me concentrate on all of the things. During the sample, I was responsible for the weather maps, Nitrate δ15N and δ18O, Helium and salt. Thanks for two students MATLAB code from another cruise (Natalie Freeman and Seth Travis). We developed the new version S04P code based on them. The code was very efficiently to plot the ship path and forecast stations on the weather map. What's more, Taimoor also wrote a Python code to format the input files. That's nice! The δ18O is very easy to sample since the bottle is already cleaned before and the bottle is very small. For the Helium, I enjoy the music of "bang bang bang" to remove the bubbles from the tube. It is very interesting to sample Helium. We need to press or copper the tube after collecting sample. At the beginning I failed, I almost wasted 50% of the tube! But after Yves told me how to do it correctly, I did it with more patience! Then the success rate with the copper is 100%! These samples are going to help our community learn all sorts of interesting things about the interaction of the cryosphere and the ocean. It is my pleasure to make contributions to them! After all of the samples finished, we need to collect salt bottles together. I usually did it very quickly and try to finish all of it as soon as possible, but it will make some problems and make the result not accurate. Thanks to ODF's instruction, I know that I should have more patience to

collect salt samples. After that, Alison told us that the result was much better than before. I am very proud of it! I think the most important knowledge that I learned is the patience!

When the storms approaching, our ship moves to south. It is so beautiful in South Pole! The big iceberg, the penguins, seals, whales are wonderful! This is the first time I see this kind of animals out of TV and Seaquarium!

All of the cruise members and scientists are very kind, I have made lots of friends from this cruise. Thanks for this opportunity and I think it refreshes my mind about the ocean and research! AWESOME!

26.5 Chanelle Cadot

My name is Chanelle Cadot, and I am an undergraduate studying Oceanography at the University of Washington. I work as a student technician at the UW Argo Float Lab, and our lab builds SOCCOM floats. Argo floats are autonomous sensor platforms that are deployed throughout the worlds' oceans and measure salinity, temperature, and depth. SOCCOM floats are part of the Southern Ocean Carbon Climate Observation and Modeling project, and they are outfitted with additional biogeochemical sensors to measure nitrate, pH, chlorophyll, and oxygen. I have worked with these instruments in the lab, but I have never had the opportunity to take part of their deployments. When I found out that I would be going on the S04P research cruise to be a CTD watch stander and help oversee float deployments, I was ecstatic.

There were 6 SOCCOM floats from our lab on the cruise, but there were 18 floats in all from a total of 4 different institutions. Each institution had a different variation of a float, so they all had varying deployment procedures. My job was to make sure that all the floats were ready to go, and that they were deployed according to their protocol. Once the float was deployed, I would then contact the various PI's to give them all the information regarding the deployment information of their floats. Of course, not everything always went exactly according to plan. For example, 10 of the floats had these deployment harnesses that were operated with a water-soluble release mechanism. The idea is that you dunk the release mechanism in the water, and upon contact with the water, it dissolves and the float is released into the water. This works great in warm water, but when we tried it in the Southern Ocean, the release mechanism froze and would not dissolve. We were able to improvise other methods to deploy these floats, which was a good lesson in trouble shooting.

Another issue we ran into was activating the 5 MRV floats. This process involved hauling these floats outside, securing them to the side, activating them with a magnet swipe, and getting confirmation that they sent a message. This proved to be challenging sometimes because the activation had to happen during a certain window prior to deployment, but sometimes we got unexpected weather delays. There were also days where we couldn't go outside to do this because of weather conditions, so we had to be strategic about the timing of the magnet swipe. We also had trouble with a few of the floats with actually activating them. The magnet swipe was over a magnetic relay switch, which is denoted on the outside of the float with a "reset" sticker. It was sometimes hard to reach the reset sticker with the surrounding cardboard box that the float was in, so finally the PI overseeing those floats told me to conduct a magnet "dance" rather than a magnet swipe. The magnet dance was a fancy way of saying to make sure that the magnet traveled around a broad swath of the float in case the magnetic relay is offset from the reset sticker. Once the magnet dance was suggested, we were usually able to activate the floats pretty easily. Sometimes it would be frustrating when we couldn't get a float activated or it wasn't sending a message, but overall it was satisfying to problem solve and finally get it to work.

I'm probably biased, but my favorite deployments were the SOCCOM floats. The SOCCOM program also has an outreach program called Adopt-a-Float, which is where classrooms across the country can pick a float and name it. The students then follow the float deployment and study the data profiles that the float produces once it is in the ocean. All of the SOCCOM floats on board were "adopted", so we had fun decorating the floats according to their given names. I then took lots of pictures of the floats before and during deployment to send back for the students. The SOCCOM stations were also interesting because we did special CTD casts for these stations. We fired extra bottles on the rosette at the surface and at the chlorophyll maximum. There was also a lot of sampling that occurred on these stations. This is because data obtained from the casts at SOCCOM stations are used to validate the data of the float's profiles to ensure that the sensors on the floats are measuring reasonable values.

I could go on and on about the float deployments, but my other job on the cruise was to be a CTD watch stander. This meant that I helped oversee the CTD console as the CTD did a cast and then I participated in the sampling when the CTD was back on deck. I usually helped out with the Radiocarbon, alkalinity, and salts sampling. Radiocarbon was interesting because it had this whole post sampling procedure that required greasing and sealing the stoppers to the sample bottles. I liked being a CTD watch stander because you get to be really involved with all the science. You're there watching the cast itself and seeing the profile of the cast. You're also helping out with the sampling and sometimes overseeing the sampling as a "sample cop".

