

## AAIW 2005

R/V KNORR, KN182-7

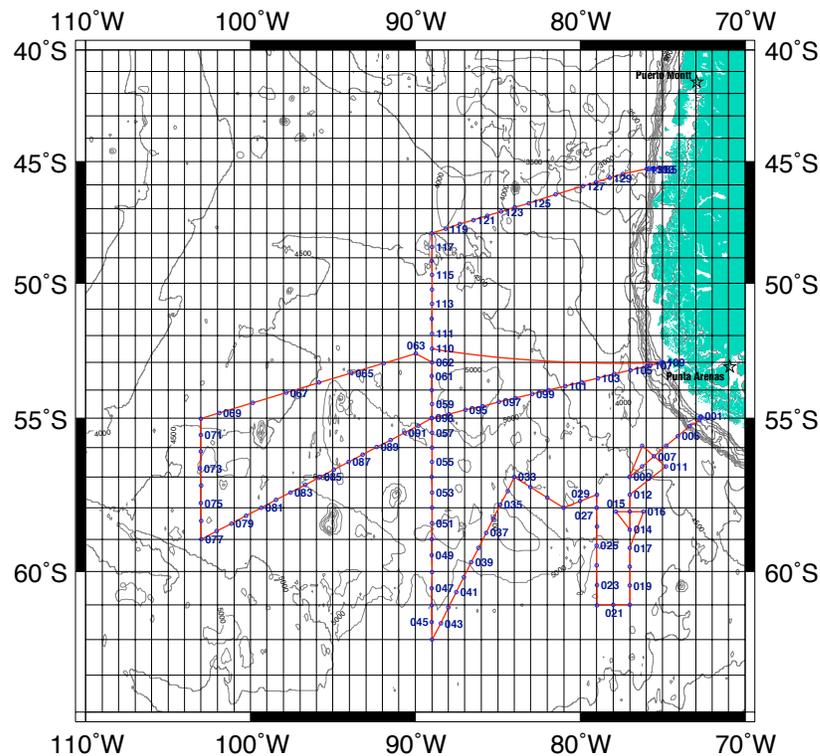
21 August 2005 - 6 October 2005

Punta Arenas, Chile - Puerto Montt, Chile

Chief Scientist: Dr. Teresa Chereskin

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### Preliminary Cruise Report 5 October 2005

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## Summary

A hydrographic survey consisting of LADCP/CTD/rosette sections, underway shipboard ADCP, XCTD profiling, float and drifter deployments in the southeast Pacific was carried out August to October 2005. The R/V Knorr departed Punta Arenas, Chile on 21 August 2005. A total of 135 LADCP/CTD/rosette stations were occupied, 399 XCTDs were launched, 13 ARGO floats and 20 surface drifters were deployed from 23 August - 5 October. Water samples (up to 24), LADCP, and CTD data were collected on each cast in most cases to within 10 meters of the bottom. Salinity, dissolved oxygen and nutrient samples were analyzed for up to 24 water samples from each cast of the principal LADCP/CTD/rosette program. Water samples were also measured for CO<sub>2</sub> and CFCs, and underway surface pCO<sub>2</sub>, N<sub>2</sub>O, temperature, conductivity, oxygen, and meteorological measurements were made. The cruise ended in Puerto Montt, Chile on 6 October 2005.

## Introduction

Antarctic Intermediate Water (AAIW) is a low salinity water mass that fills most of the southern hemisphere and the tropical oceans at about 800 to 1000 m depth. As the densest of the circumpolar Subantarctic Mode Waters (SAMW), AAIW is formed as a thick, outcropping mixed layer in the southeastern Pacific just north of the Subantarctic Front (SAF). SAMW and AAIW formation have a major impact on the oceanic sink for anthropogenic CO<sub>2</sub>, whose largest uncertainty is at intermediate depths. The goal of Knorr cruise 182-07 was to characterize the wintertime AAIW formation processes. A follow-on summer hydrographic survey of the AAIW outcropping region and the fronts that bound it is scheduled for January to March 2006.

