RV *Investigator* Voyage Summary

Voyage #:	**IN2016_V03**		
Voyage title:	Monitoring Ocean Change and Variability along 170ºW from the ice edge to the equator		
Mobilisation:	Hobart, Tuesday 26 April, 2016		
Depart Leg 1:	Hobart, 2000 Tuesday 26 April, 2016		
Arrive Leg 1:	Wellington (NZ): 1100 Thursday 26 May		
Depart Leg 2:	Wellington (NZ): 1230, Friday 27 May, 2016		
Arrive Leg 2:	Lautoka (Fiji), 0800 Wednesday, 30 June, 2016		
Demobilisation:	Hobart, Thursday July 14th, Friday July 15th & Monday July 18th, 2016		
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Supplementary Project			
Principal Investigator:	Alex Forrest, University of Tasmania		
Project name:	Working from the other side: facing the challenges of under-ice for autonomous navigation in Antarctica		
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Scientific objectives

Sloyan, Wijffels, Cowley, Tilbrook, Bullister, Warner, Bodrossy:

The full suite of key ocean parameters and the deep ocean heat and carbon reservoirs remain poorly measured. This proposal will complete full-depth, high-precision hydrographic, carbon, and tracer measurements, along 170°W from the sea-ice edge to the equator, to monitor and detect ocean variability and change including changes in the carbonate chemistry associated with acidification. The line comprises the line P15S that is part of the international GO-SHIP repeat global survey network (www.go-ship.org). These data, together with other observational data and numerical models, will allow for the detection and attribution of ocean change and variability and to assess the impact of the ocean on climate variability.

This hydrographic section will monitor ocean change and variability by:

1. Directly measuring the full suite of ocean water properties (temperature, salinity, velocity, nutrients, tracers and ocean mixing) at high vertical and spatial resolution throughout the entire water column and in the deep boundary currents, contributing to the international GO-SHIP program.
2. Providing high precision biogeochemical measurements to monitor changes in ocean carbon storage and oxygen concentrations, contributing to the IOCCP international program to monitor the global carbon budget.
3. Directly measure ocean mixing to improve our knowledge of the ocean Meridional Overturning Circulation.
4. Provide high precision baseline data to calibrate the Argo array, XBT program, and other autonomous observations (ocean gliders, moorings and satellites) in the vicinity of the section.
5. Deploy Argo floats for the core mission and contributions to the international SOCCOM project.
6. Obtain side-by-side CTD/XBT data for the assessment of bias errors in XBT measurements.

Voyage objectives

Sloyan, Wijffels, Cowley, Tilbrook, Warner, Bullister, Bodrossy:

The primary voyage objective is to obtain a repeat occupation of the 155 full-depth CTD and Niskin casts that comprise the GO-SHIP P15S section, with chemistry performed on water collected at 36 bottle levels. We measured temperature, salinity, pressure, oxygen, fluorometry, shear and micro-scale temperature continuously, and the major nutrients, oxygen, salinity, CFC and carbon components discretely via chemical analysis on board. Small amounts of material will be filtered and stored for genomic analyses back on land. CSIRO has completed this line twice before and international groups have completed similar work along lines further east. The work plan and timings are based on these past voyages.

Argo float deployments will also be carried out – usually when just leaving a CTD station (SOCCOM floats) or during transit (we may slow the ship speed slightly). These will be over the ship’s stern (preferred).

Results

2016 occupation of the P15S Hydrographic section: Overall delivery against the original plan was around 90%.

Of the 155 stations originally planned, before leaving port, the plan was scaled back to 150 stations due to emerging information about the time required for the Wellington port call and a recommended reduction in the planned transit speeds from 12 to 11 knots. However, two extra ship days were provided later to compensate for time lost due to winch/wire issues. Ultimately of the original 155, we achieved occupation of 140 stations. Ten stations were abandoned on Leg 1, most due to wire or termination damage, one to weather and one to sea ice. One station was abandoned on Leg 2 due to a winch brake failure, ongoing winch alarm and wrap laying issues. Besides the CTD sensor traces, most casts provided Niskin bottle water samples for on board analyses. A few stations did not collect samples due to electrical damage to the CTD cable and subsequent loss of communication to the rosette.

The heave compensation system (only used during Leg 2) on the CTD winches appears to be a key factor which enabled the completion of the section without further wire damage. It also has a profound and beneficial impact on the raw sensor streams, almost entirely removing package flow contamination in these data. The other key event was the near-loss of the entire frame, instruments and our main CTD wire due to a winch break failure at station 83. The safe recovery of both the wire and instrument package by the ship's crew was nothing short of a miracle. The winch was rebuilt, the cable trimmed, spooled out and de-torqued, and the system was put back into service. This was voyage saving, as we later learned that our spare CTD (#22) had an unrepairable leak and there were no other spare CTD buses on board.

CTD traces: The performance of the CTD system was mixed, but the issues are largely recoverable through post-calibration. While the sensors were generally stable throughout the voyage, large and uncharacteristic offsets were found between the sensor behaviour at sea (compared to excellent bottle salts) and in the calibration laboratory. This issue remains unexplained. Two secondary C-cells were somehow damaged and not working within specifications. Despite this, due to the sensor stability, having dual sensor lines, and the high quality of the bottle salts and through assistance from SeaBird, the final calibrated data will be excellent. See Appendix 1 for details on C-cell troubleshooting. Table 2 has the full list of CTD stations occupied.

Optics: On leg 1 (stations 1-50), and in support of SOCCOM (see below), a University of Maine Wetlabs FLBBRTD (SN3698) was installed onto the 9plus analogue channels, measuring the optical parameters fluorescence, backscatter, Photosynthetically Active Radiance (PAR) and light transmission. This was removed in Wellington. From stations 56-140, the MNF's Chelsea Aquatracker was fitted onto the frame, returning fluorescence, backscatter, and light transmission.

Hydrochemical Data: Laboratory results for the major nutrients, oxygen and salinity, from the CSIRO hydrochemistry team are excellent and will meet GO-SHIP standards. This is the best deep section data set this team has ever delivered and it is an outstanding effort. The team kept up with the intense throughput associated with processing 36 bottle samples per cast. The good instrumentation, standards used and very stable laboratory temperatures were also vital ingredients, along with the teams' dedication and thorough preparation.

Anthropogenic trace gases: The measurements of the chlorofluorocarbon-11 (CFC-11), CFC-12 and sulphur hexafluoride (SF_6) by the University of Washington/NOAA-PMEL team are of high quality -2187 samples were collected in coordination with the carbon chemistry team. See Appendix 2 for details and highlights.

Carbon chemistry: A total of 2625 water samples were analysed for total dissolved inorganic carbon from a subset of the Niskin water samples, with an additional 269 duplicate samples analysed. Also, 2628 seawater samples were analysed for total alkalinity, plus 224 duplicate samples. The data are deemed of very high quality. See Appendix 3 for details and highlights from the carbon team.

Helium Data: Seawater was collected from some of the Niskin bottles at 20 stations to produce 219 duplicate 10-inch long sealed (crimped) copper tubes for future analysis of helium isotopes onshore. Originally we had planned to sample 22 stations, however the sea ice edge did not permit sampling as far as 68ºS. At CTD station 2 the helium crimping equipment froze. We relocated the crimper to the dry-clean laboratory and helium sampling was completed out of the normal water sampling order. See Appendix 9 for an overview of the helium sampling.

Velocity Shear: Data was collected via a two unit Lowered Acoustic Doppler Current profiler system on nearly all casts. On some casts, data download delays meant we had to abandon those data in order to avoid a schedule slip. The data are also somewhat compromised by two factors:

- Heading on the master (150kHz) instrument was bad
- One beam on this instrument also failed.

However, we believe these data will be still very useful after processing for mixing and flow studies. See Appendix 10 for further details.

Temperature microstructure: On nearly all casts, fast (100Hz) temperature and package motion were measured via Chi-pods. This data can be used to determine ocean mixing and dissipation rates. Typically, 2 instruments sampled the waters at the leading edge of the frame (above and below). Data were downloaded every second day or as needed. See Appendix 4 for more detail.

Underway velocity: Both RDI Ocean Surveyors (150kHz and 75kHz) acoustic Doppler profilers (ADCPs) were run continuously for the voyage. The raw data looks good, and will likely underpin an excellent final velocity data set. The OS150 alignment error used on acquisition was wrong and the correct value is currently unknown since the instrument was refit in October 2015. This requires a new bottom tracking data set to be collected for calibration. There is a heading error in the processing for the Leg 1 data that also remains unresolved. The acquisition system appeared to drop navigation data intermittently, possibly due to buffer limits. We believe these can all be recovered in post processing. Both ringing and bubble contamination afflict the upper bins, but their impact was partially reduced by extending the drop keel to its medium setting.

eXpendable BathyThermograph side-by-side data: At several groups of station, two teams would drop eXpendable BathyThermograph (XBT) probes during the upper 1000db of the downcast. The purpose is to diagnose and quantify depth and temperature biases in XBT types and ages to help improve their use for climate studies. Several probe types and temperature regimes were covered. In total 295 probes were deployed. See Appendix 5 for details.

Nitrogen processes, budgets, plankton and bacterial phylogeny: The data arising from this study will be a major source of new information on N_2 fixation rates and the controls of the N-cycle contributing to regional primary productivity in the different water masses along the P15 GO-SHIP line**.** They will fill in a major knowledge gap in regards to N and C cycling in the world open oceans. Most of these data require substation shore-based analyses.

Samples that were taken for:

- Picoplankton analysis, using flowcytometry back on land
- Chlorophyll *a* and phytoplankton pigment analysis, using HPLC back on land
- DNA analyses using targeted functional gene expression analyses and high-throughput sequencing back on land
- Primary productivity, following isotopic tracer incorporation into the particulated matter, using stable isotopes ^{13}C, aboard using incubation bins

- Dissolved inorganic nitrogen uptake measurements, using standard ^{15}N protocols, aboard using incubation bins
- N_2-fixation rates, using ^{15}N gas as an injected tracer to measure fixation rates, aboard using incubation bins
- Nitrification rates

See Appendix 6 for details.

Profiling Float deployments: The Argo community joined together to take full advantage of the relatively rare chance to deploy profiling floats into the far Southern Ocean with a shipped-based high quality GO-SHIP deployment profile with full chemistry for calibration. The aft laboratory was literally filled with floats of various types when it left Hobart. In total we deployed 43 profilers – 25 floats for the core Argo mission, 2 prototype deep Argo floats, 13 bio-geochemical floats for the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) experiment. In addition, 3 non-Argo shear and BGC floats were deployed for the University of Tasmania. Floats were deployed on leaving a completed station or during transit. At each SOCCOM float deployment CTD, samples were collected for pH sample for depths to 2000m, up to 24 per cast plus 2 duplicates at any of those depths (0.8 litres each). High Pressure Liquid Chromatograph samples at surface and chlorophyll max, plus a duplicate at one of those depths (1-2 litres each). Particulate Organic Carbon sample at surface and chlorophyll max, plus a duplicate at one of those depths (2-3 litres each). These samples were sent back to the US for shore-based analysis.

The details of the float deployments can be found in Table 1.

Deep Argo CTD testing: Two prototype SBE-61 internally recording CTDs were attached to the frame above the SBE 9plus intakes. The SBE-61 is being developed for use in the deep Argo program and is still being tested and refined. The SBE's were on for all 140 CTD casts, and survived the sea floor impact on station 83. The data will be returned for analysis by SeaBird Electronics, Seattle.

Inertial Navigation System test (U. Tasmania piggy back project): The PHINS (PHotonic Inertial Navigation System) is a device capable of measuring all navigational parameters associated with the motion of a vehicle (e.g. heading, speed, position, and attitude), and is to be used in Autonomous Underwater Vehicle navigation and control. This cruise provided the perfect opportunity to test the behaviour of the PHINS technology at a range of different latitudes, with the aim of quantifying the effect of latitude on the accuracy of heading and position. To this end, the PHINS was operated continuously, with a repeating 12 hour testing regime, for the duration of the voyage. See Appendix 7 for details.

Atmospheric Chemistry and Aerosols: During the voyage, instrumentation was run continuously to investigate the chemical composition, size distribution, optical properties and cloud nucleating properties of marine aerosol over the southern hemisphere. These parameters are important in the quantification of regional contributions of aerosols to radiative forcing, and will help to improve meteorological and climate change models. With a few exceptions, the instrumentation has operated with only minor issues and a wealth of data has been successfully collected. See Appendix 8

Graduate student training: In addition to the science objectives, we were able to offer a seagoing observational experience to several graduate students in marine science from Australia and New Zealand. As well as assisting with the CTD and water sampling, the students undertook small projects in data analysis, and helped trouble shoot the systems on the ship. We believe this was a terrific and successful learning experience for these students, in the challenges of observational science and physical oceanography.

Voyage Narrative

Leg 1- Narrative by Bernadette Sloyan

Tuesday 26 April – Tuesday 3 May 2016

We departed Hobart on Tuesday 26 April at 2000 and began our transit to our first plan CTD stations of the P15S hydrographic section (170W, 68S). On the transit we stopped to completed a test CTD station (149 25.704'E, 45 29.813'S) and all CTD volunteers were shown how to run the CTD console and instructed on water sampling method for carbon, oxygen, helium, nutrients and salt. The CTD watches were established and everyone settled into their respective watches.

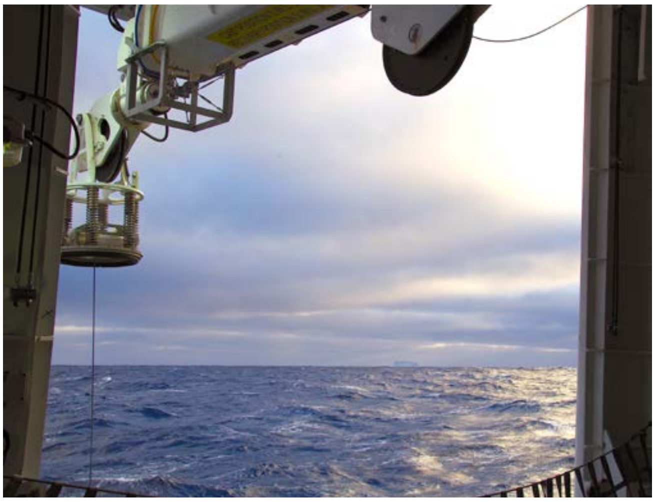
We provided a link to the Master of the sea ice images that were being update daily by Benoit Legrassy (CSIRO). The Master found these images very useful for navigation during the last few days of the transit, determining the position of the northern edge of the sea-ice and likely location of our most southern station.

The weather during the transit was relatively calm and we averaged 11-12 knots.

On the transit 12 Argo floats were deployed (see Table 1).

Wednesday 4 May – Sunday 8 May 2016

As *Investigator* approached the ice edge the outside air temperature decreased to sub-zero temperatures. We consulted with Steve Rintoul, Nathan Bindoff and Mark Rosenberg regarding strategies to mitigate freezing of CTD sensors and Niskin bottles. Following their advice, we will dried the conductivity sensors prior to deployment and opened the CTD door at the last possible moment.



We started CTD operation on CTD Winch 2 (outboard) and using CTD 20. We arrived at our first CTD (CTD 002) location (169 59.97 W, 66 20.08 S) at 8pm. Air temperature was -17.0C and decreasing. Condition were calm with less than 10 knots of wind. The CTD was deployed smoothly and the station completed successfully. The CTD upon removal from the water snapped froze – frozen sensor, tubing, and spigots. In the CTD room pipes (freshwater and salt) and the Helium crimping equipment froze during the duration of the door being open. We had to use a hair dryer to defrost the niskin spigots. Once the pipes and taps defrosted water leaked from cracks and all water valves to the CTD room were isolated. The CTD water samplers were very cold by the end of sampling. No damage was done to the CTD sensors, Niskins, or rosette.

The current configuration of the CTD room is not suitable for sub-zero CTD operations. A heater needs to added to ensure we raise the room above 0^{o}C.

After CTD 002, we continued south in anticipation of a CTD station further south. During the transit the wind increased to 40 knots and spray froze when hitting the ships superstructure. Sea-ice was seen on the surface. At 5am Thursday morning we decided with sea-ice in the area and strong winds it was unlikely we would be able to complete a CTD station further south. Therefore, we turned north and CTD 002 became our most southern CTD station.

CTD stations, 003, 004, 005 and 006 were completed without incident, although CTD 005 was undertaken in a confused sea. We completed our first mechanical re-termination at the end of station 005.

On Saturday (7 May) as we prepared to deploy CTD 007 the CTD winch wire jumped the pulley and was jammed between the winch cheeks. The wire required an electrical re-termination. We moved to CTD Winch 1 in an attempt to continue CTD operations.

At 350 m the CTD deck box sounded an alarm indicating loss of communication with the CTD. The deck box was turned off and the rosette was returned to the deck. Upon recovery the wire was tested and found to be damaged. We now need to re-terminate both CTD wires. With both CTD wires requiring re-termination we were unable to undertake CTDs for 24 hours. Given the delay we abandoned CTD 007 and made a slow transit to CTD 008. During the transit, we tested the deck box using the spare CTD; It tested okay. The fuses were examined and they had not blown. Water was found in both cables and over 500m was cut from each cable.

On Sunday as we prepared the CTD (CTD 008) ready for deployment the deck unit failed and was turned off. On inspection the transformer on the deck unit had failed and CTD instrument (CTD 20) was now faulty. The problem was sourced to an incorrect fuse in the unit which was corrected.

Working on CTD winch 2 and the spare CTD (CTD 22) we completed CTD 008 and 009.

CTD 010 was deployed but at 2000 m the deck box alarmed and blew a fuse. The broken fuse was replaced but blew immediately. The CTD/rosette package was recovered. Upon recovery we found that the electrical termination failed. We now have to re-terminate CTD winch 2.

For CTD 011 we moved to the CTD winch 1 and completed the abandoned station 10. No LADCP data were taken as the connecting cable was broken. The MNF electronic technicians repaired the CTD 20 unit. We now have 2 working CTD units.

At the end of most of these stations either an Argo or SOCCOM float was deployed.

Monday 9 May – Sunday 15 May 2016

CTD 012 and 013 were completed. On CTD 014 at 3300 dbar on the up-cast we lost communication to CTD. The station was aborted and we hauled the CTD/rosette back to the surface. Another broken electrical termination. Only bottom water samples were collected.

We now have another 24-hour delay as both CTD winch wires require an electrical re-termination.

By Wednesday we were back in the water and completed CTD 015. On CTD 016 we again lost communication to the CTD package at 7 dbar on the downcast. We abandoned the station.

We switched to CTD winch 2 (outboard) and deployed the wire with a 35 Kg weight. The electrical termination had failed on return. Now have two winch cables that need re-termination. We moved to cold terminations. These take 2-3 hours to be completed.

CTD 017 was further delayed due to weather (12 hours). The station was eventually completed. Niskin bottles 2-7 failed to close. Signal to close was sent but no reply received. Alarm sounded as CTD/rosette was returned to deck when a cable distortion went over a sieve. Electrical termination had failed on deck.

For CTD 018 we moved to CTD winch 2 (cold mould) and completed the station, however the bottles failed to fire; No bottle samples were collected. A CTD cable was changed and the carousel tested, bottle non-firing issue was fixed.

Moving to cold mould electrical termination increased the success rate of CTD stations. During Saturday we completed CTD stations 019 through to 022.

We had further issues at CTD 023. We had two attempts at starting the station. On the first the CTD deck unit alarmed just as the rosette entered the water. The rosette was recovered and all electrical connections were tested; these were all working. We then tested all connections by spraying water on the CTD rosette with tension on the wire. Everything seemed fine. We then re-deployed the package and it again failed on entry to the water, just as the mechanical termination entered the water. We recovered the CTD, went to breakfast to decide what to do next. It was decided to move the distorted wire past the mechanical termination and coil this excess wire within the rosette frame. Thus the new mechanical termination was on an undamaged section of wire. We also found that we had lost a nut that holds the package to the wire, on inspection a few other bolts were hanging on by one thread. The crew then checked and tightened all nuts and bolts on the rosette frame. We re-deployed the CTD with the damaged wire past the mechanical termination. The CTD deck box did not alarm and we proceeded with the stations. The wire had no kinks on return, but the deck box did alarm as we came back on board. The cable tested positive, so a new mechanical termination was completed with more damaged wire coiled inside the CTD frame.

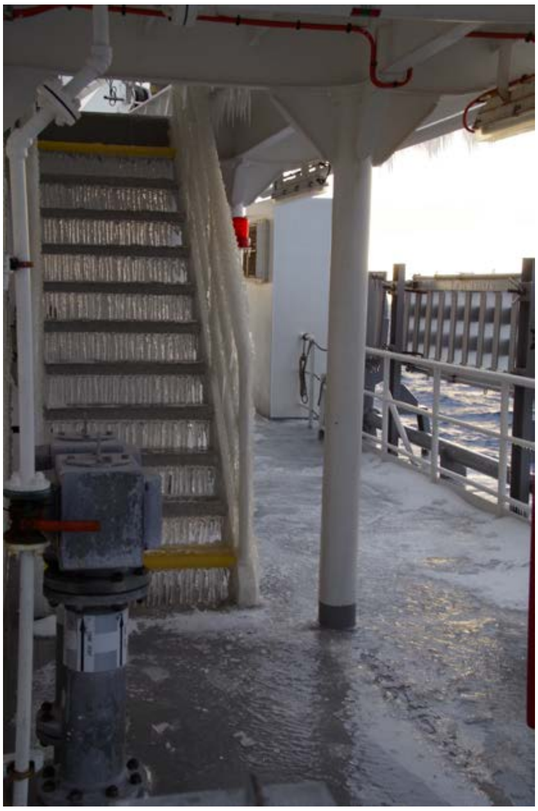
Continuing to take these mitigation steps – moving wire through the mechanical termination and re-terminating using cold mould - we were able to complete CTD 023 -025. We lost approximately 93 hours due to wire issues.

Monday 16 May – Sunday 22 May 2016

This was our most successful week, with the mitigation steps, we averaged 4 CTD stations a day. We completed 18 CTD stations – CTD 026 - 043. We added to our mitigation steps, rotating the CTD anti-clockwise, some times 3-4 times, at the end of a station before landing the rosette on the deck. This action was implemented given that LACDP initial processing showed that the CTD was rotating during the cast.

With the CTD situation somewhat under control, we had a chance to begin to look at the data. The nutrient data was compared to the previous occupations of this section. The LADCP was processed using the CTD and SADCP data. This showed that there was a significant difference between the headings of the downward and upward ADCPs. Using software developed for ADCP processing (moorings) we determined that the lower ADCP unit heading was noisy and “wanders” significantly during a cast. We have implemented a LADCP processing that uses only the up-ward ADCP heading data.

Saturday and Sunday saw our first significant weather delays. Our planned CTD station at 45 56.41 S, 171 49.84 W was not attempted as the wind was 35-40 knots and we are running out of time. We decide to move to the next station. We expect the front to slide southeast and have improved weather conditions at the next station. We continued to transit to 45 33.52 S, 172 16.71. We arrived at this location at midnight and the wind was still 45-50 knots. We decided to heave-to and wait out the weather. At 5am the wind was still averaging 40 knots. We had a look at the weather forecast and the strong winds were predicted to continue for the next 6-10 hours. We decided to move to the next station at 45 10.57 S, 172 43.92 W.