Overall, this cruise was an incredible experience, and I feel fortunate to have been able to be a part of it.

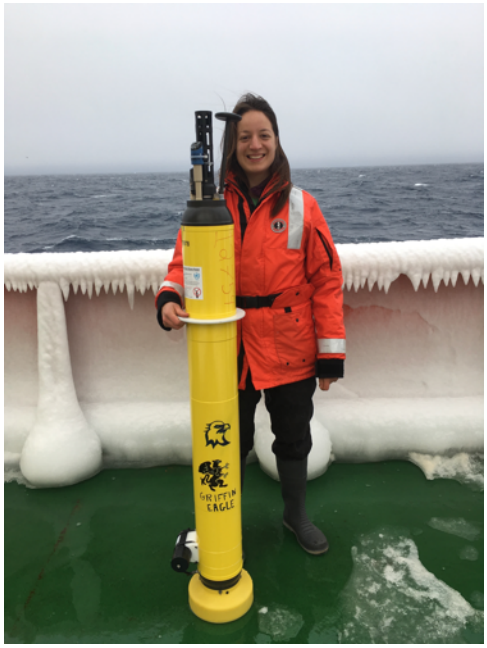

Fig. 26.2: I'm standing with one of the SOCCOM floats shortly before its deployment.

APPENDIX

A

ABBREVIATIONS

ADCP Acoustic Doppler Current Profiler

ANU Australian National University

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

CSIRO Commonwealth Scientific and Industrial Research Organisation

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

eNd Neodymium Samples

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 Acoustic Doppler Profiler

MBARI Monterey Bay Aquarium Research Institute

MPIC Max Planck Institute of Chemistry

N2O Nitrous Oxide

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

Oxford Oxford 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

U Alaska University of Alaska

U Arizona University of Arizona

UCI University of California Irvine

UCSB University of California Santa Barbara

UCSD University of California San Diego

U Colorado University of Colorado

UdeC University of Concepción, Chile

U Edin. University of Edinburgh

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

UVP Underwater Vision Profiler

UW University of Washington

UWA University of Western Australia

U. Wisconsin University of Wisconsin

VIMS Virginia Institute of Marine Science

VUB Vrije Universiteit Brüssel

WHOI Woods Hole Oceanographic Institution

W&M College of William & Mary

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APPENDIX

B

BOTTLE QUALITY COMMENTS

APPENDIX

C

CALIBRATION DOCUMENTS

Pressure Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 1281
CALIBRATION DATE: 12-DEC-2017
Mfg: SEABIRD Model: 09P CTD Prs s/n: 136428

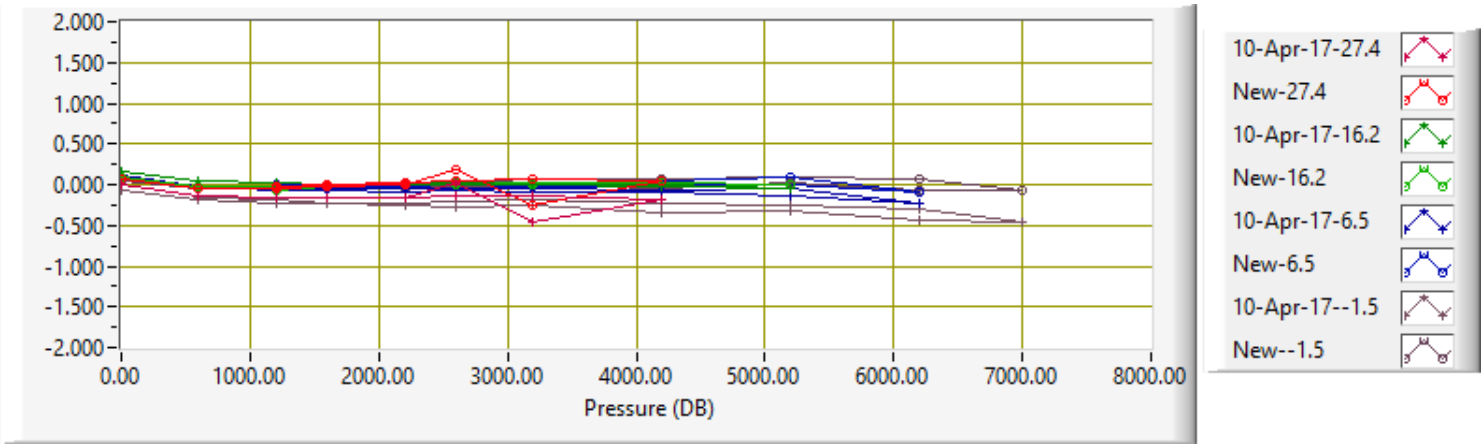
C1= -4.160303E+4
C2= -4.604479E-1
C3= 1.585404E-2
D1= 3.546467E-2
D2= 0.000000E+0
T1= 3.013997E+1
T2= -3.831629E-4
T3= 3.608677E-6
T4= 1.200552E-8
T5= 0.000000E+0
AD590M= 1.27846E-2
AD590B= -9.25586E+0
Slope = 1.00000000E+0
Offset = 0.00000000E+0