A sea-going science team gathered from three oceanographic institutions participated on the cruise. Several other science programs were supported with no dedicated cruise participant. The science team and their responsibilities are listed below.

## Personnel

Duties	Name	Affiliation	email
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Scientific Personnel AAIW 2005

## Principal Programs

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Principal Programs of AAIW 2005

## Cruise Narrative

The Knorr departed Punta Arenas, Chile on 21 August 2005 at 0900 local. Almost immediately we have to for repairs on the starboard steering, which was not functioning when we left the dock. The repairs took about 8 hours during which time the various groups finished testing equipment and tying down gear. We also took the opportunity to deploy a shallow test cast in the Straits of Magellan. The other serious problem that was discovered in Punta Arenas was that the wire on both winches had only one good conductor. We used the starboard one for the duration of the survey. The condition of the wire influenced our choice of a 24-place over a 36-place rosette and dictated conservative wire speeds for this cruise. Another major factor influencing wire speed was wire tension, especially during times when we had several sets of large swells coming from multiple directions.

During AAIW, CTD stations at roughly 50 km spacing were supplemented by XCTD sampling every 15 to 20 km. Generally, three XCTDs were launched between CTD stations. Additionally, two intensive surveys were carried out in regions of deep mixed layers, steaming a diamond pattern centered on the main AAIW track, with dense XCTD sampling throughout and CTD stations at the corners. The first intensive survey began after CTD station 9, triggered by deep mixed layers (400 m) observed at stations 6 and 7. We turned back and steamed a diamond pattern centered on station 7, with CTD stations 8, 10, 6, and 11 located at the corners. The second intensive survey was triggered by crossing the Subantarctic Front (station 14). We turned back to survey the deep mixed layers north of the front. We again steamed a diamond pattern, centered on station 13, with CTD stations 14, 15, 12, and 16 at the corners. Surface drifters were deployed at the corners of the intensive surveys, accounting for 8 of our 20 deployments.

In total we made 6 crossings of the Subantarctic Front (SAF) and 2 crossings of the Polar Front (PF). Microwave SST images made for our region by Lynne Talley and downloaded from the internet were very helpful in tracking the fronts. Based on a 1980 cruise by McCartney, we anticipated that the first pair of SAF crossings along 77W and 79W, nearest to Drake Passage, would have the deepest mixed layers. In fact, we found equally deep mixed layers on the second pair of SAF crossings, located near/on the 89W meridian. The 89W PF crossing was our furthest south, to 62S.

The third pair of SAF crossings was our furthest west, meant to measure the SAMW upstream condition. ARGO floats supplied by Dean Roemmich (SIO) were deployed at predetermined sites, with the first deployments made along this section of our track. It was also along this portion of our survey that we encountered our heaviest seas and winds. The steaming speed fell below 9kts and our wire speed was often limited to 20 m/s for the upper 1500 m. From station 62 to 69, our station spacing was increased from 50 km to 100 km in order to keep on schedule, and the density of XCTDs was increased to compensate. However, strong and gusty winds (above 50 kts) were often the cause of XCTD cast failure along the westward line from station 62 to station 70. Finally, at station 70, conditions were deemed

unsafe for deployment and we have to for 24 hours until winds and seas abated. Sea cable re-terminations were required after several of these stations to remove wire kinks caused by snap loading of the wire by ship roll/heave.

Our weather improved from stations 77 to 92, but from 92 to 100 we again encountered high winds and swell as we continued east towards the Chilean coast. However, we maintained 50 km station spacing, closer at the coast. From the coast, we transited back to pick up our line northward along 89W. The 89W line repeats the 1980 McCartney cruise line, as does our final eastward segment to the coast along 45S. On our final eastward segment we replaced 3 stations with XCTD casts, because of time constraints.

Science operations halted at 1000 local on 5 October 2005 to begin the 26 hour steam to Puerto Montt, which required making rendezvous with pilot boats at two locations for our final transit through Chilean coastal waters.