We arrived at the station location and waited 1.5 hours for the wind to decrease. We started CTD 044 at 12:30. The station was completed and the wind speed had decreased to 15 knots. After completion of station 044 we decided to back-track south to pick up the CTD station at 45 33.52 S, 172 16.71 W. We examined the GRIB charts and decided that although the wind would increase as we moved south there was the chance of completing a station at the base of the Chatham Plateau. 1.5 hours into the transit the wind had increased to a mean of 35 knots and gusts over 40 knots. It was decided that we would be unable to complete a station further south. Thus we turned around and headed north. Unfortunately, we have missed stations at the based of the Chatham Plateau.

Station 045 was completed successfully.

Processing of CTD 040 LADCP data showed that the 150 kHz downward unit had a broken beam – beam 4. We have now implemented a 3-beam solution method

Monday 23 May – Tuesday 24 May

At CTD 046, the deck unit alarm sounded on deployment. The CTD was brought back on board. The cabling was checked and everything tested positive. The CTD was redeployed, alarm sounded again. The alarm is the bottom depth alarm. The property traces looked fine. It was decided to continue the station and move to CTD 20 at the next station. Large wire kinks were found on recovery of the CTD. We decided move to CTD winch 1 and re-terminate the wire (CTD winch 2).

At CTD 047, now using CTD 20, the pumps switched off at approximately 1200 dbar on the down-cast. Given the time constraints, we decided to continue the station. Pumps came on at approximately 1600 dbar, however the pump again turned off on the upcast. There were large kinks in the wire. A new CTD cable fixed the pump issue, however we required another cold mould re-termination.

Deployment of CTD 048 was delayed due to the short distance between stations and having to fault find the issues of pumps turning off and on, and re-terminate the wire. We were further delayed due to CAP computing issues.

These delays required constant re-planning of CTD stations. The delays resulted in the dropping of three planned station on the Chatham Rise (shallower than 1200 m) and two station on the northern slope of the Plateau. We hope leg 2, that has been provided with an extra 24 hours, will be able to complete the stations on the northern slope.

CTD 049 and 050 were successfully completed. Our final CTD station (050) was completed at 0830 on Tuesday morning. We then began our transit to Wellington.

In total we lost a total of 10 planned CTD stations on leg 1, of which two were due to the northward extent of sea-ice.

Investigator arrived in Wellington at 10am on May 27. Handovers began around midday and went until late afternoon. SOCCOM samples were removed from the vessel and shipped to Scripps for analysis.

Leg 2- Narrative by Susan Wijffels

Friday May 27

We left around 1230pm with a largely new science party and new marine crew. All of our 63 day'ers returned after a night ashore. Every one settled in, we ran the safety induction, muster and held a brief science/life-aboard briefing. Most started to move into watches.

Saturday May 28

We made quick headway downwind and swell towards our first station, making up some time. We trained the watches on water sampling techniques and the underway systems. We also had many discussions on managing or mitigating against the wire damage experienced on leg. These centred around:

1. Preventing zero tension events that might lead to a snap and high-load sequence – this means only lowering slowly in the upper few 100ms on the downcast. We discussed this with the bosun (Graham) and winch drivers and need to manage these low tension events in big sea states.
2. Measuring the rotation of the package via a newly installed Motion Reference Unit (MRU) and attempting to compensate the observed rotation on retrieval by spinning the package.
3. In cases where the ship is rolling on station, reduce the CTD-boom extension to reduce the swell effect on the tensions
4. Trying heave compensation during a down cast to see if that helps reduce tension shocks.

Sunday May 29

CTD 51 was started around 4am and proceeded smoothly in a fairly mild sea state. The acquisition went smoothly. Sampling took a while as the watches are still being trained, and many were down with sea sickness. CTD 52, 53 and 54 went relatively smoothly- though we noticed a few snap and load events in the building sea state. Many volunteers are out of action due to seas sickness and the DAP and SIT team, Bernie Heaney and I are assisting the watches.

Monday May 30

CTD 55 resulted in some kinks forming just above the frame. These were pulled through the mechanical termination and stowed inside the frame to avoid an electrical re-termination. We are firing the near surface bottle on the fly to reduce exposure to the surface waves. We realized the Boss Flourometer had been offloaded in New Zealand. We worked on finding the MNF flourometer to prepare it to be added to the frame.

CTD 56 After discussion and with the strong support of the ship's bosun, we decided to employ heave compensation on the downcast and lowered the speed to 50m/min. This will reduce exposure to a snap/load event during the downcast where drag is opposing gravity. Upcast was slowed to 50m/min until 2500db and then increased to 60m/min. Heave compensation was not used on upcast due to the danger of a bad wrap at the lay turnarounds at the drum ends. CTD station 57 we used HC at 60m/min, but with slow uphaul speeds out of HC. A SOCCOM float was deployed in dirty conditions over the aft port corner. MNF's Chelsea Aquatracker was fitted to the 9plus on channel 6.

CTD 58 revealed new kinks developing. As the station was delayed as a squall came through we pulled the wire through the mechanical termination again. The cast proceeded fine but again with slower wire speeds, which is driving an unsustainable schedule slip.

Tuesday May 31

CTD 59 Tried increasing downcast wire speeds with HC on, and successfully used HC during the bottom approach. Upcast speeds were kept to 50m/min until 2500db and then increased to 60m/min.

CTD 60 Used HC during the upcast but with a switch off during the drum end wraps. The deck team worked this well, diligently working with the CTD watch to monitor the wraps on the drum. CTD61 – Successful and operated as above. SOCCOM float deployed.

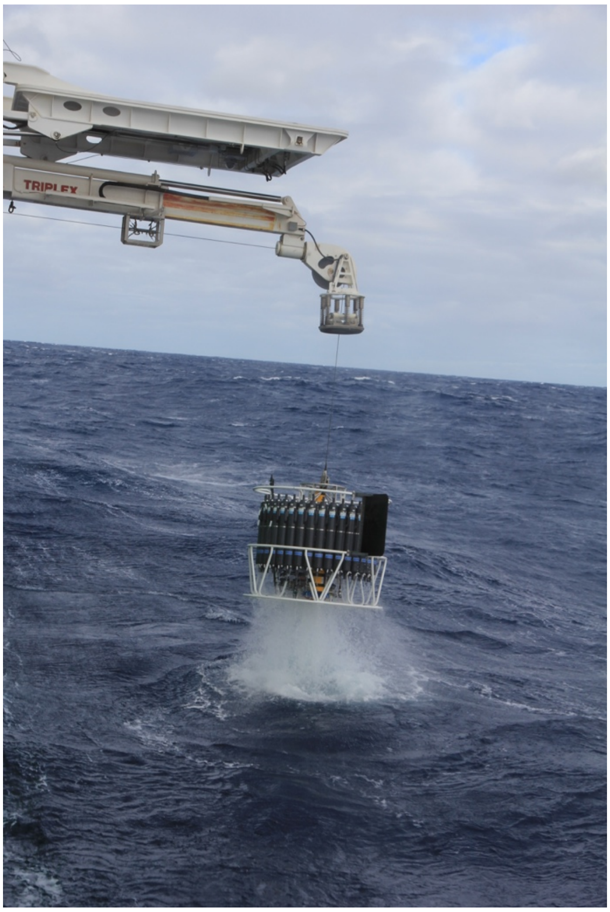
Wednesday June 1

CTD 62 completed as above.

During CTD 63 after firing eight bottles, the deckbox fuse blew at 2900db and we lost communication with the 9plus. We retrieved the CTD and frame without communication. When the frame came aboard and the wire de-tensioned, many spools sprung loose on the drum indicating the cable was under high torque, which agreed with the MRU readings showing the package was continuously rotating clockwise (3-10) times per upcast. Subsequent diagnosis on the wire shows that it has a short 4km from the termination. This essentially makes this winch/wire unusable for the rest of our voyage. I sent out a call to international colleagues to ask for advice on managing wire damage. The response was excellent from our GO-SHIP collaborators. Suggestions included minimizing snap/shock load events, putting on a vane to reduce rotation and thus increased torqueing of the wire, and streaming out the wire with a swivel and weight to de-torque the cable.

The mechanical termination was moved to CTD Winch 1. The system tests all looked OK.

CTD 64. As we spooled out this new cable we came across many messy wraps and gaps on the drum near the end plates. During the upcast this required careful spooling to ensure the cable lays went on properly, reducing the effective wire speeds considerably. HC was used on both the up and down casts (but switched off when the cable lay is at the drum ends). SIT team and ship's engineers start work on manufacturing a vane from material we sourced from NIWA in New Zealand.



Thursday June 2

CTD 65 - 67. Went smoothly except for stops for minor wrap adjustments – we are now in HC and doing up and down casts at 60m/min. Both CTD watch and deck crew are monitoring the winch drum. Frame continues to rotate.

Friday June 3

CTD 68 – completed without incident though the frame continues to rotate. A vane constructed by SIT staff and the ship's engineers was fitted to the package. As a test we deployed down to 500db and back up, to confirm that it worked as hoped. On the full cast the vane very effectively prevented any rotation of the frame. CTD 70 – 71 were completed. Several CAP crashes occurred and there were several incidents of having to spool back out and in again on the upcasts to prevent a bad lay on the drum.

Saturday June 4

CTD 72-74 – we attempted to upgrade the software on Winch 1 to the same version as Winch 2, but this has failed. There is a continuing need to stop and adjust spooling during these casts, costing between 5-20 minutes per cast.

Sunday June 5

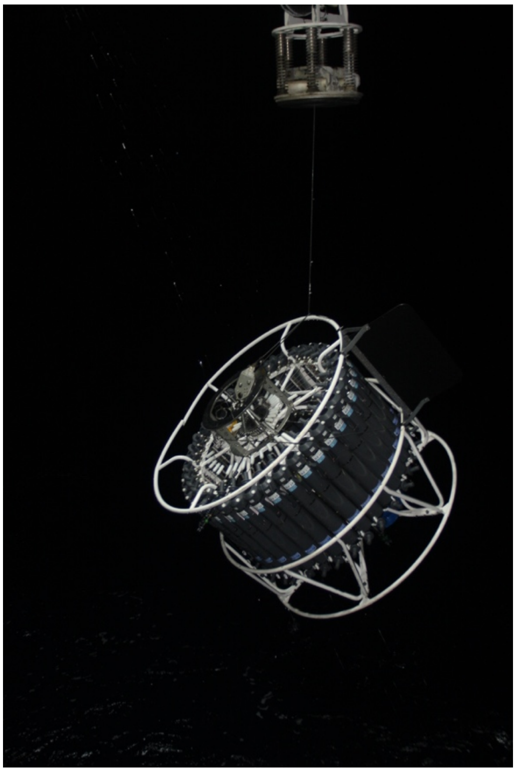
CTDs 75-78 completed. Around three spool adjustments per cast with both deck team and CTD watch monitoring the cable wraps carefully.

Monday June 6

CTDs 79-81 completed as above. Schedule slowly sliding behind.

Tuesday June 7

CTD 82 was completed as above. CTD 83 proceeded smoothly. At 1103am, just after firing the second bottle on, the winch brake failed completely and the cable started to spool out violently at over 200m/min. In a few minutes our CTD frame was on the sea floor. By the time the Chief Engineer had managed to manually screw down the break band at least a further 1000m of cable was also payed out. The ship's crew then put in a mammoth effort over the next 36 hours to retrieve the cable and rosette.



Tuesday June 8

Ongoing activities to prepare for the retrieval of the frame. This included stoppering off the cable with 3 Chicago clamps, keeping the ship hovering over the package, stripping and rebuilding the CTD winch break, testing its efficacy and then checking the winch gearbox, motor and controls.

Once the winch was tested and ready, tension was transferred back to the winch drum, and uphaul began slowly at 10-20m/min. There were some moments with large tension spikes just before we lofted the wire off a rough bottom, and then the tension returned to what we would normally expect for the frame on uphaul. Once we were certain the frame had been lifted off the sea floor, we powered on the deckbox, and the CTD started sending data as usual. This turned out to be remarkable given the wire damage.

A slow agonizing retrieval near 20-30m/min ensued, with the frame rotating very rapidly. A few hundred meters above the termination, there were knots in the conducting cable (which took hours to unsnarl and feed through the blocks) and the wire was wrapped around the package on retrieval. The frame was back on deck around 410am

Once on deck we could see the top guard rail of the frame was snapped, but amazingly no Niskins were smashed. Even the upper LADCP, which was pushed over, remained functional. As far as we can tell nearly all our sensors had no calibration shift. The ships engineers and deck crew rebuilt and tested the winch break, checked the system and readied it for use. If this had failed we would have had to move to the 24 bottle frame and coring boom out of the shelter deck. Just in case, this backup system was set up in the shelter deck area.

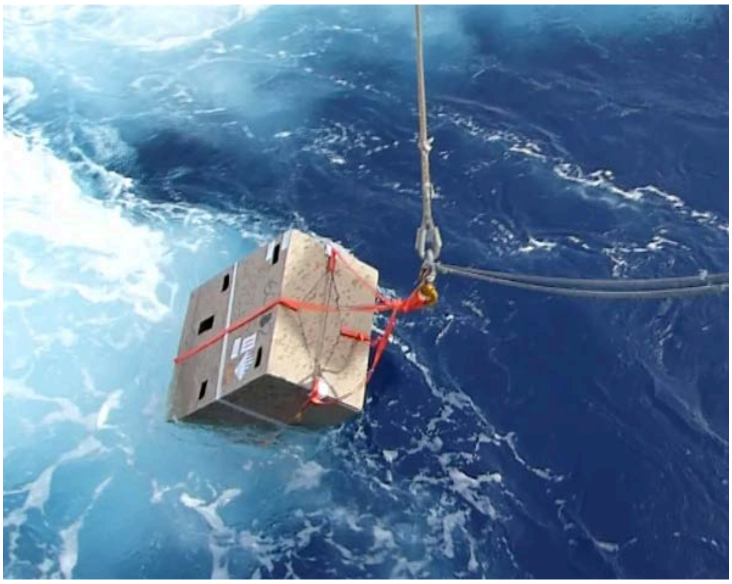
The kinked and knotted cable was cut away and then we spooled out the cable with a small weight and swivel to help de-torque it. This took another 11.5 hours to complete, with the uphaul very slow due to frequent winch alarms constantly shutting down power and interrupting the operation. An entire 1.5 hours was lost trying to diagnose the source of these somewhat random winch alarms. Rather than continue to lose time, once the wire was fully on board, we moved the ship 15nm, which merged two stations and resulted a 45nm spacing. The transfer of the newly terminated cable to the CTD and frame, and the set up for the next station by the science team was fast. The LADCP was mounted on a bracket from the 24 bottle frame, and as a result it blocked lanyards from two Niskins, so these were left off.

Tuesday June 9

CTD 85 was a merger of two stations resulting in 45' separation at this part of the section. The rebuilt winch seemed to work reasonably well, though many stops and rewinds were needed. The upward looking LADCP was remounted on its old frame which had been repaired by the ship's engineers. CTDs 86-87 proceeded well, with 2-3 spooling adjustments. Upcast speeds are slowed to keep tensions below 2.1-2.2T at depth but were sped up to 70m/min above ~3000db to make up time. This seems to work well. A request to the MNF for additional ship time to help compensate for the time lost to date due to the winch break failure was successful with the granting of an additional 24 hours to this leg.

Wednesday June 10 – Saturday June 11

CTD 88-95 proceeded smoothly with 2-3 spooling adjustments. The secondary conductivity sensor continued to develop an anomalous salty bias in the upper 1000m (both compared to the bottle salts and the primary channel). Swapped in SBE C4 SN 4718 and checked the line plumbing. A deep SOLO was deployed gently in its box after station 88.



Sunday June 12

CTDs 94-95 were completed. The new C cell did not fix the anomalous behaviour of the secondary channel. SIT fitted a new pump to that line. We continue to require close attention to cable lays on the drum by both the deck crew and the CTD watch. Each station has several stops to adjust the spool or to backwind to correct a bad lay. Random winch alarms also slowed down the stations. We realigned the flow path on both 9plus channels to go from deep to shallow.

Monday June 13 - Hump Day

CTDs 96-100 proceeded as above. Further delays occurred due to the CTD door opening. A Hump Day meeting was held. We could see the lights of Nuie from the bridge.

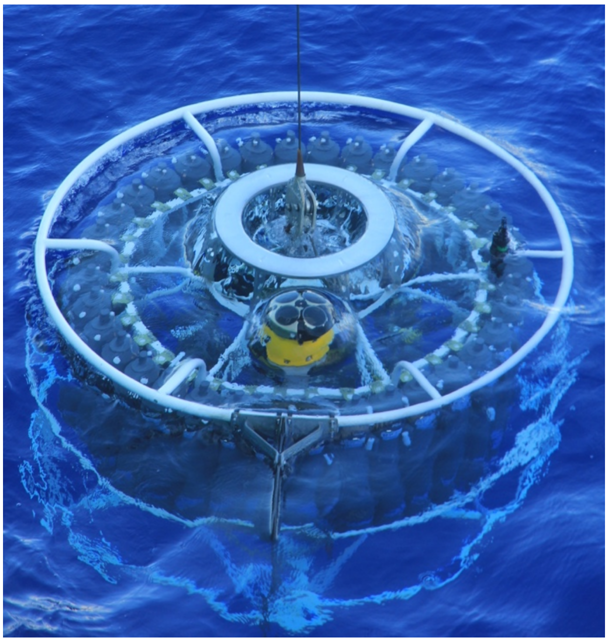
Tuesday June 14

We continue to search for the causes of the bad conductivity in the secondary channel. After CTD 101, we pulled the 9plus forward to give greater clearance of the rosette frame struts. This did not solve it in the data from CTD 102.

Wednesday June 15

CTD 103. We decided to try the other 9plus (CTD #22 SN 1324) to ensure we had a useable secondary C trace. However at 300db the oxygen values corrupted and then the deckbox alarmed. Power was shut down and the frame was retrieved. On inspection it was found that the 9plus had leaked. We had to switch back to CTD #22 (SN 552). The aborted cast data was parked and a new station 103 was completed. It is likely that we have no spare 9plus on board at this point.

CTDs 104-105 completed. The old square vane was put back on as the new version was not preventing rotation as well.



Thursday June 16

CTD 106-111completed as normal (2-3 spooling adjustments). As we are passing across a deep ridge we have close station spacing. The station turnarounds are fast and this is tough on the chemistry laboratories. After CTD 110 we changed out the oxygen sensor (SN 3195).on the secondary line, based on a suggestion by Dave Murphy at SeaBird.

Friday June 17

CTDs 112-114 completed. Before 113, Ben Baldwin suggested trying yet another C cell in the secondary line. This fixed the problem! We had, in fact, two bad C-cells, one after the other! It is a relief to have a backup channel as there is more sea snot and other fouling turning up on the frame and in the bottles.

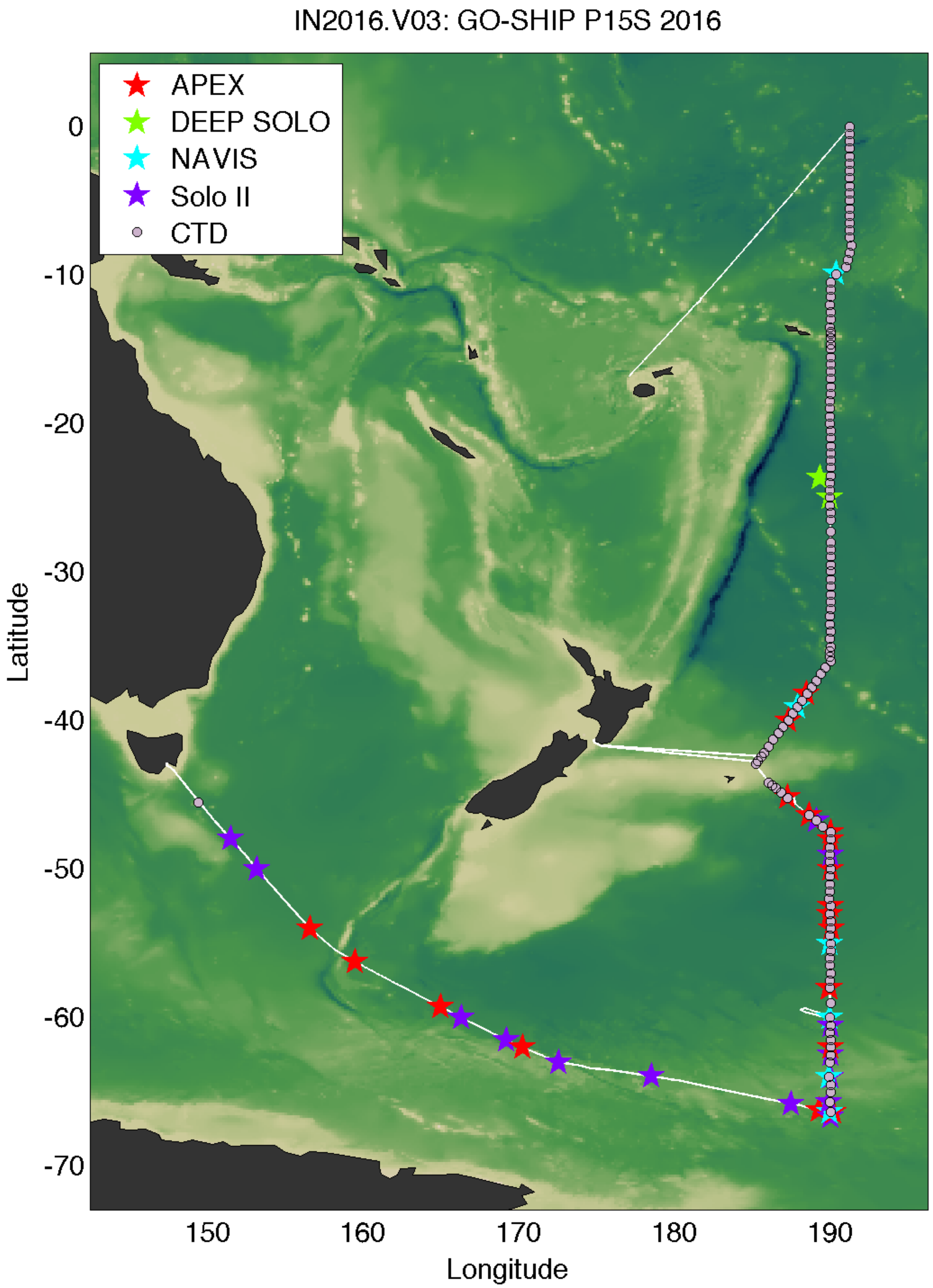
Saturday June 18 – Sunday June 24

CTDs 115 – 141 were completed without incident in hot steamy conditions. The deck crew became very efficient at minimizing spooling stops while still closely monitoring the cable and winch drum, and the deployments and retrievals were honed down to an efficient operation between the deck, bridge and science crews. Faster upcast speeds above ~3500db also helped us bank time. In this way we were able to occupy nearly all of the planned stations. A great achievement given the challenges we faced at the start and the near loss of our primary cable and instrument package.