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
33192.918	0.27	0.19	-0.00	0.07	28.04	27.370
33537.972	600.30	600.34	-0.14	-0.04	28.05	27.372
33878.938	1200.32	1200.36	-0.17	-0.04	28.06	27.372
34104.071	1600.33	1600.36	-0.17	-0.03	28.07	27.372
34438.600	2200.36	2200.36	-0.17	-0.01	28.07	27.371
34659.451	2600.36	2600.17	0.01	0.19	28.08	27.372
34988.130	3200.38	3200.64	-0.46	-0.26	28.08	27.371
35527.535	4200.37	4200.32	-0.18	0.05	28.09	27.370
34987.957	3200.38	3200.32	-0.14	0.06	28.09	27.371
34659.542	2600.36	2600.33	-0.14	0.03	28.09	27.372
34438.595	2200.36	2200.34	-0.15	0.01	28.10	27.372
34104.064	1600.33	1600.34	-0.15	-0.01	28.10	27.371
33878.934	1200.32	1200.34	-0.15	-0.02	28.10	27.371
33537.967	600.30	600.32	-0.12	-0.01	28.10	27.371
33190.468	0.27	0.18	0.17	0.08	17.05	16.244
33535.477	600.32	600.34	0.04	-0.02	17.05	16.244
33876.394	1200.34	1200.37	0.02	-0.02	17.04	16.244

Sensor Output	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
34101.504	1600.37	1600.39	0.01	-0.02	17.03	16.244
34436.000	2200.40	2200.41	0.00	-0.01	17.04	16.244
34656.933	2600.42	2600.42	-0.00	-0.01	17.04	16.244
34985.312	3200.45	3200.43	0.01	0.02	17.04	16.244
35524.823	4200.46	4200.44	-0.01	0.02	17.05	16.244
36054.993	5200.46	5200.47	-0.05	-0.01	17.05	16.244
35524.812	4200.46	4200.43	-0.00	0.03	17.04	16.243
34985.311	3200.45	3200.43	0.00	0.01	17.03	16.244
34656.918	2600.42	2600.40	0.02	0.02	17.03	16.244
34435.994	2200.40	2200.40	0.01	-0.00	17.03	16.244
34101.503	1600.37	1600.39	0.01	-0.02	17.03	16.244
33876.411	1200.34	1200.40	-0.02	-0.06	17.03	16.244
33535.457	600.32	600.31	0.06	0.00	17.03	16.243
33187.405	0.27	0.19	0.11	0.08	7.42	6.485
33532.379	600.32	600.34	-0.02	-0.02	7.41	6.484
33873.285	1200.35	1200.39	-0.07	-0.05	7.40	6.484
34098.377	1600.37	1600.41	-0.07	-0.04	7.40	6.484
34432.850	2200.40	2200.43	-0.09	-0.03	7.40	6.484
34653.753	2600.42	2600.43	-0.08	-0.01	7.40	6.484
34982.120	3200.45	3200.46	-0.10	-0.01	7.40	6.484
35521.574	4200.46	4200.45	-0.10	0.01	7.40	6.484
36051.701	5200.46	5200.47	-0.14	-0.01	7.40	6.484
36572.912	6200.45	6200.53	-0.23	-0.08	7.40	6.485
36051.645	5200.46	5200.37	-0.04	0.09	7.39	6.484
35521.549	4200.46	4200.42	-0.07	0.04	7.38	6.484
34982.085	3200.45	3200.41	-0.05	0.03	7.38	6.484
34653.726	2600.42	2600.39	-0.04	0.02	7.38	6.484
34432.815	2200.40	2200.39	-0.05	0.01	7.37	6.485
34098.350	1600.37	1600.38	-0.05	-0.02	7.36	6.484
33873.239	1200.34	1200.34	-0.01	0.01	7.36	6.484
33532.352	600.32	600.33	-0.01	-0.01	7.35	6.484
33184.225	0.27	0.23	-0.07	0.03	-0.70	-1.522
33529.188	600.31	600.37	-0.19	-0.06	-0.70	-1.522
33870.068	1200.34	1200.39	-0.22	-0.05	-0.70	-1.522
34095.146	1600.36	1600.39	-0.22	-0.03	-0.70	-1.522
34429.614	2200.39	2200.43	-0.26	-0.04	-0.71	-1.522
34650.510	2600.40	2600.43	-0.27	-0.03	-0.71	-1.522
34978.846	3200.43	3200.43	-0.26	0.00	-0.72	-1.522
35518.317	4200.45	4200.48	-0.34	-0.03	-0.72	-1.522
36048.383	5200.45	5200.42	-0.31	0.02	-0.72	-1.522
36569.578	6200.41	6200.48	-0.44	-0.07	-0.72	-1.522
36980.327	7000.39	7000.46	-0.45	-0.07	-0.72	-1.522
36569.513	6200.43	6200.37	-0.31	0.06	-0.73	-1.522
36048.338	5200.44	5200.36	-0.26	0.08	-0.74	-1.521
35518.248	4200.43	4200.37	-0.24	0.06	-0.74	-1.522