The science parties and the officers and crew of the Knorr are to be commended for their hard work and careful measurements. A CDROM of preliminary data obtained within the Chilean EEZ was produced and given to the Chilean observer/participating scientist, Eduardo Navarro.

### Description of Measurement Techniques

#### 1. CTD/Hydrographic Measurements Program

The basic CTD/hydrographic measurements consisted of salinity, dissolved oxygen and nutrient measurements made from water samples taken on CTD/rosette casts, plus pressure, temperature, salinity, dissolved oxygen and transmissometer from CTD profiles. A total of 136 CTD/rosette casts were made usually to within 10 meters of the bottom. No major problems were encountered during the operation. The distribution of samples is illustrated in figure 1.0 - 1.8.

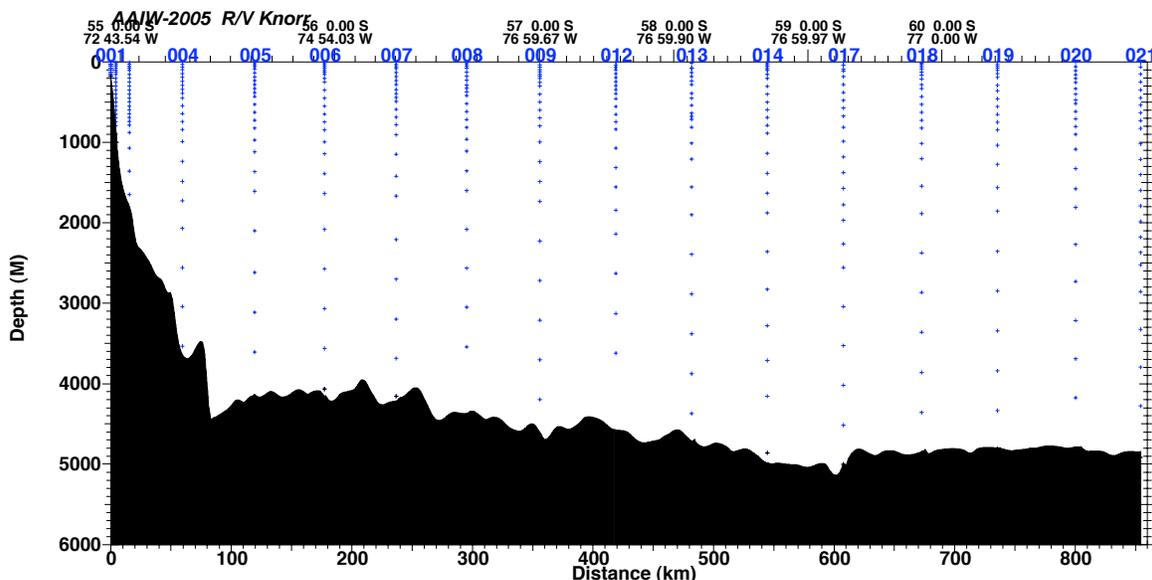


Figure 1.0 Sample distribution, stations 1-21.