Summary

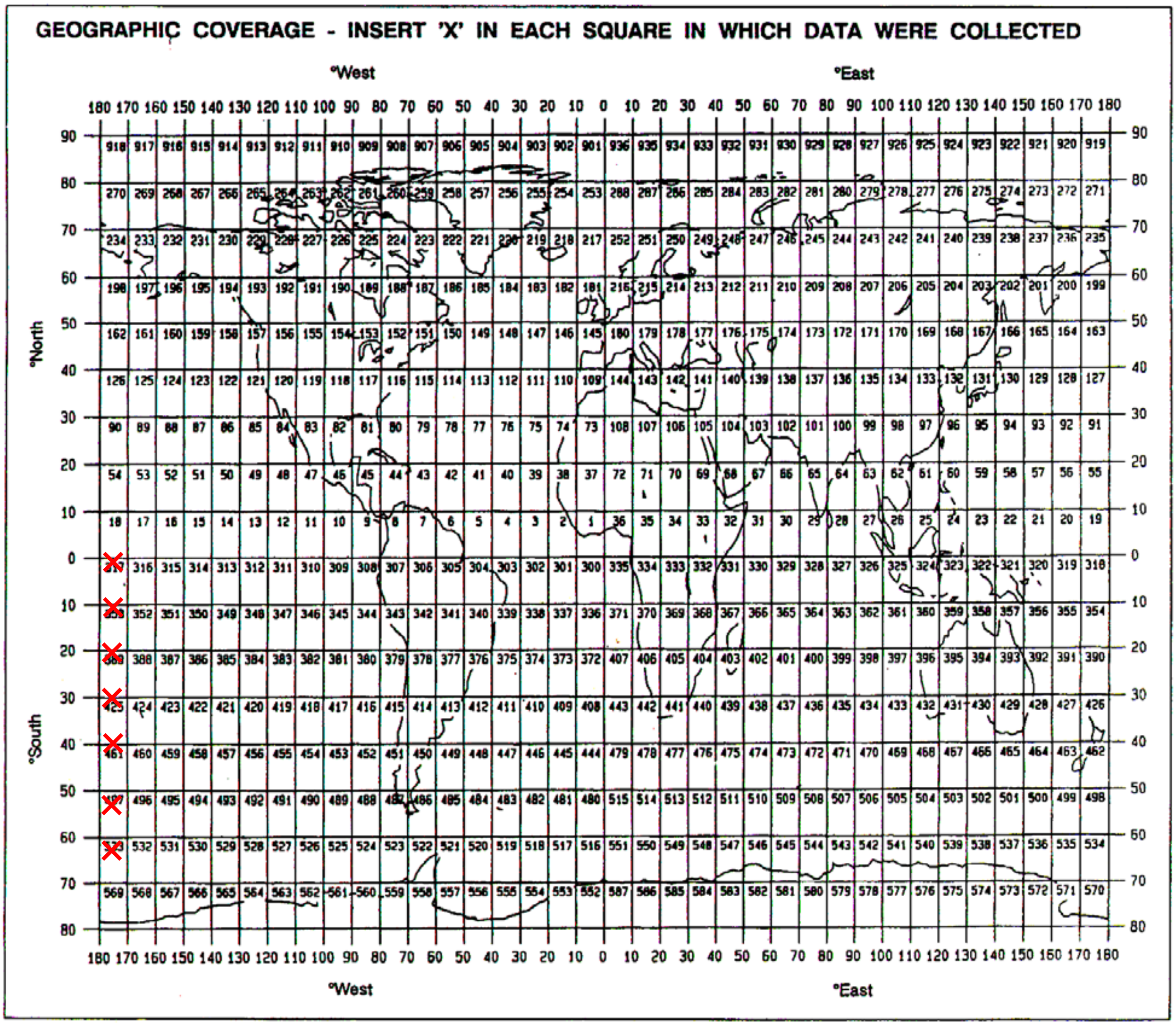
Despite the challenges we were able to overcome most problems and complete the bulk of our planned work. The quality of the data collected is very high, particularly from the chemistry teams who have delivered an excellent and very high resolution (due to the 36 bottle sampling) data set. We are confident that this occupation of P15S has uncovered clear and ongoing changes to the deep ocean heat and carbon content, and chemistry. The novel genomic and production sampling coordinated by Eric Raes will likely deliver some ground-breaking insights. The mixing information taken via the shear measured by the LADCP, sADCP and fine and microscale properties via the chi-pods and CTD will also be very insightful and unprecedented along this line.

Voyage Track



Marsden Squares

Move a red "x" into squares in which data was collected



Moorings, bottom mounted gear and drifting systems

Table 1: Float details in order of deployment. All deployments have code: D06

Institutions/PIs are as follows:

SIO = Scripps Institution of Oceanography -PI – Dean Roemmich

SOCCOM = Southern Ocean Carbon and Climate Observation and Modelling experiment – PI Lynne Talley

UTAS – University of Tasmania, PI - Helen Phillips and Pete Strutton

CSIRO PI – Susan Wijffels.

Deploy Order	Hull No.	Date/time	Longitude	Latitude	Type	Owner
1	8390	27/4/2016 22:04	151 27.29' E	47 57.20' S	Solo II	SIO
2	8447	28/4/2016 04:33	152 21.20' E	49 59.90' S	Solo II	SIO
3	7741	29/4/2016 12:50	156 33.97' E	54 0.03' S	APEX	CSIRO
4	7738	30/4/2016 04:04	159 28.82' E	56 14.40' S	APEX	CSIRO
5	7742	1/5/2016 01:50	164 59.00' E	59 14.90' S	APEX	CSIRO
6	8352	1/5/2016 07:09	166 16.19' E	60 0.06' S	Solo II	SIO
7	8448	1/5/2016 17:37	169 10.20' E	61 31.00' S	Solo II	SIO
8	7743	1/5/2016 21:14	170 14.04' E	62 00.07' S	APEX	CSIRO
9	8454	2/5/2016 04:48	172 33.76' E	63 0.36' S	Solo II	SIO
10	8455	3/5/2016 06:47	178 30.22' W	64 45.00' S	Solo II	SIO
11	8456	4/5/2016 01:30	172 29.70' W	65 47.20' S	Solo II	SIO
12	7740	4/5/2016 5:47	170 43.41' W	66 11.79' S	APEX	CSIRO
13	8457	4/5/2016 17:20	169 58.60' W	66 39.30' S	Solo II	SIO
14	F0568	5/5/2016 06:25	170 03.95' W	65 39.84' S	NAVIS	SOCCOM
15	7739	4/5/2016 21:23	169 49.30' W	66 20.50' S	APEX	CSIRO
16	F0570	4/5/2016 12:10	170 0.10' W	66 20.51' S	NAVIS	SOCCOM
17	8462	5/5/2016 06:20	170 03.95' W	65 39.84' S	Solo II	SIO

Deploy Order	Hull No.	Date/time	Longitude	Latitude	Type	Owner
18	8463	6/5/2016 12:56	169 58.50' W	63 59.70' S	Solo II	SIO
19 – CTD 6	F0565	6/5/2016 07:42	170 04.30' W	64 0.00' S	NAVIS	SOCCOM
20 – CTD 9	8464	8/5/2016 09:22	169 59.82' W	62 29.71' S	Solo II	SIO
21 – CTD 11	9761	8/5/2016 18:35	169 59.30' W	61 59.90' S	APEX	SOCCOM
22 – CTD 15	F0571	11/5/2016 15:37	170 01.10' W	59 59.70' S	NAVIS	SOCCOM
23	8460	10/5/2016 02:46	169 59.20' W	60 30.40' S	Solo II	SIO
24 – CTD 19	9265	13/5/2016 16:10	170 0.50' W	57 59.80' S	APEX	SOCCOM
25 – CTD 25	F0566	15/5/2016 15:18	170 0.70' W	55 0.70' S	NAVIS	SOCCOM
26 – CTD 27	7718	16/5/2016 07:10	169 56.04' W	53 59.15 S	APEX	UTAS
27 – CTD 29	7719	16/5/2016 21:31	170 0.92' W	52 59.92' S	APEX	UTAS
28 – CTD 29	7789	16/5/2016 21:27	170 0.87' W	53 00.06' S	APEX	UTAS
29 – CTD 31	9660	17/5/2016 11:57	170 04.20' W	57 59.70' S	APEX	SOCCOM
30 – CTD 30	7612	17/5/2016 04:51	169 59.30' W	52 29.70' S	APEX	CSIRO
31 – CTD 35	9632	18/5/2016 16:27	169 59.50' W	50 0.50' S	APEX	SOCCOM
32	8453	18/5/2016 06:32	170 0.00' W	49 0.00' S	Solo II	SIO
33 – CTD 39	9634	19/5/2016 20:11	169 59.30' W	47 59.16' S	APEX	SOCCOM
34 – CTD 40	7611	20/5/2016 03:56	169 58.90' W	47 29.03' S	APEX	CSIRO
35 – CTD 42	8465	20/5/2016 18:14	170 54.60' W	46 42.80' S	Solo II	SIO
36- CTD 43	9762	21/5/2016 05:23	171 22.20' W	46 19.80' S	APEX	SOCCOM
37 – CTD 44	7610	22/5/2016 04:11	172 43.90' W	45 10.50' S	APEX	CSIRO
38 – CTD 57	9630	30/5/2016 09:17	172 41.70' W	39 58.00' S	APEX	SOCCOM
39 – CTD 59	F0634	31/5/2016 00:43	172 07.55' W	39 04.13' S	NAVIS	CSIRO

Deploy Order	Hull No.	Date/time	Longitude	Latitude	Type	Owner
40 – CTD 61	9752	31/5/2016 15:03	171 30.98' W	38 11.09' S	APEX	SOCCOM
41 – CTD 88	6012	9/6/2016 22:46	170 0.13' W	24 57.53' S	DEEP SOLO	SIO
42 – CTD 92	6013	11/6/2016 05:16	169 99.38' W	22 98.93' S	DEEP SOLO	SIO
43 – CTD 120	F0632	18/6/2016 18:29	169 37.59' W	9 55.35' S	NAVIS	CSIRO

Summary of Measurements and samples taken

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list on last page	DESCRIPTION
	Sloyan/Wijffels	140	CTD		Full depth continuous profiles of temperature, conductivity, pressure, oxygen, flourescence, PAR, light transmission, scattering, temperature microstructure, velocity, and additional prototype measurements of temperature, pressure and conductivity.
	Sloyan/Wijffels	140	Niskin casts		With the above, discrete water samples were capture by 36 Niskin bottles per cast, and analysed by onboard laboratories for : nitrate, nitrite, phosphate, oxygen, silicate, and salinity.
	Tilbrook	140	Niskin		From a subset of the Niskins above, alkalinity, total dissolved inorganic carbon.
	Raes/Bodrossy	140	Niskin		From a subset of the Niskins above, microbial material was filtered and stored for later genomic analysis
	Warner/Bullister	140	Niskin		From a subset of the Niskins above, concentrations of CFC-11, CFC-12 and SF-6.
	Cowley/Wijffels	295	XBT drops		At some CTD stations, XBTs were dropped simultaneous with the downcast from 0-1000db.
	Sloyan/Downes	20	Niskins		From a subset of the Niskins between 66S and 42.73S
	Alroe/Brown		underway		Atmospheric Chemistry and Aerosols

Table 2. List of all CTDs completed.

Station	Start Time	End Time	Longitude	Latitude	Depth (m)
1	2016-04-27T04:00:32.472Z	2016-04-27T06:59:57.909Z	149.428	-45.497	4299
2	2016-05-04T08:44:01.018Z	2016-05-04T11:46:03.271Z	189.992	-66.332	3277
3	2016-05-05T03:20:41.153Z	2016-05-05T06:00:56.633Z	189.968	-65.662	3297
4	2016-05-05T13:20:24.907Z	2016-05-05T16:12:14.822Z	189.984	-64.995	2836
5	2016-05-05T21:45:09.215Z	2016-05-06T00:44:24.863Z	-170.003	-64.502	2348
6	2016-05-06T05:01:56.231Z	2016-05-06T07:28:53.065Z	189.958	-63.990	2807
8	2016-05-08T01:41:57.338Z	2016-05-08T03:16:23.764Z	189.968	-63.001	3046
9	2016-05-08T06:50:03.329Z	2016-05-08T09:11:46.453Z	190.008	-62.499	2539
10	2016-05-08T12:21:19.393Z		189.998	-62.001	3302
11	2016-05-08T15:35:30.046Z	2016-05-08T18:19:30.052Z	-170.004	-62.003	3360
12	2016-05-08T21:46:21.480Z	2016-05-09T00:50:36.208Z	189.998	-61.491	3470
13	2016-05-09T16:31:07.920Z	2016-05-09T20:32:56.941Z	189.988	-61.001	4483
14	2016-05-09T23:35:04.451Z		190.002	-60.500	3951
15	2016-05-11T11:51:23.283Z	2016-05-11T15:25:39.232Z	189.996	-60.000	3905
16	2016-05-11T18:40:15.773Z		-169.997	-59.498	4672
17	2016-05-12T20:00:04.319Z	2016-05-13T00:57:54.416Z	190.002	-58.994	4763
18	2016-05-13T04:41:15.570Z	2016-05-13T08:56:24.213Z	189.986	-58.491	5190
19	2016-05-13T12:19:34.718Z	2016-05-13T16:02:55.979Z	-170.010	-58.001	4432
20	2016-05-13T19:10:57.839Z	2016-05-13T23:12:03.895Z	189.994	-57.503	5019
21	2016-05-14T02:14:19.014Z	2016-05-14T06:32:38.209Z	190.003	-57.002	5078
22	2016-05-14T09:26:16.442Z	2016-05-14T13:52:34.294Z	189.991	-56.498	5090
23	2016-05-14T21:22:12.759Z	2016-05-15T01:56:39.672Z	-170.008	-56.002	5121
24	2016-05-15T04:41:21.185Z	2016-05-15T08:21:22.581Z	189.989	-55.514	4833
25	2016-05-15T11:08:33.772Z	2016-05-15T15:04:08.054Z	-170.002	-54.996	4843
26	2016-05-15T20:00:12.895Z	2016-05-15T23:57:17.125Z	189.997	-54.500	4831
27	2016-05-16T02:49:06.749Z	2016-05-16T06:58:44.984Z	-169.985	-53.996	5142
28	2016-05-16T09:54:08.128Z	2016-05-16T13:49:43.812Z	190.009	-53.501	5226

Station	Start Time	End Time	Longitude	Latitude	Depth (m)
29	2016-05-16T16:37:36.199Z	2016-05-16T21:18:15.385Z	189.989	-53.004	5220
30	2016-05-17T00:16:45.970Z	2016-05-17T04:29:21.431Z	189.990	-52.505	5161
31	2016-05-17T07:55:27.336Z	2016-05-17T11:47:36.463Z	189.922	-52.002	4913
32	2016-05-17T14:36:45.966Z	2016-05-17T18:37:59.133Z	189.984	-51.492	4732
33	2016-05-17T21:41:11.848Z	2016-05-18T01:43:26.543Z	189.990	-51.002	5248
34	2016-05-18T04:20:50.075Z	2016-05-18T08:27:37.658Z	190.004	-50.497	5052
35	2016-05-18T11:37:36.343Z	2016-05-18T16:13:53.136Z	190.007	-50.006	5384
36	2016-05-18T19:15:06.047Z	2016-05-18T23:30:41.690Z	189.983	-49.504	5220
37	2016-05-19T02:15:29.121Z	2016-05-19T06:14:07.361Z	189.996	-48.995	5262
38	2016-05-19T09:15:42.998Z	2016-05-19T13:13:36.267Z	190.000	-48.502	5298
39	2016-05-19T15:59:05.698Z	2016-05-19T19:58:50.793Z	190.007	-47.995	5310
40	2016-05-19T23:38:42.257Z	2016-05-20T03:49:04.376Z	190.009	-47.503	5379
41	2016-05-20T06:49:55.735Z	2016-05-20T10:51:27.177Z	-170.466	-47.109	5412
42	2016-05-20T13:48:55.354Z	2016-05-20T18:06:13.182Z	189.089	-46.719	5296
43	2016-05-21T01:16:15.147Z	2016-05-21T05:18:16.866Z	188.624	-46.326	5100
44	2016-05-22T00:21:11.875Z	2016-05-22T04:06:09.426Z	-172.736	-45.176	4665
45	2016-05-22T10:03:02.223Z	2016-05-22T13:20:54.416Z	-173.141	-44.835	3830
46	2016-05-22T16:39:56.631Z	2016-05-22T19:39:03.940Z	186.498	-44.525	3414
47	2016-05-22T23:35:42.231Z	2016-05-23T02:40:24.000Z	-173.746	-44.328	3102
48	2016-05-23T06:20:59.593Z	2016-05-23T08:21:23.577Z	186.063	-44.156	1892
49	2016-05-23T15:42:28.390Z	2016-05-23T17:01:48.390Z	185.215	-42.931	1057
50	2016-05-23T18:19:40.160Z	2016-05-23T19:55:49.608Z	185.347	-42.746	1584
51	2016-05-28T16:14:20.306Z	2016-05-28T18:54:54.994Z	-174.410	-42.400	2666
52	2016-05-28T21:29:48.241Z	2016-05-29T00:04:10.766Z	-174.250	-42.167	2866
53	2016-05-29T03:10:55.467Z	2016-05-29T06:24:11.017Z	186.052	-41.717	3116
54	2016-05-29T09:20:12.256Z	2016-05-29T12:48:15.813Z	186.363	-41.273	3292
55	2016-05-29T16:03:03.069Z	2016-05-29T19:21:51.563Z	186.668	-40.832	4178
56	2016-05-29T22:03:34.309Z	2016-05-30T02:04:33.488Z	186.976	-40.392	4592

Station	Start Time	End Time	Longitude	Latitude	Depth (m)
57	2016-05-30T04:47:48.414Z	2016-05-30T09:01:22.620Z	187.294	-39.958	4739
58	2016-05-30T12:14:08.948Z	2016-05-30T16:12:59.901Z	-172.414	-39.511	4776
59	2016-05-30T20:33:42.659Z	2016-05-31T00:29:43.153Z	187.883	-39.068	4861
60	2016-05-31T03:40:12.877Z	2016-05-31T08:05:21.954Z	-171.808	-38.628	4929
61	2016-05-31T10:54:53.015Z	2016-05-31T14:55:29.261Z	188.499	-38.187	4945
62	2016-05-31T17:39:55.439Z	2016-05-31T21:49:35.251Z	-171.201	-37.757	5028
63	2016-06-01T00:46:26.310Z		189.107	-37.307	5146
64	2016-06-01T07:45:39.848Z	2016-06-01T12:21:23.997Z	189.394	-36.871	5303
65	2016-06-01T15:00:17.591Z	2016-06-01T18:57:40.511Z	189.706	-36.450	5087
66	2016-06-01T21:52:55.429Z	2016-06-02T02:10:17.334Z	189.998	-36.002	5084
67	2016-06-02T07:11:03.580Z	2016-06-02T08:09:51.319Z	189.993	-35.680	4372
68	2016-06-02T10:05:44.979Z	2016-06-02T14:11:33.883Z	190.000	-35.337	4909
69	2016-06-02T17:14:37.276Z	2016-06-02T21:02:31.630Z	-169.995	-35.014	5264
70	2016-06-02T23:56:59.914Z	2016-06-03T04:17:59.232Z	-170.006	-34.505	5505
71	2016-06-03T06:55:55.109Z	2016-06-03T11:30:53.771Z	190.001	-34.012	5547
72	2016-06-03T14:09:08.789Z	2016-06-03T18:18:02.498Z	190.000	-33.501	5446
73	2016-06-03T21:12:13.104Z	2016-06-04T01:32:03.632Z	189.994	-33.000	5591
74	2016-06-04T04:25:07.081Z	2016-06-04T09:44:26.841Z	190.003	-32.500	5572
75	2016-06-04T12:27:50.130Z	2016-06-04T16:51:53.619Z	190.005	-32.002	5700
76	2016-06-04T19:44:17.163Z	2016-06-04T23:48:47.511Z	190.006	-31.499	5553
77	2016-06-05T02:23:03.598Z	2016-06-05T06:52:03.414Z	190.002	-31.023	5630
78	2016-06-05T09:36:11.341Z	2016-06-05T13:56:01.685Z	190.004	-30.512	5556
79	2016-06-05T16:40:46.912Z	2016-06-05T21:25:47.606Z	-169.993	-29.999	5437
80	2016-06-05T23:53:43.091Z	2016-06-06T04:03:12.410Z	190.000	-29.501	5226
81	2016-06-06T06:53:23.015Z	2016-06-06T11:36:55.821Z	-169.995	-29.006	5605
82	2016-06-06T14:09:24.425Z	2016-06-06T18:28:26.073Z	190.001	-28.503	5454
83	2016-06-07T15:26:50.239Z	2016-06-07T15:53:02.758Z	-169.991	-27.984	5264
84	2016-06-08T10:24:16.518Z	2016-06-08T15:05:51.923Z	190.002	-27.272	5464

Station	Start Time	End Time	Longitude	Latitude	Depth (m)
85	2016-06-08T19:10:59.700Z	2016-06-09T00:17:28.530Z	190.004	-26.495	5637
86	2016-06-09T02:51:15.437Z	2016-06-09T07:54:44.048Z	190.007	-26.000	5607
87	2016-06-09T10:31:19.445Z	2016-06-09T15:11:53.560Z	190.002	-25.509	5836
88	2016-06-09T18:06:23.701Z	2016-06-09T22:29:28.525Z	189.998	-24.999	5653
89	2016-06-10T01:42:23.191Z	2016-06-10T06:08:34.689Z	189.999	-24.501	5670
90	2016-06-10T09:20:24.195Z	2016-06-10T13:53:06.924Z	189.999	-24.000	5689
91	2016-06-10T16:52:43.422Z	2016-06-10T21:20:17.826Z	190.004	-23.505	5676
92	2016-06-11T00:26:01.170Z	2016-06-11T04:56:47.183Z	190.004	-22.999	5701
93	2016-06-11T08:02:25.191Z	2016-06-11T12:32:10.517Z	190.000	-22.501	5663
94	2016-06-11T15:30:50.404Z	2016-06-11T20:06:09.433Z	190.000	-22.002	5636
95	2016-06-11T22:53:18.177Z	2016-06-12T03:03:14.292Z	190.001	-21.503	5430
96	2016-06-12T05:52:54.391Z	2016-06-12T10:06:28.855Z	190.001	-20.998	5482
97	2016-06-12T12:47:03.016Z	2016-06-12T17:32:12.377Z	190.001	-20.503	5675
98	2016-06-12T20:14:10.806Z	2016-06-13T00:23:47.764Z	-170.002	-20.000	5341
99	2016-06-13T03:03:07.613Z	2016-06-13T06:49:42.210Z	189.997	-19.498	4915
100	2016-06-13T09:33:26.523Z	2016-06-13T12:14:50.468Z	189.942	-19.004	2989
101	2016-06-13T15:03:29.146Z	2016-06-13T18:54:55.035Z	189.998	-18.503	5269
102	2016-06-13T21:39:46.446Z	2016-06-14T01:15:19.931Z	190.000	-18.001	4919
103	2016-06-14T06:52:34.183Z	2016-06-14T10:30:37.926Z	189.999	-17.499	5037
104	2016-06-14T13:19:40.044Z	2016-06-14T16:51:38.553Z	189.998	-17.003	5005
105	2016-06-14T19:49:13.424Z	2016-06-14T23:24:11.140Z	-170.000	-16.504	5140
106	2016-06-15T02:10:16.869Z	2016-06-15T06:06:31.818Z	189.999	-16.003	5150
107	2016-06-15T08:54:05.975Z	2016-06-15T12:53:20.966Z	189.999	-15.498	5095
108	2016-06-15T15:32:26.391Z	2016-06-15T18:56:06.305Z	190.000	-15.005	4826
109	2016-06-15T20:52:44.028Z	2016-06-15T23:30:52.379Z	190.001	-14.666	3330
110	2016-06-16T01:40:00.371Z	2016-06-16T04:49:52.408Z	190.002	-14.282	3546
111	2016-06-16T06:43:49.711Z	2016-06-16T09:24:24.872Z	-169.999	-13.972	2972
112	2016-06-16T11:14:01.550Z	2016-06-16T14:26:37.400Z	-169.999	-13.819	4338