Sensor Output	Standard	Sensor New_Coefs	Standard-Sensor Prev_Coefs	Standard-Sensor NEW_Coefs	Sensor_Temp	Bath_Temp
34978.800	3200.43	3200.36	-0.19	0.07	-0.74	-1.522
34650.468	2600.41	2600.37	-0.21	0.03	-0.74	-1.522
34429.579	2200.39	2200.40	-0.23	-0.01	-0.74	-1.522
34095.131	1600.36	1600.40	-0.23	-0.04	-0.74	-1.522
33870.036	1200.34	1200.36	-0.19	-0.02	-0.74	-1.522
33529.148	600.32	600.33	-0.15	-0.01	-0.74	-1.522
33184.176	0.27	0.17	-0.01	0.09	-0.74	-1.521



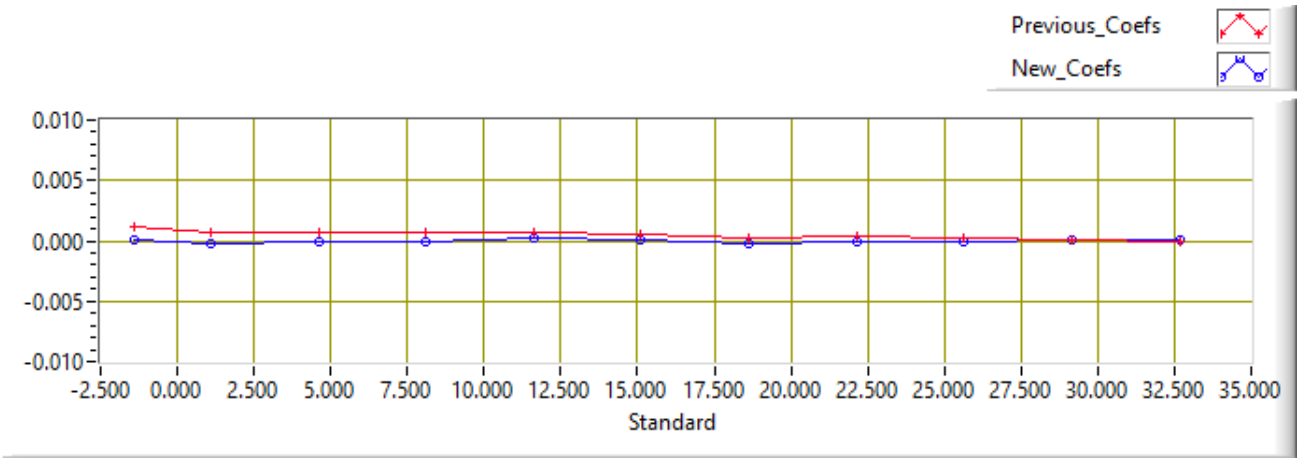
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 2309
CALIBRATION DATE: 30-Jan-2018
Mfg: SEABIRD Model: 03
Previous cal: 18-Apr-17
Calibration Tech: CAL

ITS-90_COEFFICIENTS IPTS-68_COEFFICIENTS
g = 4.35781951E-3 a = 4.35801776E-3
h = 6.45070776E-4 b = 6.45282154E-4
i = 2.42988411E-5 c = 2.43316076E-5
j = 2.35822338E-6 d = 2.35982046E-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
2976.5664	-1.4141	-1.4142	0.00112	0.00015
3148.1687	1.0899	1.0901	0.00069	-0.00019
3400.3512	4.5965	4.5966	0.00069	-0.00008
3666.9395	8.1049	8.1049	0.00068	0.00000
3948.3190	11.6151	11.6149	0.00076	0.00017
4243.8576	15.1147	15.1146	0.00061	0.00010
4555.7184	18.6251	18.6252	0.00028	-0.00016
4883.2760	22.1350	22.1351	0.00034	-0.00001
5227.0836	25.6462	25.6463	0.00024	-0.00001
5587.2448	29.1566	29.1565	0.00014	0.00001
5964.2596	32.6677	32.6677	0.00000	0.00001



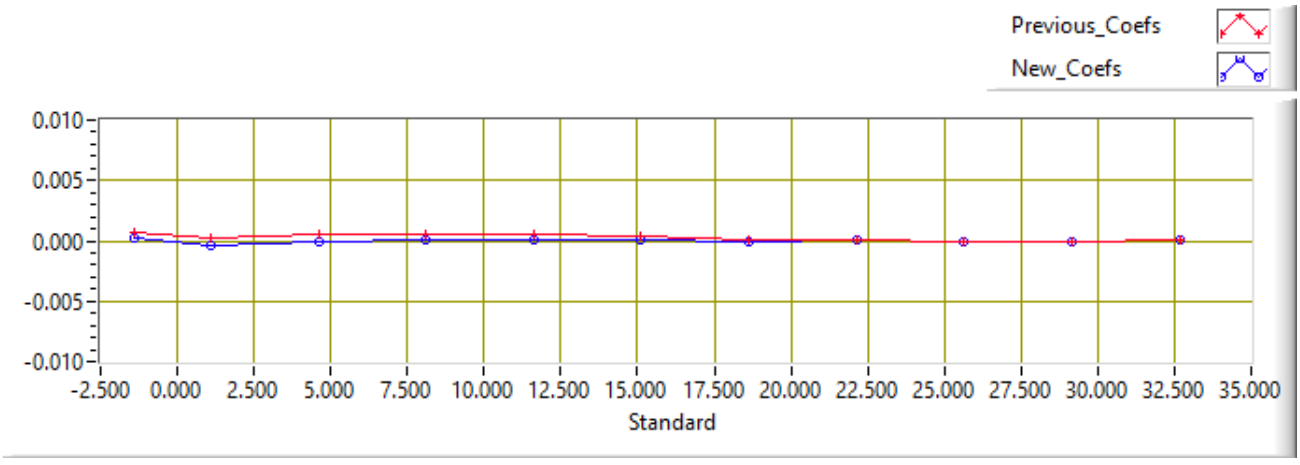
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 5844
CALIBRATION DATE: 30-Jan-2018
Mfg: SEABIRD Model: 03
Previous cal: 11-Apr-17
Calibration Tech: CAL