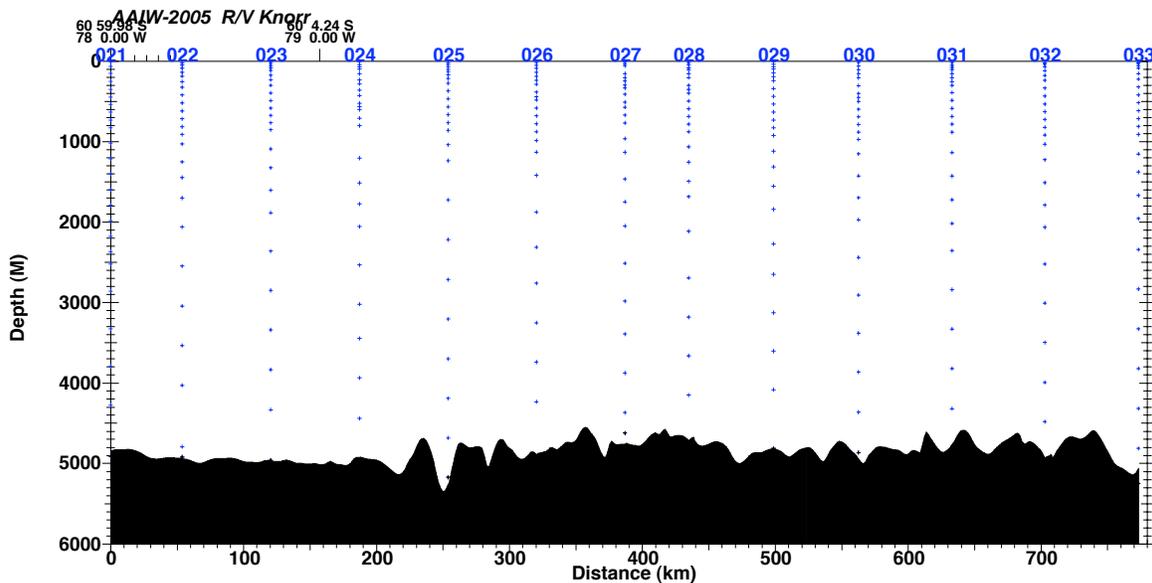


Figure 1.1 Sample distribution, stations 21-33.

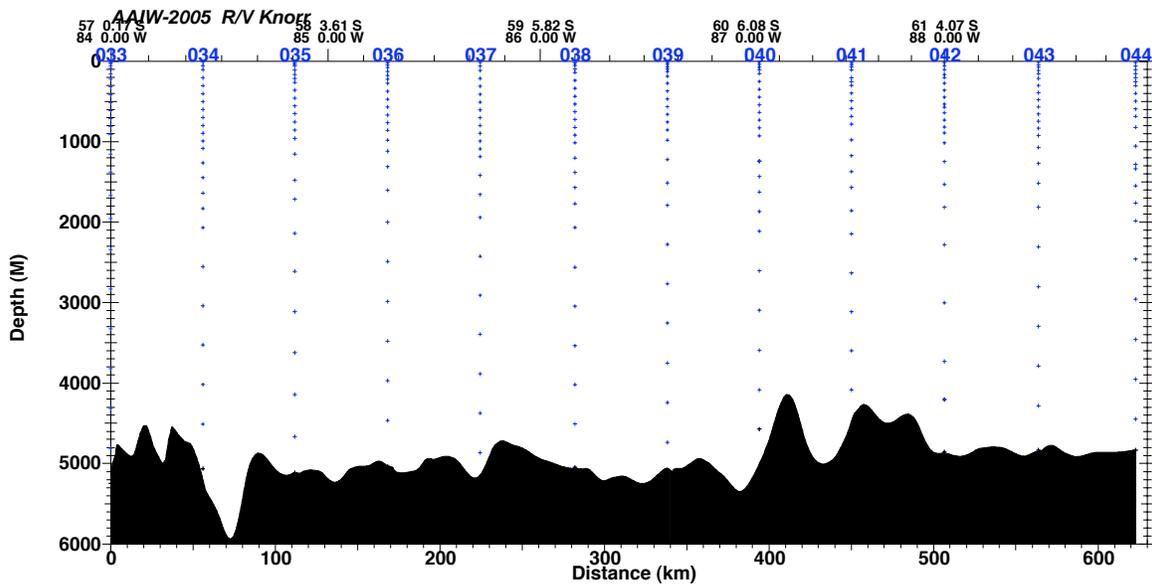


Figure 1.2 Sample distribution, stations 33-44.