Station	Start Time	End Time	Longitude	Latitude	Depth (m)
113	2016-06-16T16:18:09.474Z	2016-06-16T19:47:25.972Z	189.998	-13.504	4888
114	2016-06-16T22:54:35.623Z	2016-06-17T02:30:24.514Z	190.001	-13.000	4980
115	2016-06-17T05:22:04.447Z	2016-06-17T09:01:31.046Z	-169.999	-12.499	5012
116	2016-06-17T11:45:19.226Z	2016-06-17T15:35:37.121Z	189.997	-11.998	5097
117	2016-06-17T18:25:04.949Z	2016-06-17T21:58:04.975Z	-169.999	-11.496	5069
118	2016-06-18T00:37:17.771Z	2016-06-18T04:30:02.323Z	190.000	-11.001	5135
119	2016-06-18T07:22:02.899Z	2016-06-18T10:47:57.099Z	190.001	-10.500	4878
120	2016-06-18T14:33:07.577Z	2016-06-18T18:21:06.416Z	190.371	-9.925	5227
121	2016-06-18T22:41:57.912Z	2016-06-19T02:48:28.206Z	191.002	-9.499	5357
122	2016-06-19T05:43:59.835Z	2016-06-19T09:22:06.274Z	191.125	-8.997	4891
123	2016-06-19T12:09:30.173Z	2016-06-19T16:06:03.387Z	191.251	-8.495	5182
124	2016-06-19T18:58:14.874Z	2016-06-19T22:39:57.802Z	191.384	-8.001	5212
125	2016-06-20T01:21:14.743Z	2016-06-20T05:22:17.796Z	191.249	-7.501	5287
126	2016-06-20T08:06:41.515Z	2016-06-20T12:15:06.408Z	191.249	-7.000	5676
127	2016-06-20T14:56:28.342Z	2016-06-20T18:58:25.358Z	191.251	-6.502	5553
128	2016-06-20T21:39:59.661Z	2016-06-21T01:50:54.802Z	191.249	-6.000	5679
129	2016-06-21T04:34:11.165Z	2016-06-21T08:39:59.859Z	191.250	-5.502	5476
130	2016-06-21T11:17:38.778Z	2016-06-21T15:18:39.517Z	-168.750	-5.000	5583
131	2016-06-21T17:50:18.275Z	2016-06-21T21:47:59.558Z	191.250	-4.501	5555
132	2016-06-22T00:21:47.029Z	2016-06-22T04:27:36.064Z	191.249	-4.001	5178
133	2016-06-22T07:06:59.058Z	2016-06-22T10:53:32.647Z	191.250	-3.502	5023
134	2016-06-22T13:38:31.916Z	2016-06-22T17:25:35.631Z	191.249	-3.000	5388
135	2016-06-22T20:10:50.573Z	2016-06-22T23:53:22.984Z	191.250	-2.499	5346
136	2016-06-23T02:35:31.797Z	2016-06-23T05:19:52.127Z	191.250	-2.001	3413
137	2016-06-23T08:09:26.337Z	2016-06-23T12:30:51.322Z	191.251	-1.501	5926
138	2016-06-23T15:14:59.409Z	2016-06-23T19:24:07.539Z	191.250	-1.001	5803
139	2016-06-23T22:08:54.069Z	2016-06-24T02:01:32.511Z	191.250	-0.501	5513
140	2016-06-24T04:55:31.999Z	2016-06-24T09:09:54.961Z	191.250	-0.002	5628

Personnel List

Leg 1

	Name	Organisation	Role
1.	Don McKenzie	CSIRO MNF	Voyage Manager
2.	Lloyd Fletcher	Doctor	Aspen Medical
3.	Bernadette Sloyan	CSIRO	Chief Scientist
4.	Kate Berry	CSIRO	Carbon Team
5.	Abe Passmore	CSIRO	Carbon Team
6.	Christine Rees	CSIRO MNF	Hydrochemist
7.	Erik Van Ooijen	CSIRO	Carbon Team
8.	Eric Raes	U. WA	Bacteria/Genomics
9.	Craig Neill	CSIRO	Carbon Team
10.	Kelly Brown	CSIRO	Hydrochemist
11.	John Church	CSIRO	CTD Watch Leader
12.	Ian McRobert	CSIRO MNF	Electronics
13.	Rod Palmer	CSIRO MNF	Electronics
14.	Bonnie Chang	U. Washington	CFC
15.	Dave Wisegarver	NOAA PMEL	CFC
16.	Stephen Tibben	CSIRO MNF	Hydrochemist
17.	Anoosh Sarraf	CSIRO MNF	Data Processing
18.	Steven Van Graas	CSIRO MNF	Data Processing
19.	Matt Boyd	CSIRO MNF	GSM
20.	Peter Hughes	CSIRO MNF	Hydrochemist
21.	Taha Cowen	U. Tasmania	CTD watch
22.	Madi Rosevear	U. Tasmania	CTD watch
23.	Tobias Aldridge	U. Tasmania	CTD watch/iXblue PHINS INS
24.	Hayden Martin	ANU	Carbon Team
25.	Paul Sandery	U. Tasmania	CTD watch
26.	Rodrigo Gurdec	JCU	CTD watch
27.	Nicole Hellessey	U. Tasmania	Bacteria/Genomics
28.	Swan Sow	CSIRO	Bacteria/Genomics
29.	Nic Pittman	U. Tasmania	CTD watch
30.	Joel Alroe	QUT	Atmospherics

Leg 2

	Name	Organisation	Role
1.	Steve Thomas	CSIRO MNF	Voyage Manager
2.	Susan Wijffels	CSIRO	Chief Scientist
3.	Ben Baldwinson	CSIRO MNF	Electronics
4.	Will Ponsonby	CSIRO MNF	Electronics
5.	Hugh Barker	CSIRO MNF	Data Processing
6.	Stew Wilde	CSIRO MNF	Data Processing
7.	Bernie Heaney	CSIRO MNF	GSM
8.	Ann Thresher	CSIRO	CTD Watch Leader
9.	Mark Rosenberg	U. Tasmania	CTD Watch Leader
10.	Esmee Van Wijk	CSIRO	CTD watch
11.	Yue Hau Li	U. Tasmania	CTD watch
12.	Asha Vijayeta	Monash U.	CTD watch
13.	Maija Kaipio	U. Auckland	CTD watch
14.	Edward King	CSIRO	CTD watch
15.	Mainak Mondal	ANU	CTD watch
16.	Luwei Yang	U. Tasmania	CTD watch
17.	Tobias Aldridge	U. Tasmania	CTD watch/iXblue PHINS INS
18.	Christine Rees	CSIRO MNF	Hydrochemist
19.	Cassie Schwanger	CSIRO	Hydrochemist
20.	Kelly Brown	CSIRO	Hydrochemist
21.	Stephen Tibben	CSIRO MNF	Hydrochemist
22.	Bronte Tilbrook	CSIRO	Carbon Team/co-PI
23.	Kate Berry	CSIRO	Carbon Team
24.	Abe Passmore	CSIRO	Carbon Team
25.	Erik Van Ooijen	CSIRO	Carbon Team
26.	Craig Neill	CSIRO	Carbon Team
27.	Hayden Martin	ANU	Carbon Team
28.	Jessica Ericson	U. Tasmania	Carbon Team
29.	Charles Maxson	U. Auckland, NZ	Carbon Team
30.	Eric Raes	U. WA	Bacteria/Genomics
31.	Gaby Paniagua Cabarrus	U. Tasmania	Bacteria/Genomics
32.	Bernhard Tschitschko	UNSW	Bacteria/Genomics
33.	Reece Brown	QUT	Atmospherics
34.	Bonnie Chang	U. Washington, USA	CFC
35.	Rolf Sonnerup	U. Washington, USA	CFC

Marine Crew

Leg 1

Name	**Role**
Mike Watson	Master
Roderick Quinn	Chief Mate
Brendan Eakin	Second Mate
Thomas Watson	Third Mate
Gennadiy Gervasiev	Chief Engineer
Sam Benson	First Engineer
Ian McDonald	Second Engineer
Damian Wright	Third Engineer
John Curran	Electrical Engineer
Alan Martin	Chief Caterer
Emma Lade	Caterer
Rebecca Lee	Chief Cook
Matt Gardiner	Cook
Jonathan Lumb	Chief Integrated Rating
Dean Hingston	Integrated Rating
Darren Capon	Integrated Rating
Murray Lord	Integrated Rating
Matthew McNeill	Integrated Rating
Kel Lewis	Integrated Rating
Ryan Drennan	Integrated Rating

Leg 2

Name	Role
John Highton	Master
Gurmukh Nagra	Chief Mate
Adrian Koolhof	Second Mate
James Hokin	Third Mate
Chris Minness	Chief Engineer
Mark Elliot	First Engineer
Michael Sinclair	Second Engineer
Ryan Agnew	Third Engineer
Shan Kromkamp	Electrical Engineer
Cassy Rowse	Chief Caterer
Emma Lade	Caterer
Keith Shepherd	Chief Cook
Matt Gardiner	Cook
Graham McDougall	Chief Integrated Rating
Chris Dorling	Integrated Rating
Matt McNeill	Integrated Rating
Paul Langford	Integrated Rating
Peter Taylor	Integrated Rating
Dennis Bassi	Integrated Rating
Rod Langham	Integrated Rating

Acknowledgements

We thank the Masters and crew of the *Investigator*, and the MNF electronic and computing support teams. Their willingness to help work through some of the major issues we encountered was essential to our success. Don McKenzie and Steve Thomas, our Voyage Managers, were a joy to work with. Their thorough knowledge of the vessel and equipment was invaluable, their calm personalities and strong support for our goals and care for our team made our jobs very easy and kept all safe and happy. We thank the MNF management team for their support in organizing the large team, and for making extra time available to help reach our goals. We thank Mark Rayner and the CSIRO hydrochemistry team for their outstanding preparation for this challenging voyage. Mike Jackson was invaluable in assisting us upgrade the laboratories HVAC for the challenges of the tropics.

This voyage is the last one to be supported by the Australian Climate Change Science Program (Department of Environment). We thank our international GO-SHIP colleagues (Brian King, Greg Johnson, Toste Tanhua, Kats Katsumata, Jim Swift) for sending their advice on winches, wire torsion, tension and cable management to help us improve operation of the new systems on *Investigator*. We also thank Norge Larson and David Murphy from Seabird Electronics for their prompt and helpful advice with troubleshooting our conductivity cell issues.

Lastly, we are grateful to our Leg 2 Bosun, Graham McDougall, and Chief Engineer, Chris Minness, for their outstanding work in assisting with the winch brake failure incident and restoring a workable system to us. This enabled the successful completion of our work and their actions were truly voyage saving.

Signature

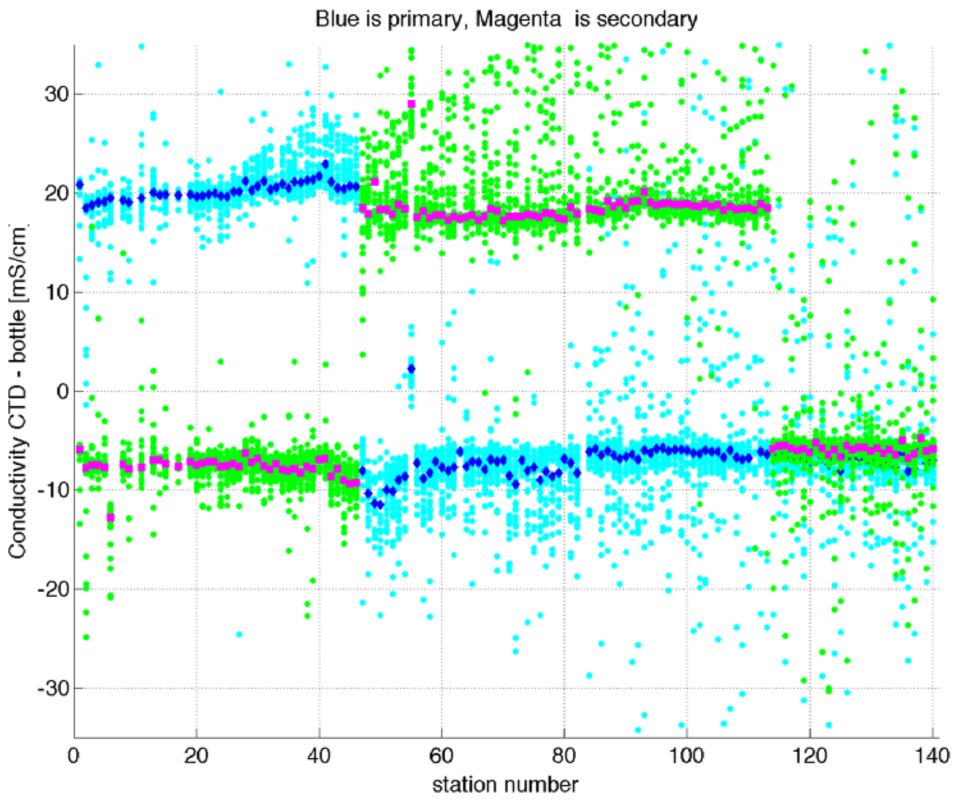
Your name	Bernadette Sloyan	Susan Wijffels
Title	Chief Scientist (Leg 1)	Chief Scientist (Leg 2)
Signature(s)	Bernadette Sloyan	
Date	14 July 2016	

List of additional figures and documents

Appendix 1 CTD calibration issues

S. E. Wijffels, June 2016

Issue 1 – Large Conductivity Offsets



Uncalibrated CTD – bottle conductivity differences are large ~ 0.01 - 0.02, for both channels and both CTDs. Stations 1-47 were done with sensors calibrated in March 2016. Note, after station 7, due to damage, the CTD was changed from # 20 to #22 but sensors from 20 were moved to 22 and operated out to station 46. Then we changed back to CTD 20 but with sensors with much older calibrations.

This is a large and surprising conductivity offset error - out of tolerance for both the instrument (SBE C4 and T3 and 9plus) and the calibration laboratories (SeaBird and CSIRO).

Steps taken to track this down at sea include:

1) Checking all SNs and calibration coefficients used on acquisition (multiple times)– while we found some errors, none explained this problem

2) Checking bottle salts against historical P15S occupations. These agreed to within tolerance (0.001) where they should, in the well mixed and ancient North Pacific Deep Waters.

3) Analysed all past CTD calibrations on CTD data from Investigator. These all showed similar sized offsets, with cells remaining stable between calibrations and across buses. Most disturbingly, the primary set used on our stations 1-46 had a lower offset (salty by 0.01) *before* it went through the CSIRO calibration lab in March (now salty by 0.025). In fact, for all Investigator data, a clear pattern emerged showing that all CSIRO calibrations resulted in a salty offset (0.01-0.025)

compared to at sea bottle salts, while all SBE calibrations were fresh (0.007-0.01). This pattern remains regardless of the 9plus bus used. See below.

4) Tested the raw hex data recorded by the CAP acquisition system against the SBE SeaSoft processing suite, and demonstrated that the resulting data are identical to within numerical precision. Thus we do not believe it to be due to CAP.

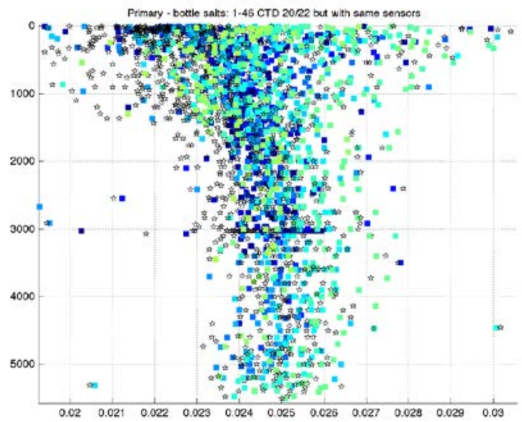
5) Engaged Norge Larsen and Dave Murphy at SBE, who kindly sent suggestions on what to test. At the end of process, they are equally mystified.

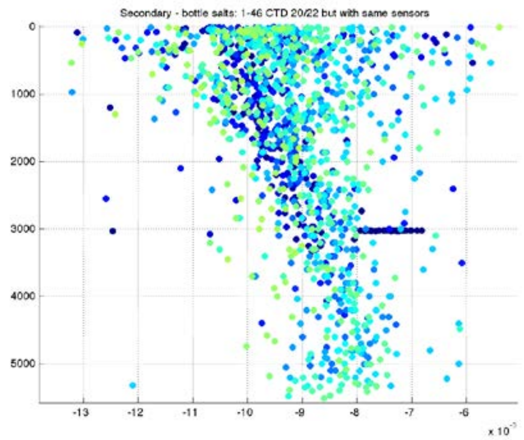
We suggest that the MNF work with the CSIRO calibration laboratory to try to understand where these offsets arise.

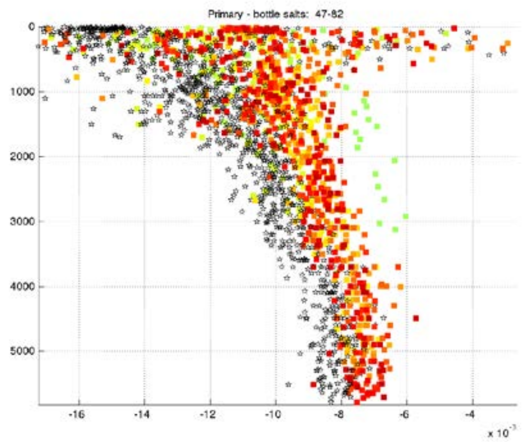
Issue 2 - Pressure dependent error in our secondary C-cells.

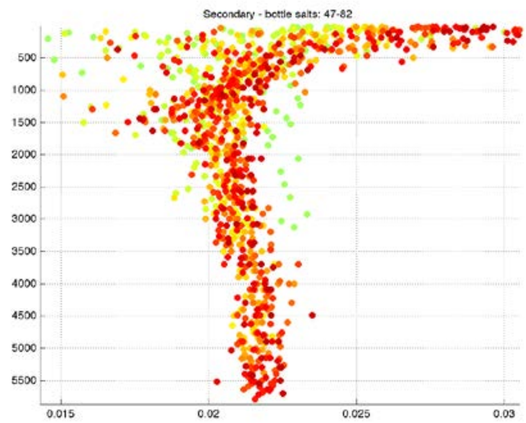
We found two types of depth dependence of CTD-bottle salt offsets in our data. Most T/C cell combinations give an offset that is downward increasing (or upward decreasing). This error is relatively small and in spec (~0.002). More concerning, the T/C secondary channel on CTD 20 had an offset that swings salty towards the surface. This persisted even when the C cell was changed! This behaviour could be seen on acquisition.

Below are example of the offsets, with the bottom right showing the large swing to salty on the secondary channels.







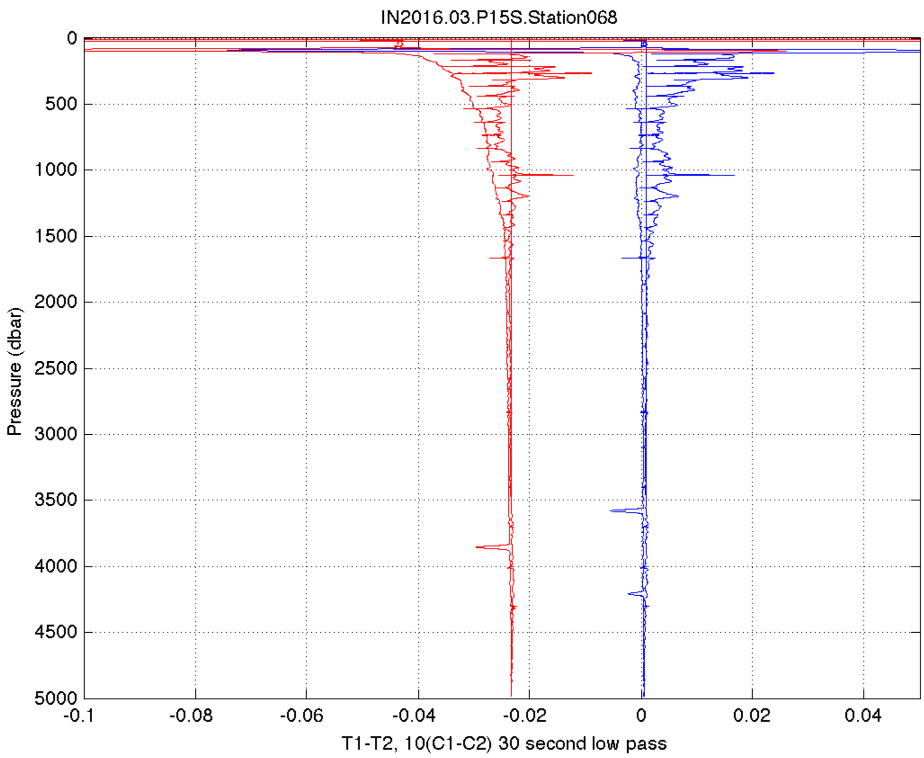


After discussions by email with Norge Larson, the linear shift with pressure is well known as explained here from Norge: "The linear pressure effect in salinity is a common feature of the SBE-4 conductivity cell. There is a pressure correction coefficient on the conductivity calibration sheet (CPCOR) which is the theoretical compression coefficient for pure borosilicate glass. In reality the conductivity cell exhibits a composite compression coefficient due to its hard epoxy coating. This expresses itself as a residual linear pressure effect of typical magnitude (0.7 - 1) * (+0.001 psu / 1000 dbar). The physical mechanism is well studied and is properly corrected by adjusting the value of CPCOR to a smaller magnitude number (coefficient remains a negative value)."

This advice has been used in the calibration model we will use to adjust the data to the bottle salts.