ITS-90_COEFFICIENTS IPTS-68_COEFFICIENTS
g = 4.36593732E-3 a = 4.36613846E-3
h = 6.30830930E-4 b = 6.31038862E-4
i = 2.06378769E-5 c = 2.06689583E-5
j = 1.63292939E-6 d = 1.63430084E-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
3080.2217	-1.4141	-1.4143	0.00076	0.00024
3260.8575	1.0899	1.0902	0.00024	-0.00032
3526.5248	4.5965	4.5965	0.00050	-0.00005
3807.6804	8.1049	8.1049	0.00053	0.00003
4104.7634	11.6151	11.6150	0.00049	0.00009
4417.1077	15.1147	15.1146	0.00045	0.00015
4747.0667	18.6251	18.6252	0.00011	-0.00007
5094.0188	22.1350	22.1350	0.00009	0.00001
5458.5869	25.6462	25.6464	-0.00010	-0.00011
5840.8984	29.1566	29.1566	-0.00006	-0.00004
6241.5384	32.6677	32.6677	0.00006	0.00007



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seabird@seabird.com
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SENSOR SERIAL NUMBER: 1880
CALIBRATION DATE: 02-Feb-18

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

COEFFICIENTS:

```
g =  -3.96678467e+000
h =   4.84542307e-001
i =  -6.60474581e-004
j =   5.63015941e-005

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

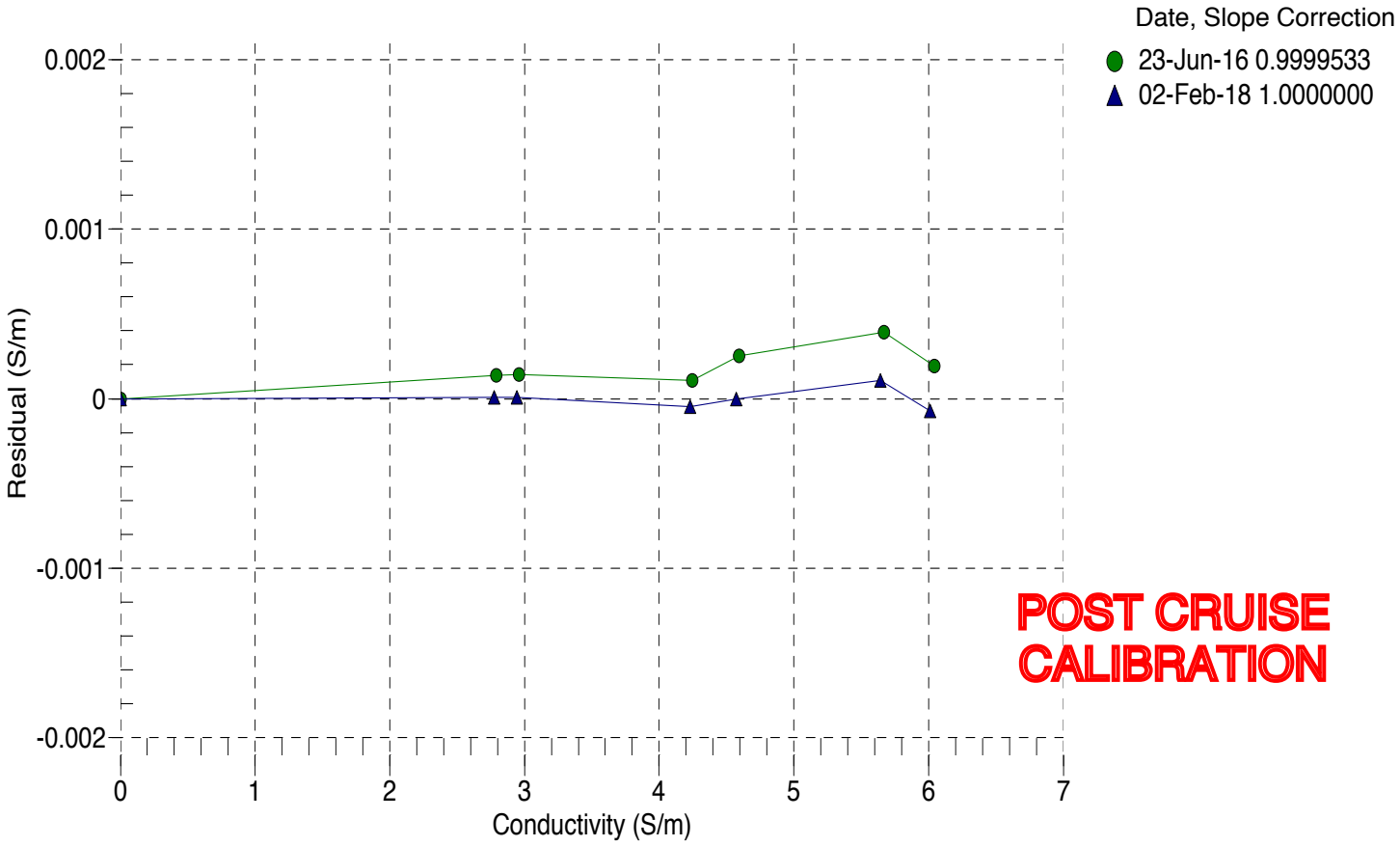
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.86546	0.00000	0.00000
-1.0000	34.4274	2.77615	8.10588	2.77616	0.00001
1.0001	34.4277	2.94590	8.31943	2.94591	0.00001
15.0000	34.4273	4.22891	9.78153	4.22886	-0.00005
18.5000	34.4258	4.57212	10.13631	4.57212	-0.00000
29.0000	34.4165	5.64416	11.17027	5.64426	0.00011
32.5000	34.4009	6.01169	11.50253	6.01162	-0.00007

f = Instrument Output (kHz)

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

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

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



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SENSOR SERIAL NUMBER: 4546
CALIBRATION DATE: 08-Feb-18

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

COEFFICIENTS:

```
g =  -9.90838065e+000
h =   1.60083819e+000
i =  -1.58153324e-003
j =   1.99854164e-004

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

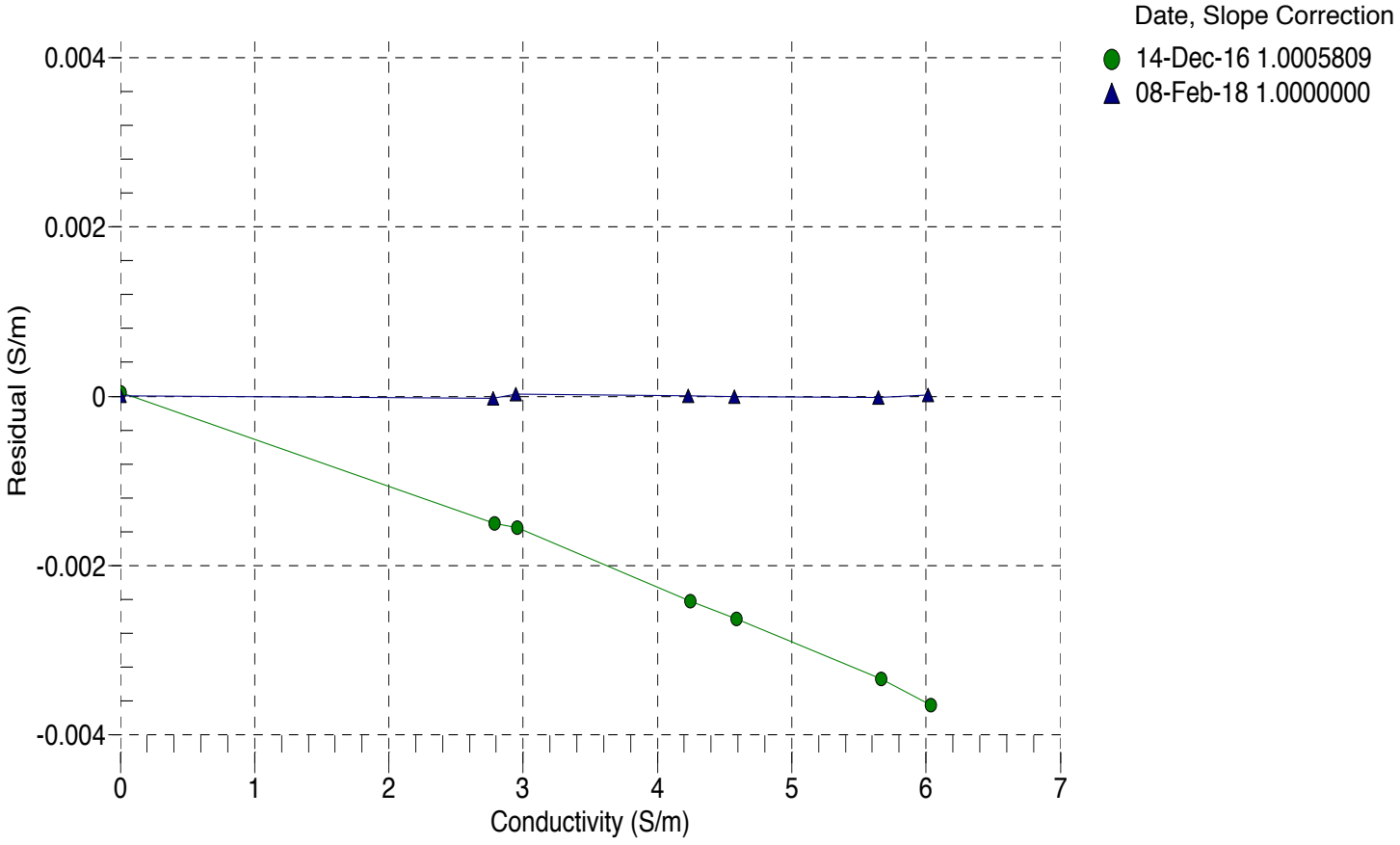
BATH TEMP (° C)	BATH SAL (PSU)	BATH COND (S/m)	INSTRUMENT OUTPUT (kHz)	INSTRUMENT COND (S/m)	RESIDUAL (S/m)
0.0000	0.0000	0.00000	2.48997	0.00000	0.00000
-1.0000	34.4399	2.77706	4.85598	2.77704	-0.00003
1.0001	34.4402	2.94687	4.96418	2.94690	0.00003
15.0001	34.4401	4.23033	5.71557	4.23033	0.00001
18.5001	34.4390	4.57369	5.90029	4.57369	-0.00000
29.0001	34.4310	5.64628	6.44303	5.64626	-0.00002
32.5000	34.4164	6.01409	6.61882	6.01410	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