The strong swing to salty values was not explained. However, after swapping out the secondary thermistor, oxygen sensor, checking the flow lines, moving the CTD to change the flow dynamics, we finally swapped in a THIRD C-cell. This last change fixed the problem. The two damaged cells (SBE 4C SNs 2312 and 2235) will be sent back to SeaBird for careful diagnosis. Norge was skeptical it could be a crack in the ceramic of the cell.

An example on this cell error can be seen in the secondary-primary differences below. This pattern was seen on acquisition.



Issue 3 – Calibration Model to apply to the Conductivity Data

The depth-dependent calibration changes noted above will not be removed by the current cell constant and offset used by CAPpro. Thus we need to include more terms. I tested 4 calibration models – a 7 term model used by Scripps ODF (constant plus quadratic in T,C and P), a fit where the SBE coefficients CTcorr and CPcorr are varied as well as the cell constant and offset (SBE model), and the current one used in CAPpro (conductivity offset and slope).

These models, were run across burst samples from both the primary and secondary channels for all sensor combinations, and the residuals compared. The upshot is that a SBE model that keeps CTcorr at the nominal value and allows CPcorr to be varied is the most physically sensible (based on advice from SBE) and fits as much of the variance as the more complex ODF model. The resulting residuals are largely unstructured, except for small time drifts and shifts (due to cell rinses or cleans). The bad C-cells in the secondary channels for stations 51-113 did not yield well to calibration (as expected) and this data should not be used.

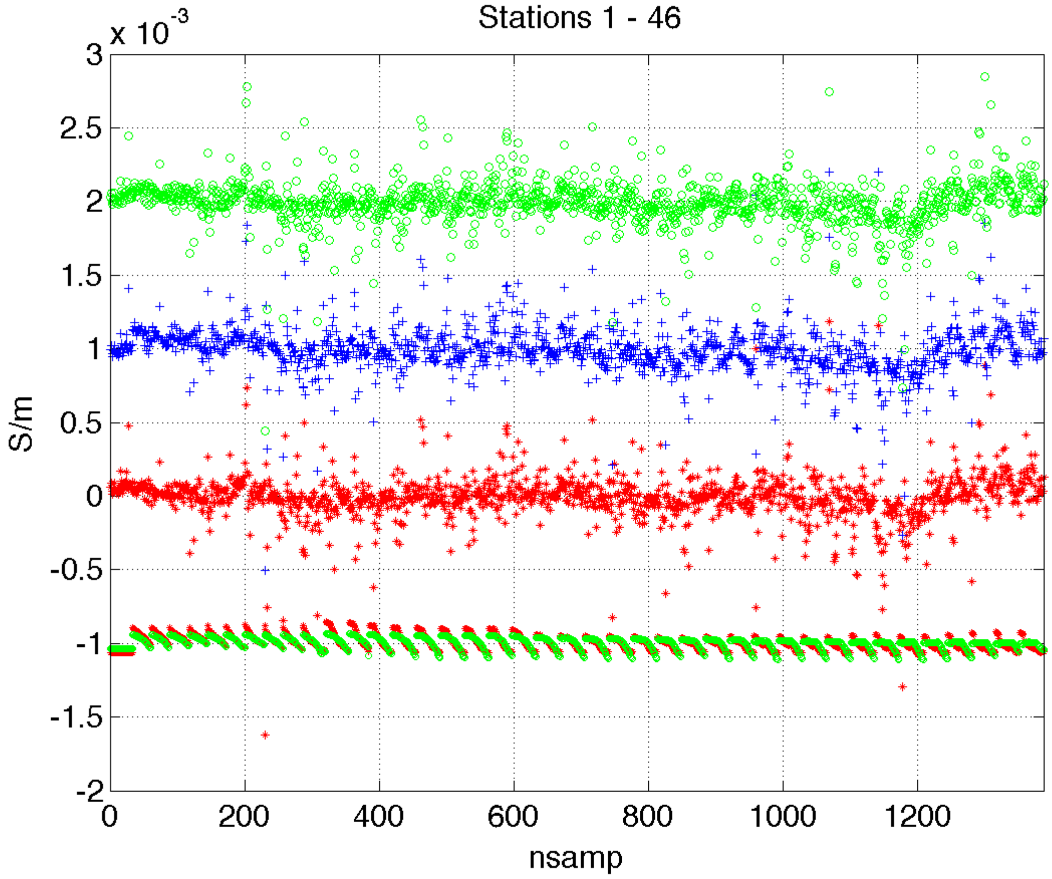


Figure 1.1

Residuals in primary CTD-bottle conductivities for stations 1-46. Red is the ODF model, blue is the current model used in CAPpro (offset by 1e-3 S/m) and green is the SBE –P model (offset by 2e-3). Below (offset by -1e-3) are the variance accounted for by the non-standard model terms. The SBE model does as well as the more complex ODF model.

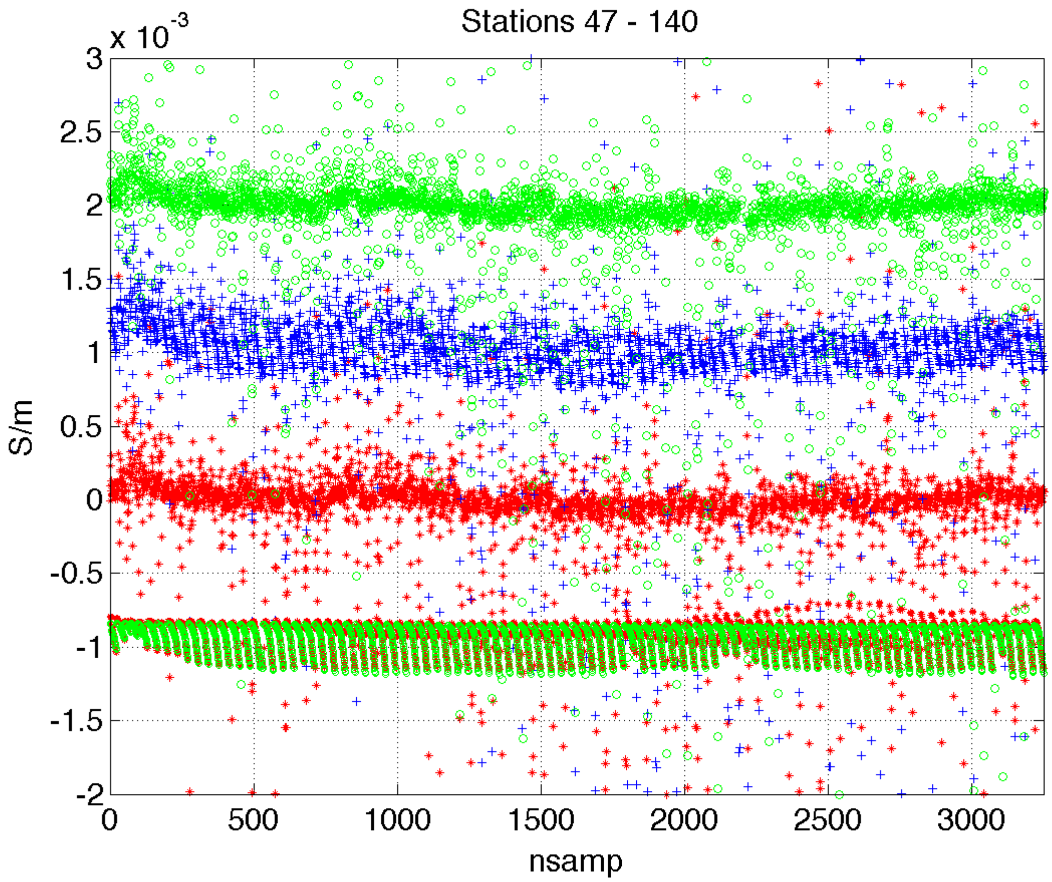


Figure 1.2

As for Figure 1.1, but for the second set of primary sensors used in stations 47-140.

Sensor combinations and calibration dates: blue shows changes made

Sensor/Station	**1-46 (Leg1)**	**47-50**	**51-87 (Leg2)**	**88-93**	**94-110**	**111-113**	**114 -**
T1	4722 CSIRO 3/16	6022 SBE 7/15	6022 SBE 7/15	6022 SBE 7/15	6022 SBE 7/15	6022 SBE 7/15	6022 SBE 7/15
C1	3868 CSIRO 3/16	4425 SBE 7/15	4425 SBE 7/15	4425 SBE 7/15	4425 SBE 7/15	4425 SBE 7/15	4425 SBE 7/15
Pump 1	2492	8344	8344	8344	8344	8344	8344
T2	4522 CSIRO 3/16	6024 SBE 7/15	6024 SBE 7/15	6024 SBE 7/15	4718 CSIRO 10/15	4718 CSIRO 10/15	4718 CSIRO 10/15
C2	4426 SBE 7/15	2312 bad	2312 bad	2235 bad	2235 bad	2235 bad	4426 SBE 7/15
Pump 2	2494	8345	8345	8345	5105	5105	5105
DO1	3154	1794	1794	1794	1794	1794	1794
DO2	3198	3199	3199	3199	3199	3198	3198
9plus	552 (1-7) 1243(8-46)	552	552	552	552	552	552

Analysis of past voyage conductivity offsets

Based on raw scan files and bottle salts

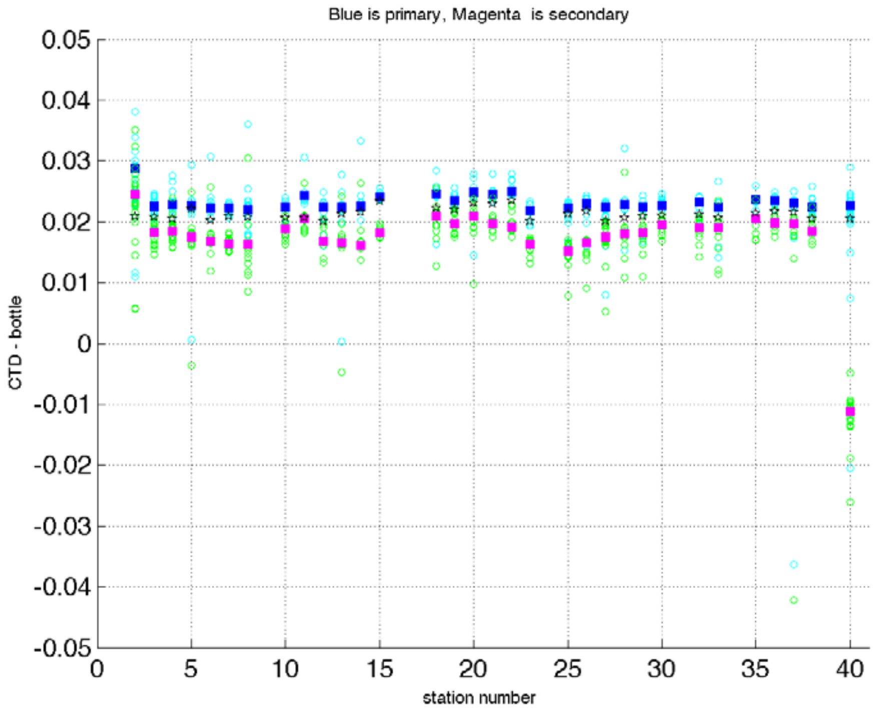
IN2016_V02

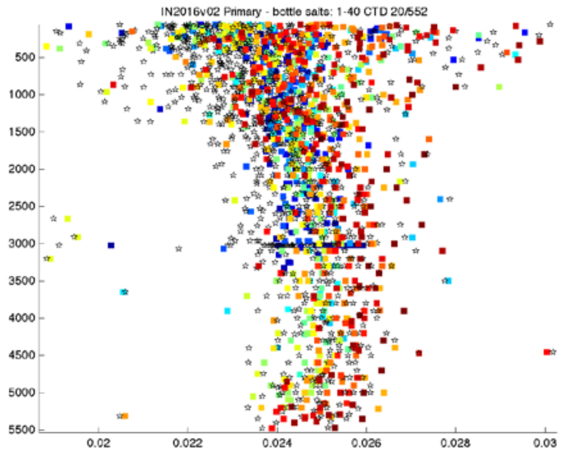
Voyage title:	SOTS: Southern Ocean Time Series automated moorings for climate and carbon cycle studies southwest of Tasmania
Mobilisation:	Hobart, Friday-Monday, 11-14 March 2016
Depart:	Monday 14th March 1000
Return:	Hobart, 0930 Saturday 16 April 2016

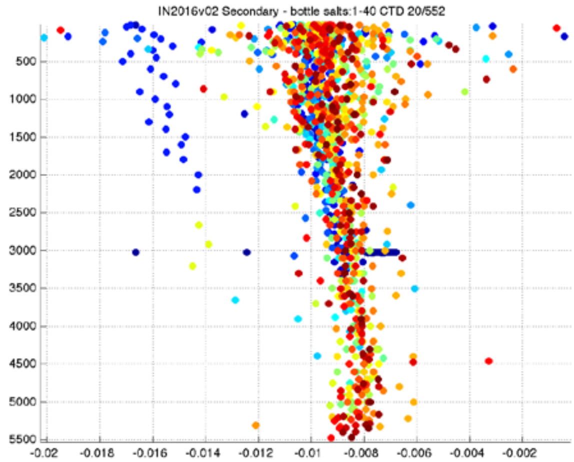
CTD Configuration

UNIT	MODEL	SERIAL NUMBER
CTD#20	SBE9+ V2	552
Primary Temperature	SBE 3T	4722
Primary Conductivity	SBE4C	3868
Secondary Temperature	SBE3T	4522
Secondary Conductivity	SBE4C	Cast1 3168 | Casts2-39 2235 |Cast 40 4426
Primary Pump	SBE5	2492
Secondary Pump	SBE5	2494
Primary Oxygen (A0)	SBE43	Cast1-1794 | From Cast2-3154
Secondary Oxygen (A1)	SBE43	Casts 1-39 3159 | Cast 40 – 3198
PAR (A2)	QCP2300	70111
Altimeter (A3)	PA500	5301
Transmissometer (A4)	C-Star	CST-1421DR
Spare (A5)		
Wetlabs ECO – Chlorophyll (A6)	FLBBNTU	3698 (User supplied)
Wetlabs ECO – Scattering (A7)	FLBBNTU	3698 (User supplied)
LADCP Downward looking	WHM150	16710
LADCP Upward looking	WHM300	16673

Table 1: Lowered CTD configuration







Same CTD and sensors as on our voyage and large S offsets are the same. Last cast changed to same C sensor as our voyage 1-46 and offsets agree. This suggests it is not the bus but is due to the calibrations.

Bottle/CTD offsets on voyages leading up to V03:

IN2016_V01

Voyage title:	HEOBI: Heard Earth-Ocean-Biosphere Interactions
Mobilisation:	Fremantle, 6th-7th January 2016
Depart:	Fremantle, 1430 Friday 8th January 2016
Return:	Hobart, 0800 Saturday 27th February 2016

CTD Configuration

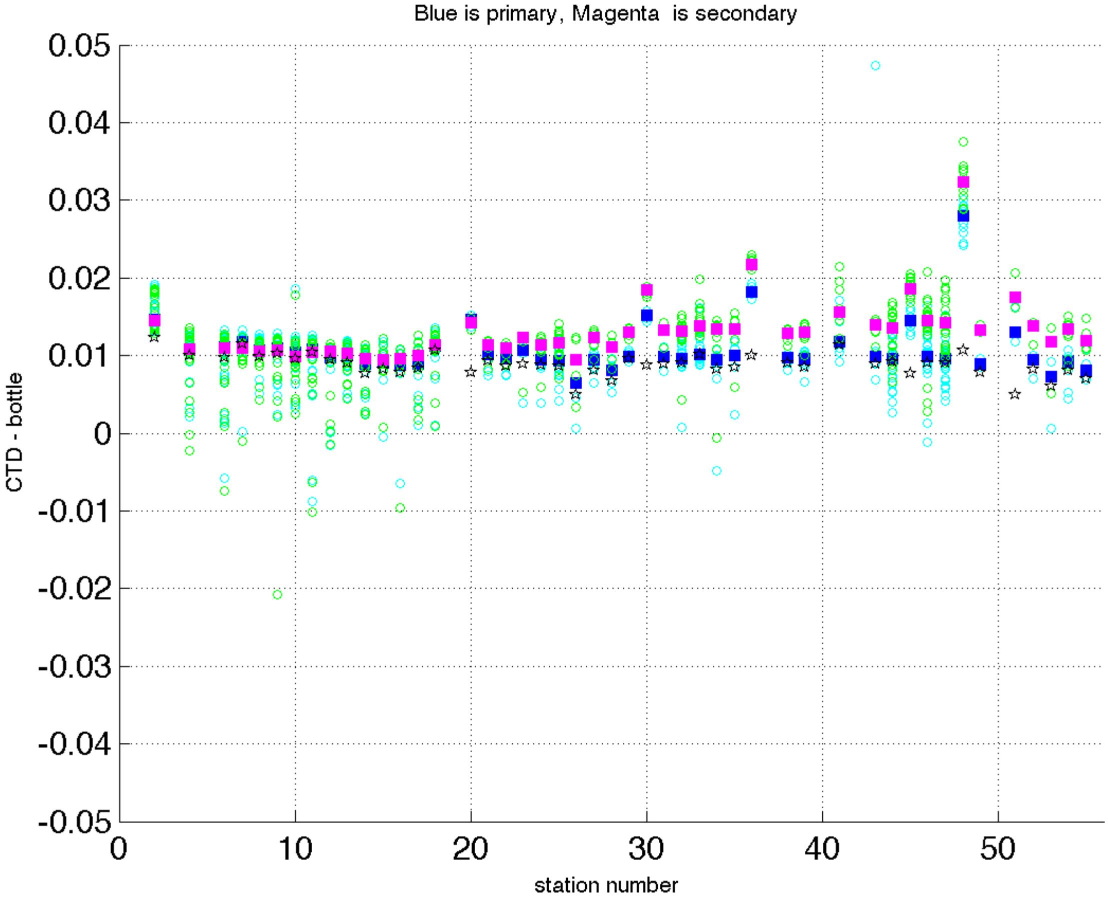
The CTD configuration used throughout the voyage is shown in Table 1.

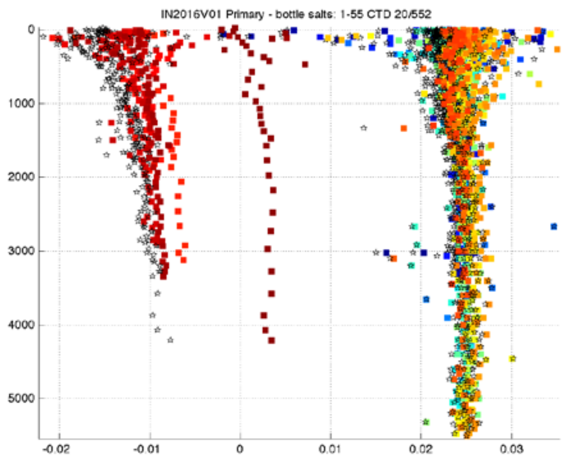
UNIT	MODEL	SERIAL NUMBER
CTD#20 V2	SBE9+	552
Primary Temperature	SBE 3T	4722
Primary Conductivity	SBE4C	3868
Secondary Temperature	SBE3T	4522
Secondary Conductivity	SBE4C	3168 / 2312 (cast 19 onwards)
Primary Pump	SBE5	2492
Secondary Pump	SBE5	2494
(A0) Primary Oxygen	SBE43	1794
(A1) Secondary Oxygen	SBE43	3159
(A2) PAR	Biospherical	70111
(A3) Altimeter	PA500	5301
(A4) Transmissometer	C-Star	CST-1421DR
(A5) ORP	ORP4CTD	ORP4CTD-09/ ORP4CTD-03
(A6) Fluorometer – Chlorophyll	FLBBRTD	3698
(A7) Fluorometer – Scattering	FLBBRTD	3698

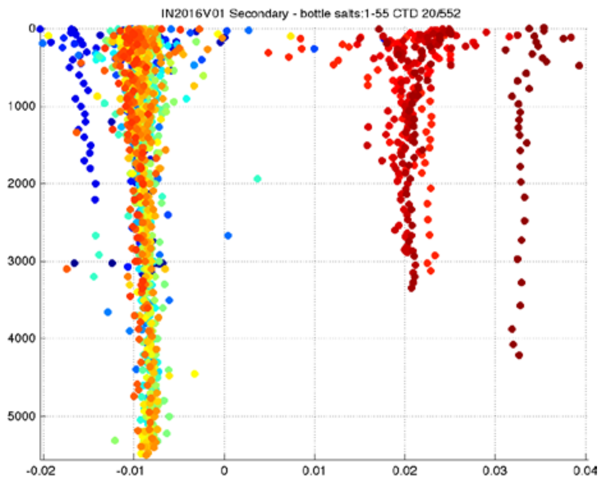
in2016_v01_instrumentationreport.docx

- 8 -

Table 1 CTD configuration


Blue is primary, Magenta is secondary
CTD - bottle
station number
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
0
10
20
30
40
50


IN2016V01 Primary - bottle salts: 1-55 CTD 20/552
0
1000
2000
3000
4000
5000
-0.02
-0.01
0
0.01
0.02
0.03


IN2016V01 Secondary - bottle salts:1-55 CTD 20/552
0
1000
2000
3000
4000
5000
-0.02
-0.01
0
0.01
0.02
0.03
0.04

Appendix 2 Anthropogenic Trace Gases

Rolf Sonnerup, U. Washington, USA

Introduction

Oceanic distributions of the anthropogenic trace gases, chlorofluorocarbon-11 (CFC-11), CFC-12 and sulfur hexafluoride (SF_6) reveal pathways and time-scales for waters to move from the surface mixed layer into the interior ocean. The 1990s World Ocean Circulation Experiment (WOCE) global survey provided a snapshot of the oceanic uptake of CFCs into the thermoclines of the subtropical gyres, and into intermediate, deep, and abyssal waters. These tracers provide critical measures of how quickly the ocean interacts with the atmosphere, and its anthropogenic changes. This project was part of the international CLIVAR Repeat Hydrography CO_2/Tracer Program (RH) effort to measure CFC and SF_6 on all of the CLIVAR RH (now GO-SHIP) lines.

An important finding of the RH program thus far has been warming of bottom waters throughout the world ocean over the past 20 years. The P15S section is vital to the RH program goals because it crosses the deep western boundary current (DWBC) of the Southwest Pacific, an important abyssal pathway for anthropogenic change, in four separate locations. In 1996 and 2009, P15S measurements sampled the leading edge of the CFCs' arrival in the abyssal Pacific as far north as 9ºS, in the Samoan Passage. The tracer observations provide an opportunity to use the CFCs to estimate the more difficult to quantify anthropogenic CO_2 and heat burdens in the abyssal Southwest Pacific.

Measurements

2187 samples were collected and analyzed following Bullister and Wisegarver, 2008.

Findings

In comparison with the most recent occupation of the P15 line for tracers (2009), we found

- Decreases CFCs in the upper 500m reflecting the recent (since 1994) decline in atmospheric CFC levels
- At low latitudes (north of 35°S) deeper penetration of CFCs by ~ 200m
- Significant increases in the abyss, reflecting the arrival of and increases in the anthropogenic influence on the abyssal Southwest Pacific. For example CFC-12 increased
    - from 0.075 to 0.12 and 0.075 to 0.14 pmol kg^{-1} at DWBC crossings to the North and South of Chatham rise
    - from 0.019 to 0.030 pmol kg^{-1} in the DWBC's transit thourgh the Samoan Passage (9°S)

The abyssal CFC plume (defined as detectable values in excess of 0.005 pmol kg^{-1}) had shoaled from 4000m in 1996 to 3400m in 2009 to 3000 m in 2016 at 30°S. Farther to the North, the abyssal plume had not shoaled significantly since 2009. Both CFCs were easily detectable at the seafloor over the full extent of the section from 66°S to the equator.

The mid-depth (1000-3000m) location where CFC-free waters are found had not moved significantly since 2009. However, as a consequence of the shoaling abyssal plume, and deepening penetration through the thermocline, the total volume of CFC free waters in this region was decreasing. In the locations where CFC12 was not detectable (North of 35S, 1500-35000m typically) we detected a bottle blank on order (preliminarily) of 0.005 pmol kg^{-1} for CFC-11. The reported CFC-11 values were not corrected for this possible offset. Bottle blanks of zero for SF_6, CFC-12, and CCl_4 were estimated from niskin samples in this region.

Appendix 3

Total Dissolved Inorganic Carbon and Total Alkalinity

PI: Dr Bronte Tilbrook, CSIRO Oceans and Atmosphere, and Antarctic Climate and Ecosystems Co-operative Research Centre, Hobart, Tasmania

Samples were analysed for total dissolved inorganic carbon dioxide and total alkalinity following techniques developed for measurements in ocean waters on WOCE/CLIVAR sections. Certified reference materials from the Scripps Institution of Oceanography are analysed to determine the accuracy and precision of the measurements. Detailed analytical procedures are provided in Dickson et al (2007).

Water sampling

Stations sampled for total dissolved inorganic carbon and total alkalinity are shown in Figure xx and listed in Table 1. For each sample, water was siphoned from a 10L Niskin bottle into 250 ml glass bottles using silicone tubing. The bottles were rinsed three times with water from the Niskin bottle and the seawater sample was then overflowed by about one half of the bottle volume. Each bottle had about a 5ml head space, and 100 microlitres of a saturated solution of mercuric chloride was added prior to sealing the samples using air-tight screw caps. Samples were sealed within one minute of collection. An additional 100 samples were collected using the same method from the ships underway seawater line while the ship was in transit to and from the P15S section. Samples were analysed onboard within 1- 3 days of collection.

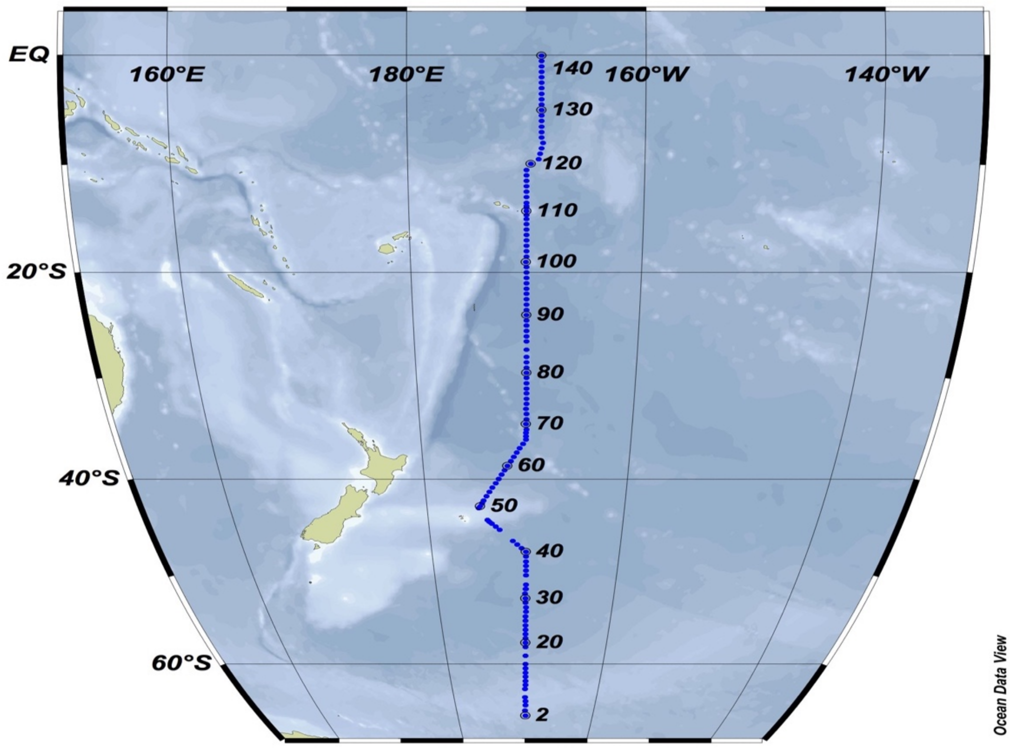


Figure 1. Carbon water sampling sites (blue dots) for section P15S with some CTD station numbers shown.

Total dissolved inorganic carbon:

Total dissolved carbon dioxide (TCO_2) was analysed using a SOMMA system and 5011 UIC coulometer (Johnson et al., 1993 and Dickson et al.,2007). The SOMMA loads seawater from a sample bottle into a calibrated pipette (21.8ml) that is thermostated to 20°C. The sample in the pipette is dispensed into a stripping chamber to which 1 ml of a 10% (v/v) solution of phosphoric acid has been added. High purity nitrogen carrier gas (>99.995%) is bubbled through the water to extract the CO_2 from the sample. The CO_2 in the carrier gas stream flows into the cathode compartment of a coulometer cell where it is quantitatively trapped in an ethanolamine solution. The absorbed CO_2 reacts to form hydroxyethylcarbamic acid, causing a change in the colour of the cell solution due to the presence of a thymolphthalein pH indicator in the solution. Base is generated at the cell cathode, until the solution colour returns to its starting point.

About 36 samples are analysed before a new coulometer cell and solution are required. This provides enough capacity for a whole station with duplicates, and certified reference material. The efficiency of the coulometric method is determined by injecting known amounts of pure CO_2 (>99.99%) at the beginning of each new cell. After the calibration of the SOMMA is complete, test seawater samples are analysed followed by certified reference material from the Scripps Institution of Oceanography. The SOMMA system also loads sample into a Seabird conductivity cell, which is used along with a temperature to determine the salinity of the sample. Concentrations are in units of micromol kg^{-1}.

For legs 1 and 2, a total of 2625 water samples were analysed for TCO_2 (Figure 2), with an additional 269 duplicate samples analysed from shallow, mid-depth and deep samples to cover the range of TCO_2 values through the water column. Certified Reference Material from Scripps Institution of Oceanography (Batch 363) was analysed at the beginning and end of the coulometer cells. Over a typical cell, the measurements of reference material drifted by 1-2 micromol kg^{-1}. The average offset for each cell was used to correct the final TCO_2 values of the samples. The initial analysis of duplicate samples gave an average absolute difference of 1.71 +- 1.24 micromol kg^{-1} (s.d., n=269) indicating a precision of better than 2 micromol kg^{-1}.

Total alkalinity:

Automated open-cell potentiometric titrations were used to measure total alkalinity (TA) (Dickson et al, 2007). Two systems were operated side by side, with Tiamo software used to control the titrations. Each titration was performed on a 100ml seawater sample measured using an Metrohm Dosino 800 burette and a 5ml burette on a Metrohm Titrando 904 was used to deliver acid titrant. The delivery volumes for the Titrando and Dosino burettes were calibrated in the laboratory prior to cruise. Metrohm combination pH electrodes were used to track the progress of the titrations. Refrigerated water baths were used to keep the acid titrant and sample at a constant temperature of 20.5C for each analysis.

For a titration, the sample is first acidified to a pH of about 3.6 using 0.1N HCl titrant, which contains 0.6 mol Kg^{-1} sodium chloride to match the ionic strength of seawater. After the initial addition of acid, the acidified seawater is stirred for 10 minutes to remove dissolved CO_2 from the sample. Smaller aliquots of titrant are then added and acid volume and electrode millivolt readings is recorded by the Tiamo software until a pH of about 2.9 is reached. A non-linear fitting routine similar to Johansson and Wedborg (1982) and Dickson et al. (2007) was used to calculate TA. The routine used was compared to a calculated result for data published in Dickson et al (2007) and both methods agree within 0.01%.

The performance of the titration systems was monitored using certified seawater reference material from the Scripps Institution of Oceanography (Batch 363), and by using duplicate water samples collected from the CTD casts. The duplicate water samples were collected from surface, mid-depth and deep water samples to cover the range of total alkalinity values for the water column. There was about a 6 micromol kg^{-1} offset between the measured and certified reference material values for TA due to the acid titrant having a slightly different concentration than originally assigned. Evaporation of acid titrant was also a source of a small drift, and the titrant was regularly replaced with new titrant that prepared prior to the cruise and stored in sealed borosilicate glass bottles. The average offset between the measured and certified reference material values were used to correct the TA for samples from each station.

For the section, 2628 seawater samples were analysed (Figure 3), plus 224 duplicate samples. The analysis of duplicate samples for both titration systems showed average absolute differences of 0.90 +- 0.90 micromol kg^{-1} (s.d., n=119) and 0.97 +- 1.17 mircomol kg^{-1} (s.d. n=106), indicating a precision of better than +-1 micromol kg^{-1}.

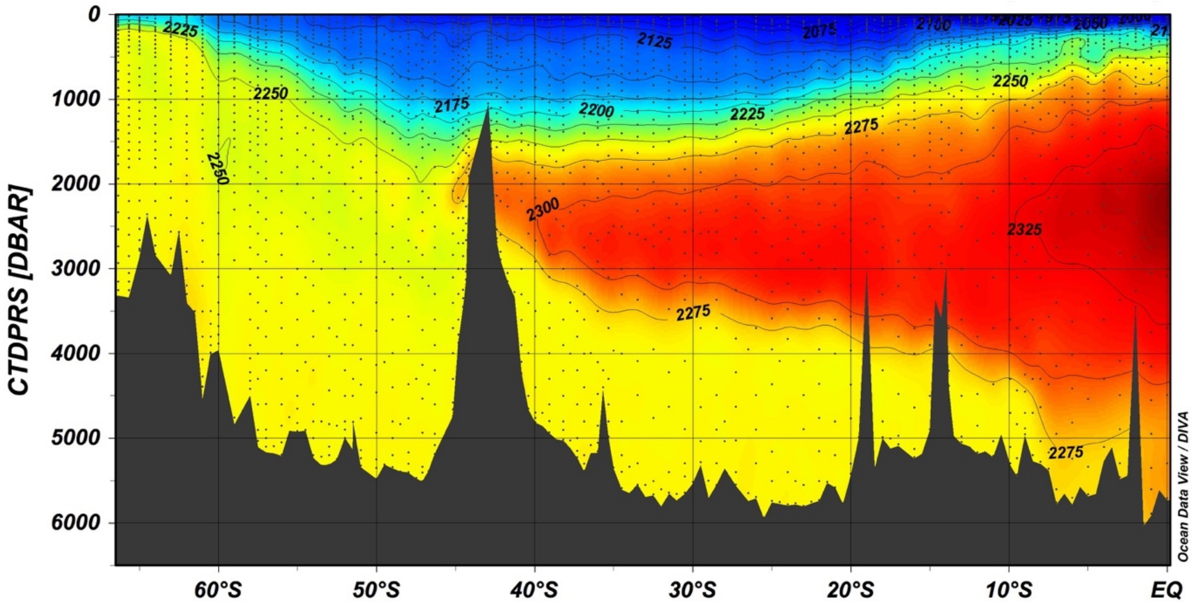


Figure 2. Preliminary total dissolved inorganic carbon (micromole kg^{-1}) measurements along the P15S section, Apr-Jun 2016.

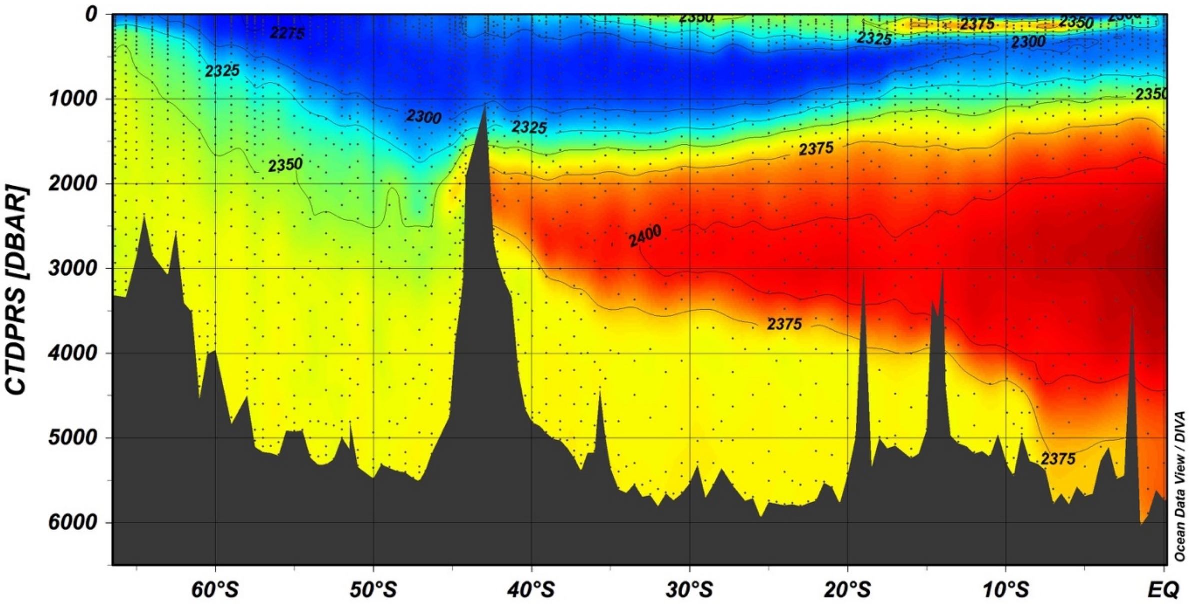


Figure 3. Preliminary total alkalinity (micromole kg^{-1}) measurements along the P15S section, Apr-Jun 2016.

Table 1. Station/CTD numbers (STNNBR), locations and numbers of TCO2 and TA samples.

STNNBR	DATE yyyymmdd	TIME hhmm	LATITUDE	LONGITUDE	DEPTH db	SAMPLE NUMBER
2	20160504	0844	-66.332	-170.008	3277	36
3	20160505	0320	-65.662	-170.032	3297	32
4	20160505	1320	-64.995	-170.016	2836	31
5	20160505	2145	-64.502	-170.004	2348	2
6	20160506	0501	-63.990	-170.042	2807	31
8	20160508	0141	-63.001	-170.032	3046	33
9	20160508	0650	-62.499	-169.992	2539	2
11	20160508	1535	-62.003	-170.004	3360	33
12	20160508	2149	-61.492	-169.997	3470	2
13	20160509	1631	-61.005	-170.004	4483	33
14	20160509	2335	-60.502	-169.991	3951	5
15	20160511	1151	-60.000	-170.005	3905	35
17	20160512	2000	-58.994	-169.998	4763	30
19	20160513	1219	-58.001	-170.010	4432	34
20	20160513	1911	-57.504	-170.006	5019	36
21	20160514	1414	-57.002	-169.998	5078	33
22	20160514	0926	-56.498	-170.009	5090	2
23	20160514	2122	-56.002	-169.008	5121	36
24	20160515	0441	-55.514	-170.011	4833	2
25	20160515	1108	-54.996	-170.002	4843	30
26	20160515	2000	-54.500	-170.003	4831	10
27	20160516	0249	-53.996	-169.985	5142	30
28	20160516	0954	-53.501	-169.991	5226	10
29	20160516	1637	-53.004	-170.011	5220	30
30	20160517	0016	-52.505	-170.010	5161	10
31	20160517	0755	-52.002	-170.078	4913	30
32	20160517	1436	-51.492	-170.016	4732	10
33	20160517	2141	-51.002	-170.010	5248	32
34	20160518	0420	-51.497	-169.996	5052	10
35	20160518	1137	-50.006	-169.993	5384	33
36	20160518	1915	-49.504	-170.017	5220	10
37	20160519	0215	-48.995	-170.004	5262	30
38	20160519	0915	-48.502	-170.000	5298	10

STNNBR	DATE yyyymmdd	TIME hhmm	LATITUDE	LONGITUDE	DEPTH db	SAMPLE NUMBER
39	20160519	1559	-47.995	-169.993	5310	32
40	20160519	2338	-47.503	-169.989	5379	10
41	20160520	0649	-47.109	-170.466	5412	32
42	20160520	1348	-46.719	-170.911	5296	10
43	20160521	0116	-46.326	-171.376	5100	32
44	20160522	0021	-45.176	-172.736	4665	32
45	20160522	1003	-44.835	-173.141	3830	31
46	20160522	1639	-44.525	-173.502	3414	28
47	20160522	2335	-44.328	-173.746	3102	15
48	20160523	0620	-44.156	-173.938	1892	26
49	20160523	1542	-42.931	-174.785	1057	16
50	20160523	1819	-42.746	-174.653	1584	23
51	20160528	1614	-42.400	-174.410	2666	21
52	20160528	2129	-42.167	-174.250	2866	11
53	20160529	0310	-41.717	-173.949	3116	24
54	20160529	0920	-41.273	-173.637	3292	8
55	20160529	1603	-40.832	-173.332	4178	29
56	20160529	2203	-40.392	-173.024	4592	9
57	20160530	0447	-39.958	-173.706	4739	30
58	20160530	1214	-39.511	-172.414	4776	8
59	20160530	2033	-39.068	-172.117	4861	30
60	20160531	0340	-38.628	-171.808	4929	8
61	20160531	1054	-38.187	-171.501	4945	32
62	20160531	1739	-37.757	-171.201	5028	8
63	20160531	0046	-37.307	-170.893	5146	8
64	20160601	0745	-36.871	-170.606	5303	30
65	20160601	1500	-36.450	-170.294	5087	9
66	20160601	2152	-36.002	-170.002	5084	31
67	20160602	0711	-35.680	-170.007	4372	8
68	20160602	1005	-35.337	-170.000	4909	30
69	20160602	1714	-35.014	-169.995	5264	8
70	20160602	2356	-34.505	-170.006	5505	29
71	20160603	0655	-34.012	-169.999	5547	4
72	20160603	1409	-33.501	-170.000	5446	28

STNNBR	DATE yyyymmdd	TIME hhmm	LATITUDE	LONGITUDE	DEPTH db	SAMPLE NUMBER
73	20160603	2112	-33.000	-170.006	5591	4
74	20160604	0425	-32.500	-169.997	5572	28
75	20160604	1227	-32.002	-169.995	5700	4
76	20160604	1944	-31.499	-169.994	5553	28
77	20160605	0223	-31.023	-169.998	5630	4
78	20160605	0936	-30.512	-169.996	5556	32
79	20160605	1640	-29.999	-169.993	5437	4
80	20160605	2353	-29.501	-170.000	5226	29
81	20160606	0653	-29.006	-169.995	5605	4
82	20160606	1409	-28.503	-169.999	5454	28
83	20160607	1526	-27.984	-169.991	5264	2
84	20160608	1024	-27.272	-169.998	5464	30
85	20160608	1910	-26.495	-169.996	5637	8
86	20160609	0251	-26.000	-169.993	5607	30
87	20160609	1031	-25.509	-169.998	5836	5
88	20160609	1806	-24.999	-170.002	5653	30
89	20160610	0142	-24.501	-170.001	5670	7
90	20160610	0920	-24.000	-170.001	5689	30
91	20160610	1652	-23.505	-169.996	5676	8
92	20160611	0026	-22.999	-169.996	5701	29
93	20160611	0802	-22.501	-170.000	5663	7
94	20160611	1530	-22.002	-170.000	5636	32
95	20160611	2253	-21.503	-169.999	5430	7
96	20160612	0552	-20.998	-169.999	5482	30
97	20160612	1247	-20.503	-169.999	5675	8
98	20160612	2014	-20.000	-170.002	5341	30
99	20160613	0303	-19.498	-170.003	4915	7
100	20160613	0933	-19.004	-170.058	2989	24
101	20160613	1503	-18.503	-170.002	5269	12
102	20160613	2139	-18.001	-170.000	4919	30
103	20160614	0652	-17.499	-170.001	5037	9
104	20160614	1319	-17.003	-170.002	5005	30
105	20160614	1949	-16.504	-170.000	5226	8
106	20160615	0210	-16.003	-170.001	5150	28

STNNBR	DATE yyyymmdd	TIME hhmm	LATITUDE	LONGITUDE	DEPTH db	SAMPLE NUMBER
107	20160615	0854	-15.498	-170.001	5095	7
108	20160615	1532	-15.005	-170.000	4826	30
109	20160615	2052	-14.666	-169.999	3330	7
110	20160616	0140	-14.282	-169.998	3546	23
111	20160616	0643	-13.972	-169.999	2972	6
112	20160616	1114	-13.819	-169.999	4338	23
113	20160616	1618	-13.504	-170.002	4888	7
114	20160616	2254	-13.000	-169.999	4980	29
115	20160616	0522	-12.499	-169.999	5012	7
116	20160617	1145	-11.998	-170.003	5097	25
117	20160617	1825	-11.496	-169.999	5069	7
118	20160618	0037	-11.001	-170.000	5135	24
119	20160618	0722	-10.500	-169.999	4878	7
120	20160618	1433	-9.925	-169.629	5227	24
121	20160618	2241	-9.499	-168.998	5357	18
122	20160619	0543	-8.997	-168.875	4891	19
123	20160619	1209	-8.495	-168.749	5182	18
124	20160619	1858	-8.001	-168.616	5212	24
125	20160620	0121	-7.501	-168.751	5287	20
126	20160620	0806	-7.000	-168.751	5676	23
127	20160620	1456	-6.502	-168.749	5553	8
128	20160620	2139	-6.000	-168.751	5679	29
129	20160621	0434	-5.502	-168.750	5476	8
130	20160621	1117	-5.000	-168.750	5583	28
131	20160621	1750	-4.501	-168.750	5555	8
132	20160622	0021	-4.001	-168.751	5178	28
133	20160622	0706	-3.502	-168.750	5023	8
134	20160622	1338	-3.000	-168.751	5388	30
135	20160622	2010	-2.499	-168.750	5346	8
136	20160623	0235	-2.001	-168.750	3413	24
137	20160623	0809	-1.501	-168.749	5926	12
138	20160623	1514	-1.001	-168.750	5803	28
139	20160623	2208	-0.501	-168.750	5512	8
140	20160624	0455	-0.002	-168.750	5628	29

Radiocarbon in total dissolved inorganic carbon:

PIs: Dr Ann McNichol, Woods Hole Oceanographic Institution, Massachusetts, USA

Dr Robert Key, Princeton University, New Jersey, USA

A total of 600 samples were collected for analysis of 14C. Seawater samples were collected about every 4 to 8 CTD stations (Table 2) using a combination of shallow sampling (upper 2000m) and sampling through the entire water column. The samples were collected in cleaned one liter ground-glass stoppered, borosilicate glass bottles. Silicon tubing attached to Niskin bottle spigots was used to fill the bottles. Each bottle was first filled about 30% as a rinse, followed by filling and overflowing the bottle by about 50%. Samples were preserved by adding 100 microlitres of a saturated mercuric chloride solution. The ground glass necks of the sample bottles were dried and Apiezon grease applied to the stopper before sealing. Samples will be analysed using an accelerator mass spectrometer at Woods Hole Oceanographic Institution.