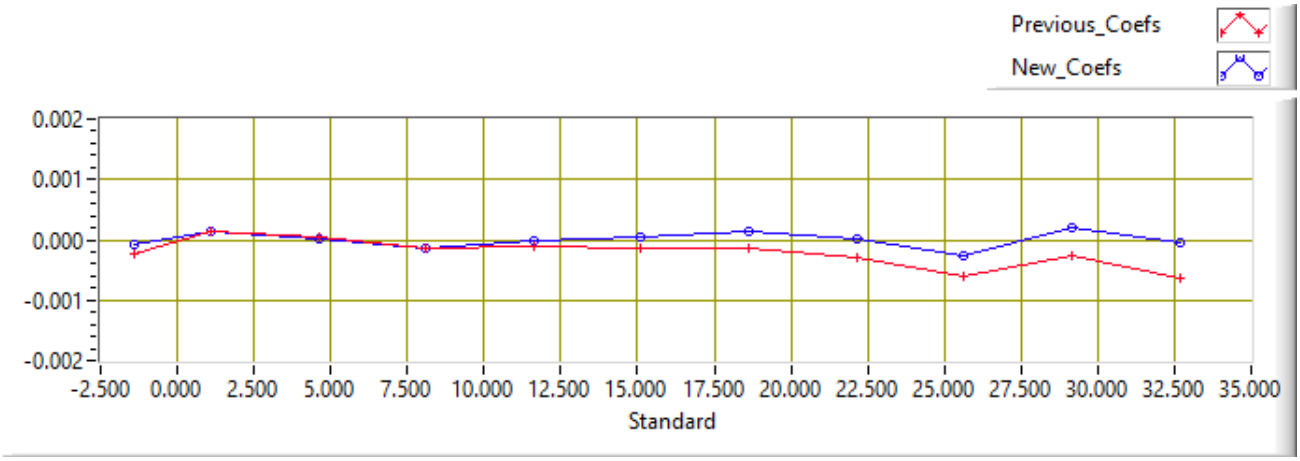
Temperature Calibration Report
STS Calibration Facility

SENSOR SERIAL NUMBER: 0035
CALIBRATION DATE: 01-Feb-2018
Mfg: SEABIRD Model: 35
Previous cal: 13-Apr-17
Calibration Tech: CAL

ITS-90_COEFFICIENTS
a0 = 4.791527218E-3
a1 = -1.309090597E-3
a2 = 1.955082742E-4
a3 = -1.086552076E-5
a4 = 2.316911178E-7
Slope = 1.000000 Offset = 0.000000
Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2

Calibration Standard: Mfg: Isotech Model: MicroK100 s/n: 291088-2
Temperature ITS-90 = 1/{a0+a1[ln(f)]+a2[ln2(f)]+a3[ln3(f)]+a4[ln4(f)} - 273.15 (°C)

SBE35 Count	SPRT ITS-T90	SBE35 ITS-T90	SPRT-SBE35 OLD_Coefs	SPRT-SBE35 NEW_Coefs
656379.7725	-1.4147	-1.4147	-0.00022	-0.00008
588220.4937	1.0889	1.0887	0.00014	0.00015
505645.6124	4.5957	4.5957	0.00006	0.00001
435835.2087	8.1031	8.1032	-0.00014	-0.00014
376639.0090	11.6137	11.6137	-0.00012	-0.00003
326489.0904	15.1148	15.1148	-0.00014	0.00005
283649.9587	18.6268	18.6267	-0.00013	0.00013
247110.8773	22.1359	22.1359	-0.00029	0.00003
215838.7256	25.6449	25.6452	-0.00062	-0.00026
188993.4830	29.1564	29.1562	-0.00025	0.00019
165901.6355	32.6672	32.6673	-0.00063	-0.00004



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

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

SENSOR SERIAL NUMBER: 0255
CALIBRATION DATE: 22-Nov-17

SBE 43 OXYGEN CALIBRATION DATA

COEFFICIENTS:
Soc = 0.4274
Voffset = -0.4964
Tau20 = 0.99
A = -2.9883e-003
B = 1.5984e-004
C = -2.4626e-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