Table 2. Station/CTD numbers (STNNBR), locations and numbers of radiocarbon samples.

STNNBR	**DATE yyyymmdd**	**TIME hhmm**	**LATITUDE**	**LONGITUDE**	**DEPTH db**	**14C samples**
3	20160505	0320	-65.662	-170.032	3297	32
6	20160506	0501	-63.990	-170.042	2807	32
13	20160509	1631	-61.005	-170.004	4483	32
21	20160514	1414	-57.002	-169.998	5078	32
29	20160516	1637	-53.004	-170.011	5220	32
35	20160518	1137	-50.006	-169.993	5384	32
41	20160520	0649	-47.109	-170.466	5412	32
45	20160522	1003	-44.835	-173.141	3830	31
51	20160528	1614	-42.400	-174.410	2666	16
55	20160529	1603	-40.832	-173.332	4178	16
61	20160531	1054	-38.187	-171.501	4945	32
66	20160601	2152	-36.002	-170.002	5084	16
72	20160603	1409	-33.501	-170.000	5446	16
78	20160605	0936	-30.512	-169.996	5556	32
86	20160609	0251	-26.000	-169.993	5607	16
94	20160611	1530	-22.002	-170.000	5636	32
100	20160613	0933	-19.004	-170.058	2989	16

STNNBR	DATE yyyymmdd	TIME hhmm	LATITUDE	LONGITUDE	DEPTH db	14C samples
106	20160615	0210	-16.003	-170.001	5150	16
112	20160616	1114	-13.819	-169.999	4338	23
118	20160618	0037	-11.001	-170.000	5135	16
121	20160618	2241	-9.499	-168.998	5357	18
124	20160619	1858	-8.001	-168.616	5212	23
130	20160621	1117	-5.000	-168.750	5583	16
134	20160622	1338	-3.000	-168.751	5388	16
140	20160624	0455	-0.002	-168.750	5628	25

pH and total alkalinity

PI: Professor Andrew Dickson, Scripps Institution of Oceanography

Samples for calibration of sensors on SOCCOM floats were collected from Niskin bottles in the upper 2000m of the water column. Floats were deployed as the ship was leaving the CTD station and just after completion of the CTD cast. The water samples were collected in pre-cleaned glass-stoppered borosilicate bottles, the same as for radiocarbon samples. Each bottle was first filled about 30% as a rinse, followed by filling and overflowing the bottle by about 50%. Samples were preserved by adding 100 microlitres of a saturated mercuric chloride solution. Apiezon grease was applied to the ground glass stoppers and the bottles sealed. Samples will be analysed at Scripps Institution of Oceanography using spectrophotometry (pH) and open cell potentiometric titration (total alkalinity), as described in Dickson et al (2007).

Table 3. Station/CTD numbers (STNNBR), locations and numbers of samples for pH and TA analyses.

STNNBR	**DATE yyyymmdd**	**TIME hhmm**	**LATITUDE**	**LONGITUDE**	**DEPTH dbar**	**NUMBER SAMPLES**
3	20160505	0320	-65.662	-170.032	3297	28
6	20160506	0501	-63.990	-170.042	2807	29
11	20160508	1535	-62.003	-170.004	3360	27
15	20160511	1151	-60.000	-170.005	3905	27
19	20160513	1219	-58.001	-170.010	4432	23
25	20160515	1108	-54.996	-170.002	4843	24
31	20160517	0755	-52.002	-170.078	4913	24
35	20160518	1137	-50.006	-169.993	5384	24
39	20160519	1559	-47.995	-169.993	5310	24
43	20160521	0116	-46.326	-171.376	5100	23
57	20160530	0447	-39.958	-173.706	4739	25
61	20160531	1054	-38.187	-171.501	4945	24

Dissolved Calcium and Magnesium

PI: Professor Stephen Eggins, Australian National University, Canberra, ACT

Duplicate samples were collected from 10 depths (approx. 20, 50, 100, 150, 200, 300, 500, 750, 1000 and 2000m) at each of the stations listed in Table 3. Seawater was collected into 30m plastic luer-lok syringes. The syringes were rinsed three times with sample, filled, and a 0.22 micron PES membrane filter attached to the syringe. The filter was flushed with about 10ml of seawater and 5ml polypropylene vials were rinsed three times with filtered water. The vials were then filled and capped and stored at room temperature in sealed plastic bags and returned to Australia for analysis by isotope dilution using a multi collector inductively couple plasma mass spectrometer.

Table 4. Station/CTD numbers (STNNBR), locations and numbers of of calcium and magnesium water column samples.

STNNBR	**DATE yyyymmdd**	**TIME hhmm**	**LATITUDE**	**LONGITUDE**	**DEPTH dbar**	**NUMBER SAMPLES**
5	20160505	2145	-64.502	-170.004	2348	10
12	20160508	2149	-61.492	-169.997	3470	10
17	20160512	2000	-58.994	-169.998	4763	10
23	20160514	2122	-56.002	-169.008	5121	10
30	20160517	0016	-52.505	-170.010	5161	10
37	20160519	0215	-48.995	-170.004	5262	10
40	20160519	2338	-47.503	-169.989	5379	10
43	20160521	0116	-46.326	-171.376	5100	10
45	20160522	1003	-44.835	-173.141	3830	10
53	20160529	0310	-41.717	-173.949	3116	10
59	20160530	2033	-39.068	-172.117	4861	10
64	20160601	0745	-36.871	-170.606	5303	10
72	20160603	1409	-33.501	-170.000	5446	10
78	20160605	0936	-30.512	-169.996	5556	10
82	20160606	1409	-28.503	-169.999	5454	10
86	20160609	0251	-26.000	-169.993	5607	10
92	20160611	0026	-22.999	-169.996	5701	10
98	20160612	2014	-20.000	-170.002	5341	10
104	20160614	1319	-17.003	-170.002	5005	10

STNNBR	DATE yyyymmdd	TIME hhmm	LATITUDE	LONGITUDE	DEPTH dbar	NUMBER SAMPLES
110	20160616	0140	-14.282	-169.998	3546	10
116	20160617	1145	-11.998	-170.003	5097	10
122	20160619	0543	-8.997	-168.875	4891	9
128	20160620	2139	-6.000	-168.751	5679	10
134	20160622	1338	-3.000	-168.751	5388	10
140	20160624	0455	-0.002	-168.750	5628	9

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Appendix 4 Temperature Microstructure

PI Jonathon Nash, U. Oregon

Report by Esmee Van Wijk, CSIRO

Chipods are instruments that measure high frequency temperature and instrument motion at 100 Hz. The data is used to estimate mixing rates; the dissipation rate of small-scale temperature variance and the turbulent diffusivity of heat.

There were 4 instrument packages installed on the 36 bottle rosette; 2 upward looking and 2 downward looking chipods. These were configured so that the upward thermistors were raised above the rosette frame near the outer rim, and on a stalk to ensure a clear view of the water passing over the package. The downward thermistors are more subject to contamination by deflection of the fluid around the instrument as they are located above the bottom limit of the rosette frame but with as clear a view of the water column as possible. The instruments are powered by 2 Lithium D-cell batteries, are internally recording and are pressure rated to 6000db.

Even though the chipods record all data internally onto memory cards, the data was downloaded every two days. It would take 25-40 mins to download each instrument (if everything was working perfectly) and there was only just enough time to do this in the time we needed to turn around the rosette and get it back into the water. It required one person to download the chipods, which was a significant diversion of time away from the core work of the sampling team. It was also necessary to then back up the data from the mixing computer onto a hard drive and then onto the server. Generating check plots to make sure that the instruments were working correctly took additional time. All of this was only possible because we had one extra volunteer from another program who was able to assist with the CTD sampling. For future cruises, the chipod team should send their own technician or ensure that these are internally recording with no downloading required as this extra work had not been considered when planning the staffing for this voyage.

Problems:

1. Often the downloading would hang on a particular file and the mini host logger would not respond. You would then need to work out which file was causing the problem and then download all of the other files around this one individually. No matter how many times you would try to download the affected file, it would continually crash.

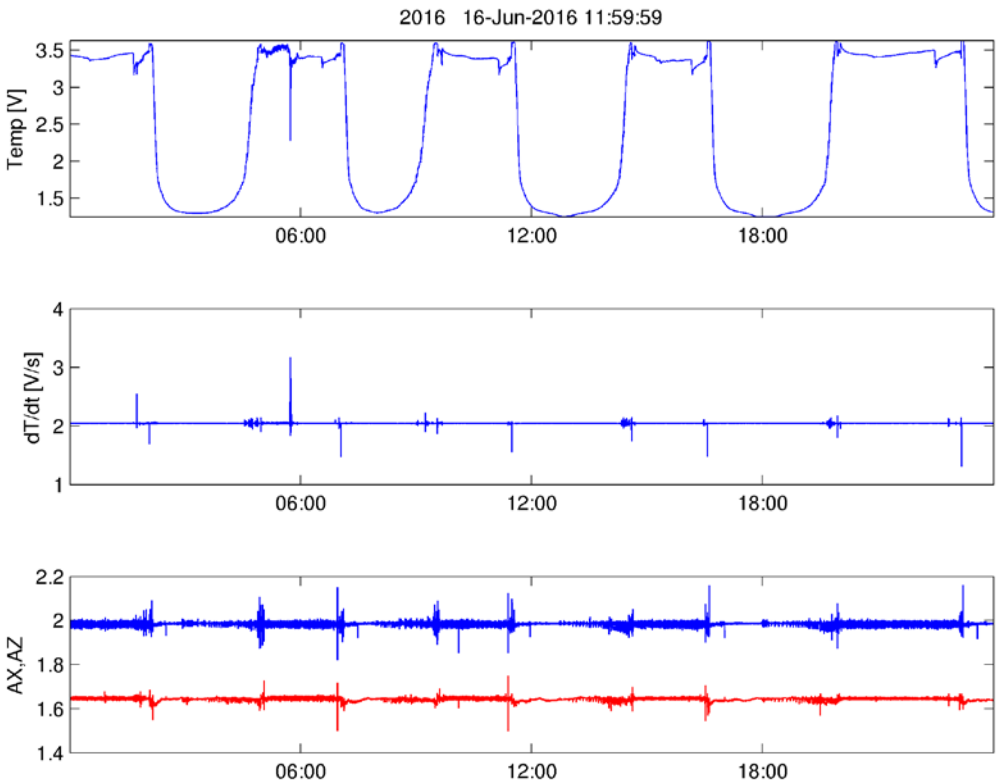
2. Occasionally one of the instruments would get stuck in a loop where it would run strange characters across the data screen. The only way to fix this would be to disconnect the USB cable and the sensor cable (difficult with a rosette that is being sampled and with the pressure case right inside the internals the only way this be done was by taking bottles off the CTD after sampling had been completed, which then delayed the CTD for the next station.

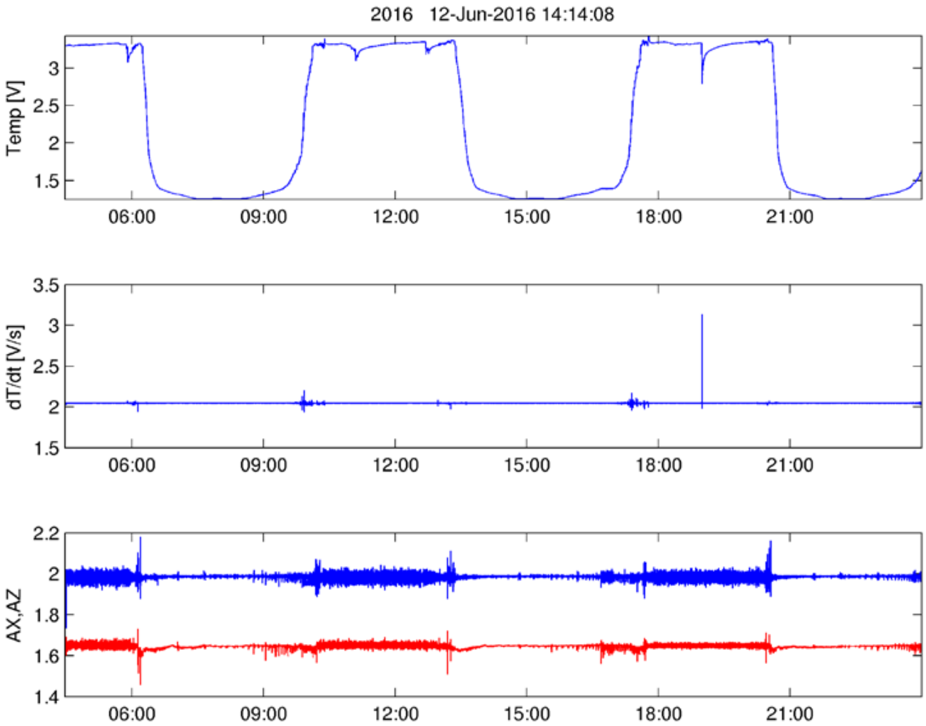
3. Once when having the above problem I was not able to communicate with the instrument after three separate tries of disconnecting and reconnecting. I left this instrument and downloaded the others and then disconnected and reconnected once again and it worked on the fourth time. This kind of troubleshooting can take up a lot of extra time.

4. I needed to replace four thermistors during Leg 2 of the voyage, plus two pressure cases and loggers, as well as a sensor cable due.

5. After cast 83 where the CTD hit bottom, the two upward thermistors were sheared off and the upward stalk had collapsed. I replaced the thermistors and re-attached the upward stalk to the frame - this was not exactly at the same height as it had been before.

6. Something to emphasise (and that would have been handy to know from the start) is that if you are having problems it is worth forcing the instrument to start logging by typing in the 'sl' (start logging) command, waiting for a few seconds and then hitting the space bar to see if bytes are being written to file. If this is the last thing you do before disconnecting the USB it would often work.




2016 12-Jun-2016 14:14:08
Temp [V]
dT/dt [V/s]
AX,AZ
06:00
09:00
12:00
15:00
18:00
21:00

Appendix 5 XBT Calibration Projects

Ann Thresher and Rebecca Cowley

XBTs measure upper ocean temperatures using a thermistor, and a calculated depth based on an assumed fall rate and time. It has been shown that this fall rate has changed over the history of the XBT resulting in a bias of the data in the archives.

In order to compute the real fall rate for XBTs of various vintages, it is necessary to drop them coincident with a CTD. An approximation of the correct fall rate is then calculated using the upper ocean thermal structure, matching features and generating new fall-rate coefficients. CSIRO has led this effort with Rebecca Cowley conducting these experiments whenever possible in order to completely characterize these changes through time.

XBTs of various ages were loaded onto *Investigator* with the aim of dropping them with CTDs during IN2016-V03. Because of the latitude range covered, this also gives us information about fall rates in water of different temperatures (which is also suspected of affecting XBT speed).

Two systems, the Ship's and the CSIRO Wireless systems, were used to simultaneously drop XBTs as a CTD was deployed. The goal was to complete as many XBTs as possible before the CTD dropped below their maximum depth. In most cases, we managed to drop 4-6 XBTs per system before the CTD reached 700-800db, providing good data for the comparison. More were dropped if they were shorter range XBTs or failed early.

During leg1, we dropped a total of 112 XBTs (62 on the CSIRO wireless system and 59 on the ship's system). During leg 2, we dropped a total of 88 XBTS using the Ship's system and 86 using the CSIRO Wireless system. A few of these were dropped for training purposes and will not be useful for analysis. For the entire voyage, 32 CTDs were used at latitudes ranging from 66^{o} S to 6^{o} 30 S. The table below shows the CTD stations vs XBT deployments.

Problems encountered were, for the most part, minor. Some boxes of XBTs had more failures (early wire break, no traces) than others. T-5 XBTs (rated to 1800db) were found to be useless and so were abandoned though we may try to collect some data when over shallower water. Given that these were manufactured in 1990, their failure is not surprising.

The wireless system sometimes had communication problems with the computer and both the box and the computer had to be rebooted several times during the tests. The Ship system had no issues, though it appeared to renumber at least one drop.

Some XBTs were misidentified early in the trip and these can hopefully be corrected. Others were dropped from the wrong system and so the serial numbers, batch dates, etc will need to be adjusted. All notes are in the log sheets.

All data and the summary log sheets can be found on the science drive in the XBT folder.

Latitude	CTD #	Ship System	CSIRO Wireless System
43° 32’ S to 43° 41’ S	NA. 26/04/2016	12 – T5 for hit bottom testing	12 – T5 for hit bottom testing
55° 30’ S to 55° 36’ S	NA. 29/04/2016	12 – T5 for hit bottom testing	12 – T5 for hit bottom testing
66° 30’ S	2	3 – DB	4 – DB
62° 30’ S	9	4 – DB	4 – DB
62° S	10	3 – DB	3 – DB
62° S	11	3 – DB	3 – DB
61° 30’ S	12	3 – DB	1 – DB
60° S	15	3 – DB	2 – DB
59° S	17	3 – DB	3 – DB
58° 30’ S	18	3 – DB	3 – DB
58° S	19	3 – DB	3 – DB
57° S	21	3 – DB	3 – DB
56° 30’S	22	3 – DB	3 – DB
55° 30’S	24	4 – DB	3 – DB
Totals Leg 1:	12	62	59
36 S	66	3 – T-5 – training/testing	3 – T-5 – training/testing
35º 40’ S	67	3 – DB	3 – DB mis-id’d as T-5s
35 º 20’ S	68	4 – DB	4 – DB
35 S	69	4 – DB	4 – DB
34º 30’ S	70	4 – DB	4 – DB
34 º S	71	4 – DB	4 – DB
13 º 30’ S	113	4 – T-4	4 – T-4
13 º S	114	4 – T-4	4 – T-4
12 º 30’ S	115	6 – T-4	5 – T-4
12 º S	116	5 – T-4	5 – T-4
11 º 30’ S	117	5 – T-4 serial #s switched with wireless	5 – T-4 serial #s switched with ship
11 º S	118	5 – T-4	5 – T-4
10 º 30’ S	119	6 – T-4	5 – T-4 Bad box
9 º 55’ S	120	7 – T-4	7 – T-4
9 º S	122	4 – DB batch date wrong	4 – DB batch date wrong
8 º 30’ S	123	4 – DB	4 – DB
8 º S	124	4 – DB	4 – DB
7 º 30’ S	125	4 – DB	4 – DB
7 º S	126	4 – DB	4 – DB

Latitude	**CTD #**	**Ship System**	**CSIRO Wireless System**
6 ° 30’ S	127	4 – DB	4 – DB
Totals Leg 2:	20	88	86
Overall totals	32	150	145

Appendix 6 Nitrogen processes, budgets, plankton and bacterial phylogeny along the p15 GO-SHIP line: From the ice edge up to the equator.

by Eric Raes, U.W.A

Introduction

The supply of biologically-available nitrogen (N) can be a bottleneck in the efficiency of the biological oceanic carbon pump. Reactive nitrogen (N_r) in the open ocean regulates primary productivity and a cascade of associated carbon-nitrogen coupled transformations mediated by both eukaryotic and prokaryotic microorganisms (Ward et al., 2013). An understanding of potential alterations at the base of the food chain particulary reductions in planktonic biomass is essential, as a decline (Boyce et al., 2010) or commumty shift (Montes-Hugo et al., 2009) in primary productivity will impact ecosystem services, such as O_2 production, carbon sequestration, biogeochemical cycling and fisheries (Lehodey et al., 2010, Hollowed et al., 2013, Séférian et al., 2014).

Rationale

While we are getting better insights in the microbial community and their taxonomy, uptake and rate measurements of N and C are still very sparse throughout the world oceans and are a high priority to accurately quantify C, N cycles and the associated primary productivity. Our research is motivated by the need to further enhance our fundamental knowledge of the N-cycle and the different biogeochemical and physical parameters that control primary productivity.

Aims

The main aim of this study was to contribute knowledge of important fluxes of key elements (nitrogen and carbon) in this largely unstudied region (from a biological oceanography point of view). In order to tackle this aim we investigated the relationships between dissolved inorganic nutrients, phytoplankton pigment composition, microbial community structures, dinitrogen fixation rates, NO_3^- and NH_4^+ assimilation rates, and nitrification rates along the p15 GO-SHIP line from 66˚S to 0˚S.

Specifically our objectives were:

1. To test whether N_2 fixation is a process facilitating planktonic CO_2 fixation along the whole p15 line.
2. To unravel the biogeochemical components of the N-cycle that control primary productivity and N regeneration.
3. To link primary productivity and N transformation processes to functional phylogenetic groups of marine protists and microbes (archaea and bacteria) involved in the C and N cycle through targeted molecular approaches which elucidate community structure and activity (functional gene expression).

Outcomes and benefits

The data arising from this study will be a major source of new information on N_2 fixation rates and the controls of the N-cycle contributing to regional primary productivity in the different water masses along the p15 GO-SHIP line. A basic understanding of the biological and physical oceanographic parameters that control primary productivity in the world's oceans is crucial to maintain clear conservation strategies of the natural marine ecology (Burrows et al., 2011). These data will provide new insights that will hopefully allow us to better understand, predict and manage the impacts of human induced climate changes.

Methods

Samples were taken for

- Picoplankton analysis, using flowcytometry back on land
    a. collaborations with University of Technology Sydney (UTS) and Macquarie University
- Chlorophyll *a* and phytoplankton pigment analysis, using HPLC back on land
    a. collaborations with CSIRO, University of Tasmania (UTAS) and Alfred Wegner Institute (AWI)
- DNA analyses using targeted functional gene expression analyses and high-throughput sequencing back on land
    a. collaborations with CSIRO and AWI
- Primary productivity, following isotopic tracer incorporation into the particulated matter, using stable isotopes ^{13}C, aboard using incubation bins
    a. collaborations with AWI
- Dissolved inorganic nitrogen uptake measurements, using standard ^{15}N protocols, aboard using incubation bins
    a. collaborations with AWI
- N_2-fixation rates, using ^{15}N gas as an injected tracer to measure fixation rates, aboard using incubation bins
    a. collaborations with Southern Cross University and AWI
- Nitrification rates
    a. collaborations with AWI

Note:

a. We have collected the first dissolved inorganic nitrogen assimilation and fixation rates along the entire p15 Line. These data will fill in a major knowledge gap in regards to N and C cycling in the world open oceans.

b. We have collected the first high resolution (every half a degree and depth stratified) data set for DNA analysis stretching from the ice edge up to the equator.

c. All these samples will be analysed back on land so unfortunately we don't have any preliminary results.