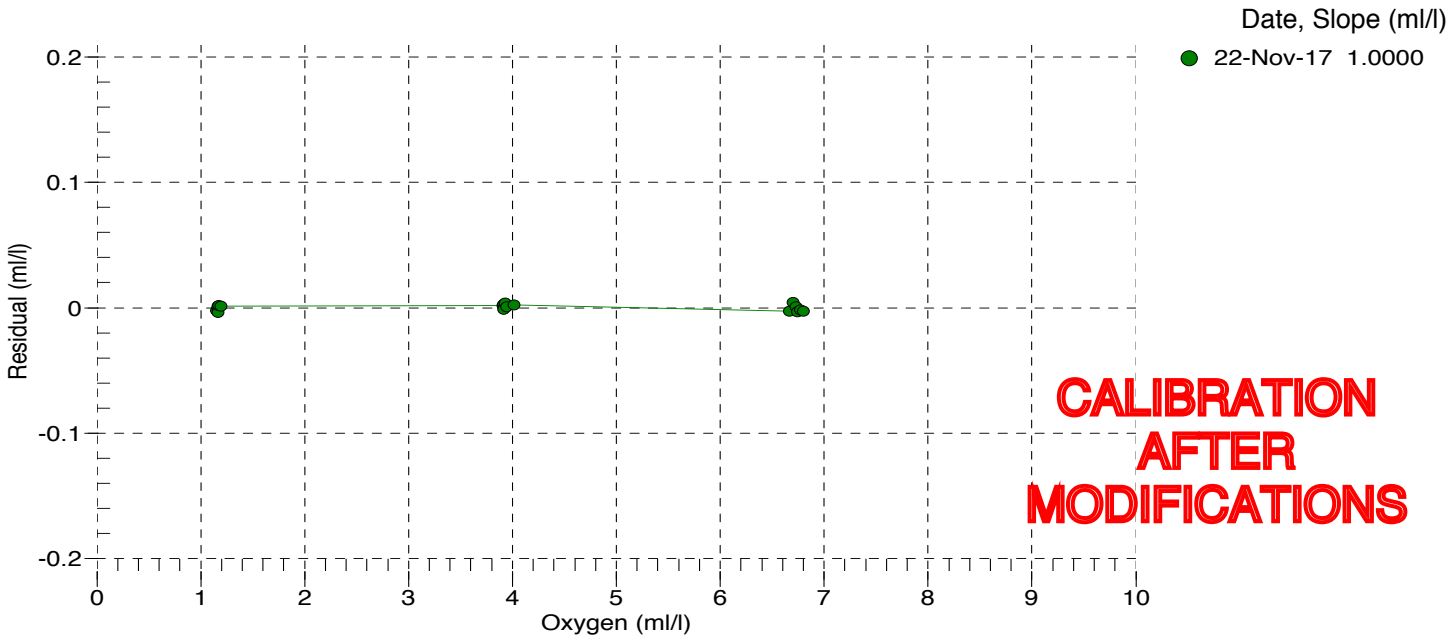
BATH OXYGEN (ml/l)	BATH TEMPERATURE (° C)	BATH SALINITY (PSU)	INSTRUMENT OUTPUT (volts)	INSTRUMENT OXYGEN (ml/l)	RESIDUAL (ml/l)
1.15	2.00	0.00	0.776	1.15	-0.00
1.16	20.00	0.00	0.931	1.16	0.00
1.16	12.00	0.00	0.863	1.16	-0.00
1.16	6.00	0.00	0.812	1.16	-0.00
1.17	26.00	0.00	0.986	1.17	0.00
1.19	30.00	0.00	1.031	1.19	0.00
3.91	2.00	0.00	1.447	3.91	0.00
3.91	6.00	0.00	1.562	3.92	0.00
3.92	12.00	0.00	1.732	3.91	-0.00
3.93	20.00	0.00	1.964	3.93	0.00
3.95	26.00	0.00	2.144	3.95	0.00
4.01	30.00	0.00	2.294	4.01	0.00
6.67	2.00	0.00	2.116	6.66	-0.00
6.70	6.00	0.00	2.321	6.71	0.00
6.73	26.00	0.00	3.307	6.73	0.00
6.74	12.00	0.00	2.623	6.74	-0.00
6.77	20.00	0.00	3.026	6.77	-0.00
6.80	30.00	0.00	3.541	6.80	-0.00

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

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

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

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



Temperature Calibration Certificate

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

1. Equation

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

2. Coefficients

A = −5.305905e+00
B = +1.666857e+01
C = −2.142681e+00
D = +4.582805e−01

3. Calibration results

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

4. Verification

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

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

Examined R. Kashida

Approved A. Fukuoka

JFE Advantech Co., Ltd.

Dissolved Oxygen Calibration Certificate

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

1. Equation

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

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

2. Coefficients

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

3. Verification

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

Acceptance: ±0.5% of full scale

Test for DO 0 %

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

Test for DO 100 %

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

Examined M. TAKEISHI

Approved A. Fukuoka

JFE Advantech Co., Ltd.

CCHDO Data Processing Notes

Data History

- **File Online** **Carolina Berys**

s04p_2018.pdf (download) #ece08
Date: 2018-06-01
Current Status: unprocessed

- **File Online** **Carolina Berys**

320620180309_ct1.zip (download) #05018
Date: 2018-06-01
Current Status: unprocessed

- **File Online** **Carolina Berys**

320620180309_hy1.csv (download) #bb9b8
Date: 2018-06-01
Current Status: unprocessed

- **File Submission** **Joseph Gum**

320620180309_hy1.csv (download) #bb9b8
Date: 2018-05-20
Current Status: unprocessed
Notes
S04P 2018 Preliminary Cruise Data

- **File Submission** **Joseph Gum**

320620180309_ct1.zip (download) #05018
Date: 2018-05-20
Current Status: unprocessed
Notes
S04P 2018 Preliminary Cruise Data

- **File Submission** **Joseph Gum**

s04p_2018.pdf (download) #ece08
Date: 2018-05-20

Current Status: unprocessed
Notes
S04P 2018 Preliminary Cruise Data