IN2016_V03 Genomics team: Nicole Hellessey, Swan Sow, Gaby Paniagua Cabarrus, Bernhard Tschitschko and Eric Raes

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Appendix 7 Inertial Navigation System tests

By Tobias Aldridge

Device Description:

The PHINS (PHotonic Inertial Navigation System) is a device capable of measuring all navigational parameters associated with the motion of a vehicle (e.g. heading, speed, position, and attitude). Designed to be used for applications such as AUV navigation, the PHINS can accept many forms of navigational aiding (e.g. GPS, acoustic, pressure, etc.); however, the unit is also capable of operating in the absence of external aids. The challenge is that the navigational accuracy of PHINS units degrades the longer they operate without said aiding. As the navigational accuracy depends heavily on the initial alignment, which in turn is a function of the forcing around the z-axis, the rate of degradation will also increase as a function of latitude.

What measurements, and where?

This cruise provided the perfect opportunity to test the behaviour of the PHINS technology at a range of different latitudes, with the aim of quantifying the effect of latitude on the accuracy of heading and position. To this end, the PHINS was operated continuously, with a repeating 12 hour testing regime, for the duration of the voyage. This testing regime included 2 hours of operation with GPS aiding for the calibration phase of the testing, and then 10 hours operation with no aiding, to measure the quality of the positioning.

Preliminary findings:

A very clear trend of increasing heading accuracy was found with a decreasing latitude, shown in Figure 1. This was expected, as the ability of an INS device to align with North is reduced with increasing latitude.

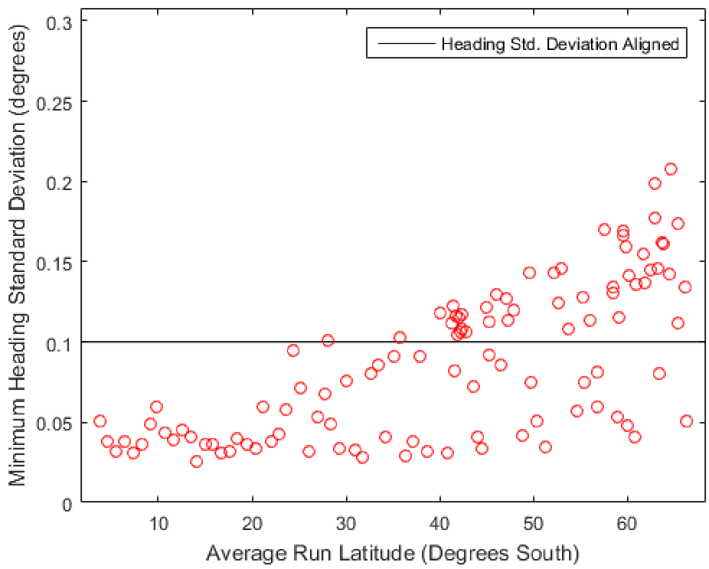

Figure 1: Preliminary results for PHINS standard deviation on heading. One data point per test. The device is considered aligned when the heading standard deviation is below 0.1 degrees

In the general operations on board an AUV, the PHINS will be supplemented with a feed from the on board Doppler velocity log (DVL), tracking the velocity of motion over the sea floor. For this configuration, the primary cause of INS position degradation is the difference between PHINS estimated heading and true heading. This will result in a position error of 0.05 – 0.1% of distance travelled. For example, 200 – 400m off after a distance of 400km travelled. As this is a function of heading accuracy, the potential for position error will increase with increasing latitude.

For a PHINS without any navigational aiding, the specified position accuracy is 0.6 nautical miles per hour error. It was expected that the position accuracy of the INS would improve with increasing latitude, as the heading uncertainty is reduced; however, preliminary results are showing no clear trend of improving position accuracy. These results are shown in Figure 2. Preliminary results are showing that the primary cause of position error for an unaided PHINS is an incorrect velocity estimation; this source of error is orders of magnitude higher than would be caused by heading uncertainty.

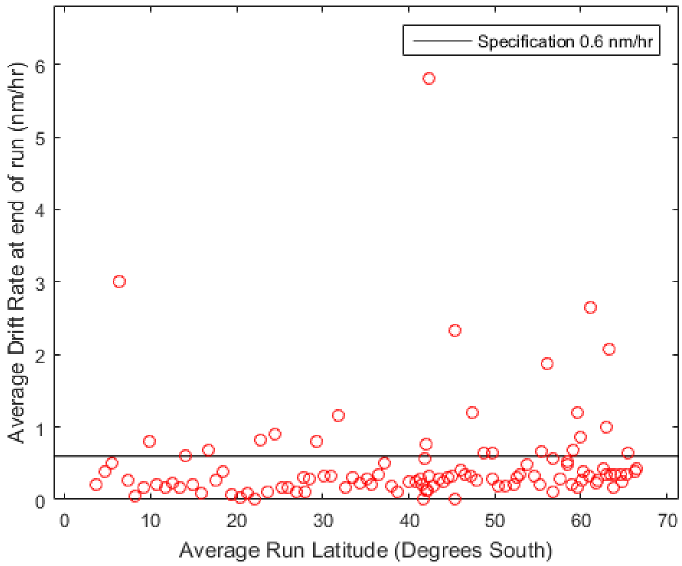

Figure 2: Preliminary results for PHINS rate of position 'drift'. One data point per test. PHINS specification for unaided operation is 0.6 nm/hr

How will these results be used?

These results will inform both AUV deployments at high latitudes in general and future ARC SRI Gateway AUV deployments specifically. This is particularly true for deployments under Antarctic ice sheets, as it is often not possible to employ bottom tracking while exploring the underside of an ice sheet.

Appendix 8 Atmospheric chemistry and aerosols

By Reece Brown

This voyage has seen the deployment of several pieces of aerosol instrumentation to investigate the chemical composition, size distribution, optical properties and cloud nucleating properties of marine aerosol over the southern hemisphere. These parameters are important in the quantification of regional contributions of aerosols to radiative forcing, and will help to improve meteorological and climate change models. With a few exceptions, the instrumentation has operated with only minor issues and a wealth of data has been successfully collected.

Two mass spectrometer systems were used to investigate the chemical composition of aerosols. Particle composition was analysed through the use of an ACSM, which provides online, high resolution chemical analysis of particles. Early data analysis shows mass concentrations of sulphate, with lower levels of organics, chlorine and ammonium. These results are consistent with the sea spray generated aerosol which are expected to be the primary source of aerosols in the open ocean. There were some periods of very high organic mass concentrations due to non-optimum wind conditions causing the diesel exhaust to blow over the sampling inlet. However, this effect was kept to a minimum due to careful ship directions placement during CTD deployments. A PTRMS system was used to perform analysis on water soluble species including DMS, however further data analysis is required before this data will be understood. Offline PM1 filter and VOC collections systems were also employed to allow for further chemical analysis at a later date.

Particle sizing measurements were performed utilizing two scanning mobility particle sizer (SMPS) systems, a NAIS, and an aerodynamic particle sizer (APS). The combination of equipment allowed for real time particle size measurements continuously from 0.5 nanometers up to 20 micrometres. The NAIS was also used to track potential particle formation events, however early analysis has not yielded any conclusive results. Particle concentrations were measured through a condensation particle counter (CPC) and were typically in the range of 200 – 300 particles per cubic centimetre of air when sampling clean ocean air. As a comparison a relatively clean city such as Brisbane will see concentrations ten times this value.

Aerosol cloud condensation properties were measured through the use of a cloud condensation nuclei counter (CCNC) and a volatility hygroscopicity tandem differential mobility analyser (VHTDMA). The CCNC concentrations were generally only slightly lower than the CPC readings, indicating that the vast majority of particles measured are potential cloud condensation nuclei. This result is expected as sea salt is very hygroscopic and will readily form cloud droplets given suitable circumstances. The VHTDMA system analysed the volatility and hygroscopicity of particles, which are important parameters in determining if a particle can become a cloud condensation nuclei.

The primary issues encountered during the first leg of IN2016_V03 were caused through sea spray entering into the inlet due to high sea swells. During leg two a similar issue was encountered due to the high humidity in the tropical regions causing condensation in the sampling lines. In both cases careful management of instrument setup and water traps, regular dryer maintenance, and clearing of condensation from the lines allowed for meaningful data to be collected despite these setbacks.

Appendix 9 - Helium Sampling

Stephanie Downes, Antarctic Climate and Ecosystems Co-operative Research Centre, Hobart, Tasmania

John Lupton, NOAA/Pacific Marine Environmental Laboratory, Newport, OR, USA

Helium is a passive tracer ideal for identifying hydrothermal activity and for tracing deep ocean circulation. However, helium has been sparsely sampled across Southern Ocean voyage transects and never before has it been sampled along the P15S line. On this voyage, 219 duplicate seawater samples were collected along 20 stations (Figure 1, Table 1). At each of the 20 stations, between 8 and 13 depths were sampled, paying particular attention to topographical features in the region to hopefully capture interesting hydrothermal activity close to mid-ocean ridges.

Water sampling

For each sample, a 24-inch copper tubing (5/8 inch in diameter) was filled with seawater drawn from the 10L Niskin bottles within two hours of the CTD arriving back on the ship. The copper tube was hermetically sealed (crimped) in three places using a hydraulic crimper to produce two 10-inch sealed duplicate samples. Directly after all samples for the station were crimped, the copper tubes were rinsed with fresh water, dried thoroughly, and stored in foam-lined cardboard boxes in fibreglass crates. Other than freezing of the crimper at the first few stations and a productive sea ice season eliminating the first proposed sampling station, all planned helium sampling stations and depths were accounted for.

Analysis

The helium isotopes will be processed and quality controlled onshore at the NOAA/Pacific Marine Environmental Laboratory (John Lupton). The samples will be processed to separate the dissolve gases from the water, followed by analysis of ^{3}He concentrations, ^{4}He concentrations and $^{3}He/^{4}He$ ratios using the extracted dissolved gases on a special mass spectrometer. Samples will be made publically available once onshore processing is completed.

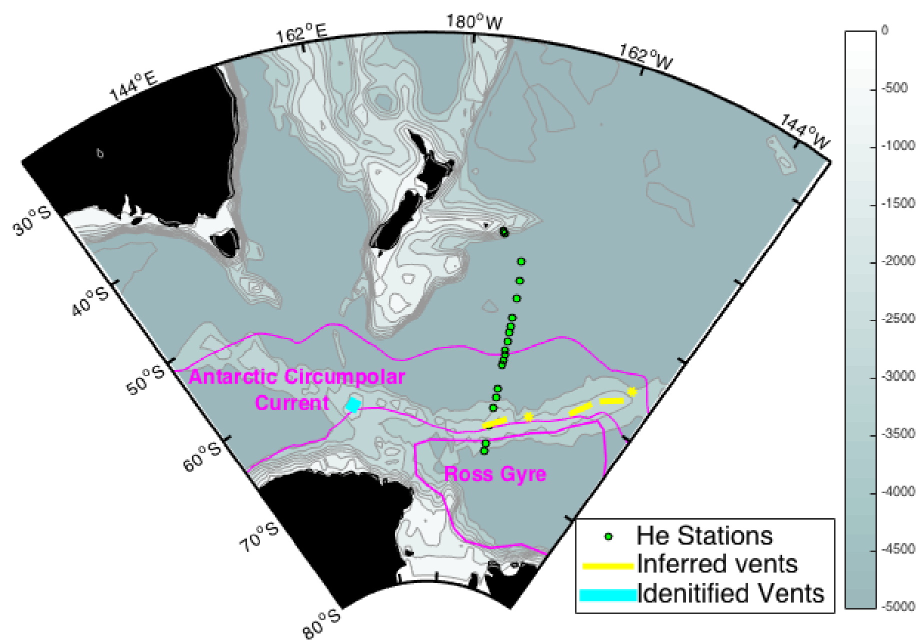

Figure 1: Helium stations (green) sampled. Also shown are major ocean currents (the Antarctic Circumpolar Current and Ross Gyre to the south), as well as previously inferred and identified hydrothermal activity (blue and yellow) within the vicinity of the P15S transect.

Table 1. Station/CTD numbers (STNNBR), locations and numbers of He samples.

STNNBR	**DATE yyyymmdd**	**TIME hhmm**	**LATITUDE**	**LONGITUDE**	**DEPTH db**	**SAMPLE NUMBER**
2	20160504	0844	-66.332	-170.008	3277	10
5	20160505	2145	-64.502	-170.004	2348	9
9	20160508	0650	-62.499	-169.992	2539	10
12	20160508	2149	-61.492	-169.997	3470	10
14	20160509	2335	-60.502	-169.991	3951	11
19	20160513	1219	-58.001	-170.010	4432	11
20	20160513	1911	-57.504	-170.006	5019	12
21	20160514	1414	-57.002	-169.998	5078	12
22	20160514	0926	-56.498	-170.009	5090	12
24	20160515	0441	-55.514	-170.011	4833	13
26	20160515	2000	-54.500	-170.003	4831	13
29	20160516	1637	-53.004	-170.011	5220	13
33	20160517	2141	-51.002	-170.010	5248	13
37	20160519	0215	-48.995	-170.004	5262	13
41	20160520	0649	-47.109	-170.466	5412	13
46	20160522	1639	-44.525	-173.502	3414	10
47	20160522	2335	-44.328	-173.746	3102	8
48	20160523	0620	-44.156	-173.938	1892	8
49	20160523	1542	-42.931	-174.785	1057	16
50	20160523	1819	-42.746	-174.653	1584	8

Appendix 10 Lowered ADCP Issues

Bec Cowley and Bernadette Sloyan, 20 May, 2016

The slave (upward, 300 kHz) and master (downward, 150 kHz) ADCPs on the CTD package were processed on-board. The processing software (LDEO LADCP) produced a warning error of a large offset in the heading between the upward and downward looking ADCP units. This error will result in incorrect velocity vectors when the data is processed.

The raw data files were loaded into RDI propriety software to investigate further the heading error. The tilt, pitch and roll of the instruments was reviewed. During the review there was found to be a time offset between the instruments where one lagged the other in tilt. The time stamps were further investigated and an offset was found between the slave and master time stamps (Figure 1).

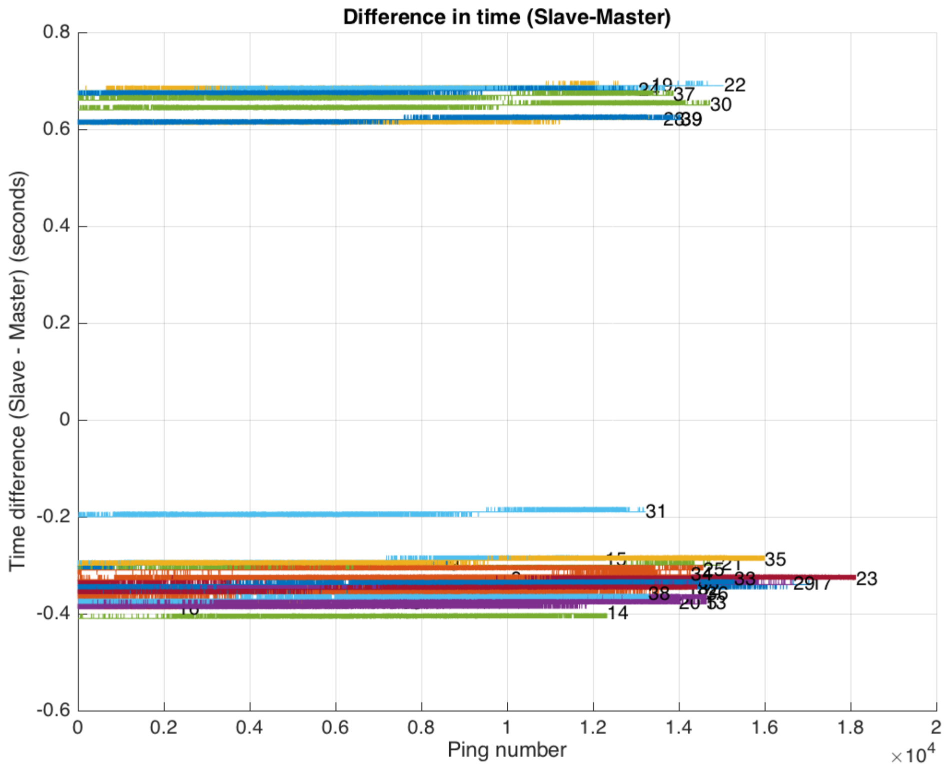

Figure 1. Difference in time stamps (Slave-Master) for each deployment (numbered).

We investigated applying a simple time offset to the raw data and re-processing, but this did not make any difference. A closer look at the heading values from the instruments gave a clear indication of the problem. The Master instrument has a poor heading record that is not consistent in it's behaviour. A single example from Cast 7 is shown in figure 2.

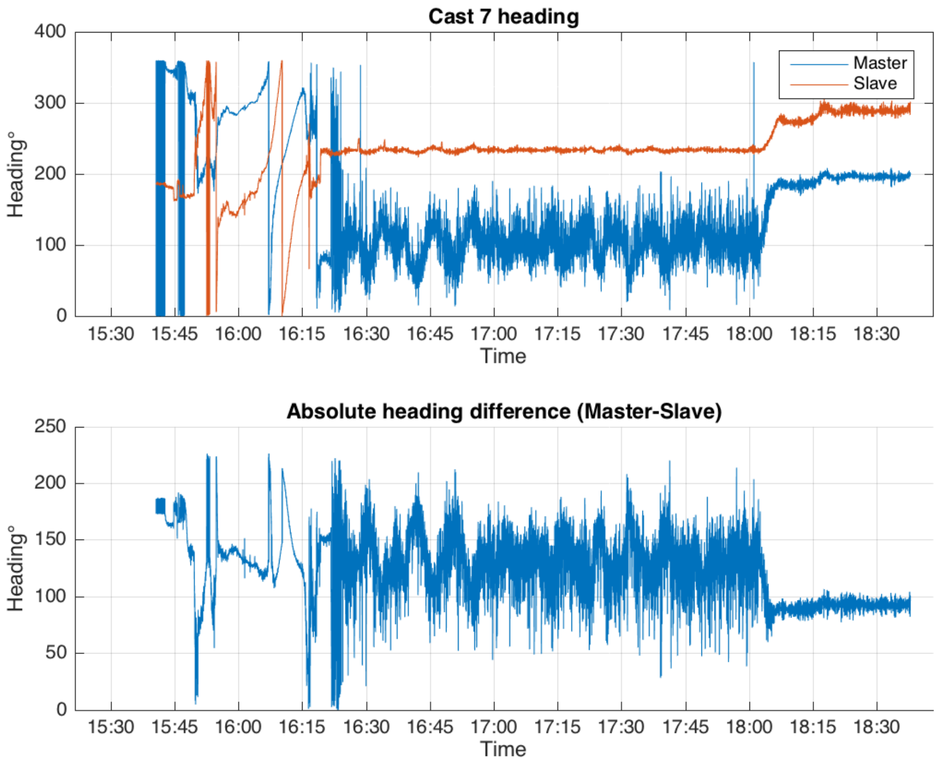

Figure 2. The upper panel shows the raw heading values for the master and slave, the lower panel the absolute difference between the two.

The tilt, pitch and roll for the master look comparable to the slave, but with an offset (Figure 3 and 4). This is the case for most of the stations. We processed the LADCP from the previous section and found the same heading error. Thus we suspect the unit was faulty prior to our voyage.

For this voyage we will process the LACDP data using only the slave heading data. Finally, during the voyage beam-4 of the downward looking unit failed.

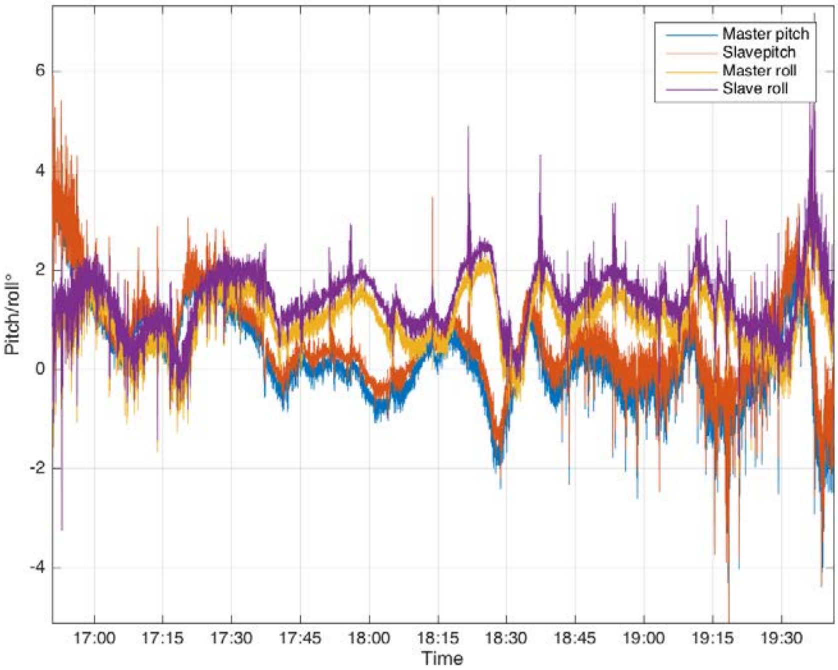

Figure 3. Master and slave pitch and roll from Station 7.

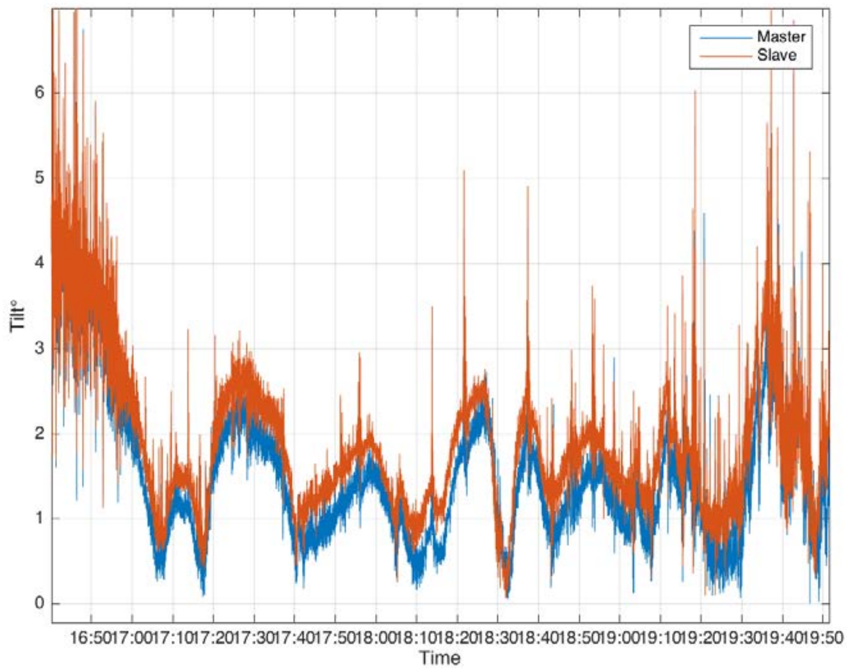

Figure 4. Master and slave tilt from station 7.