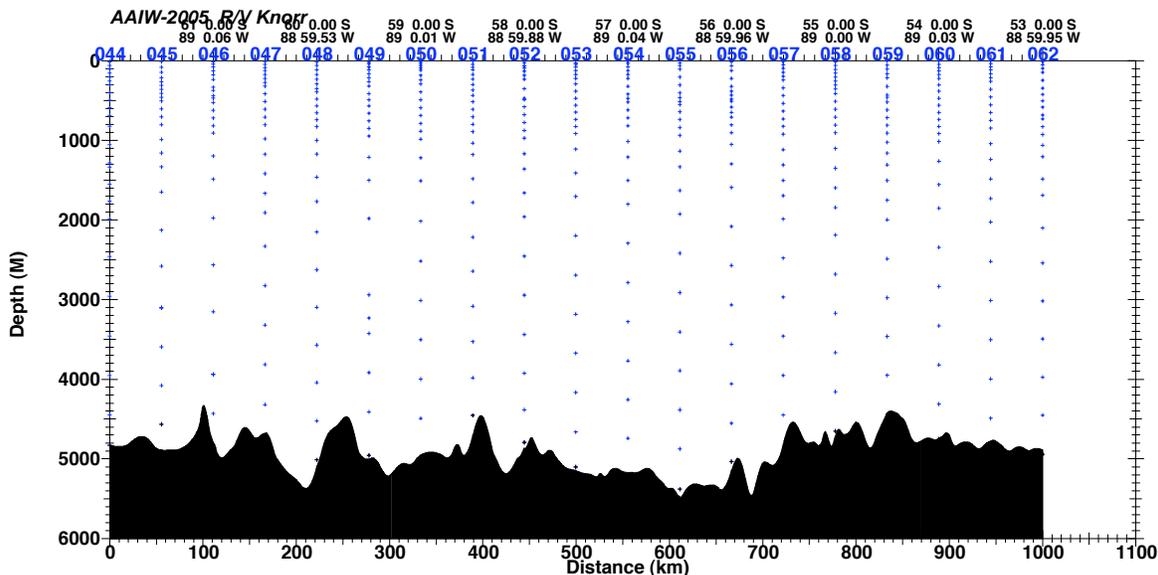


Figure 1.3 Sample distribution, stations 44-62.

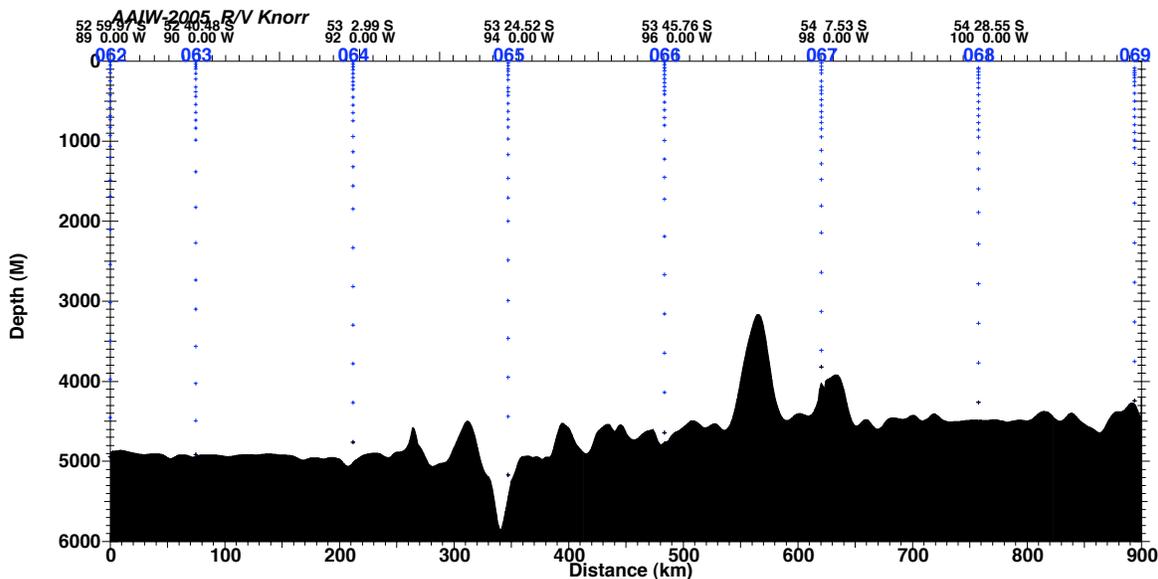


Figure 1.4 Sample distribution, stations 62-70.

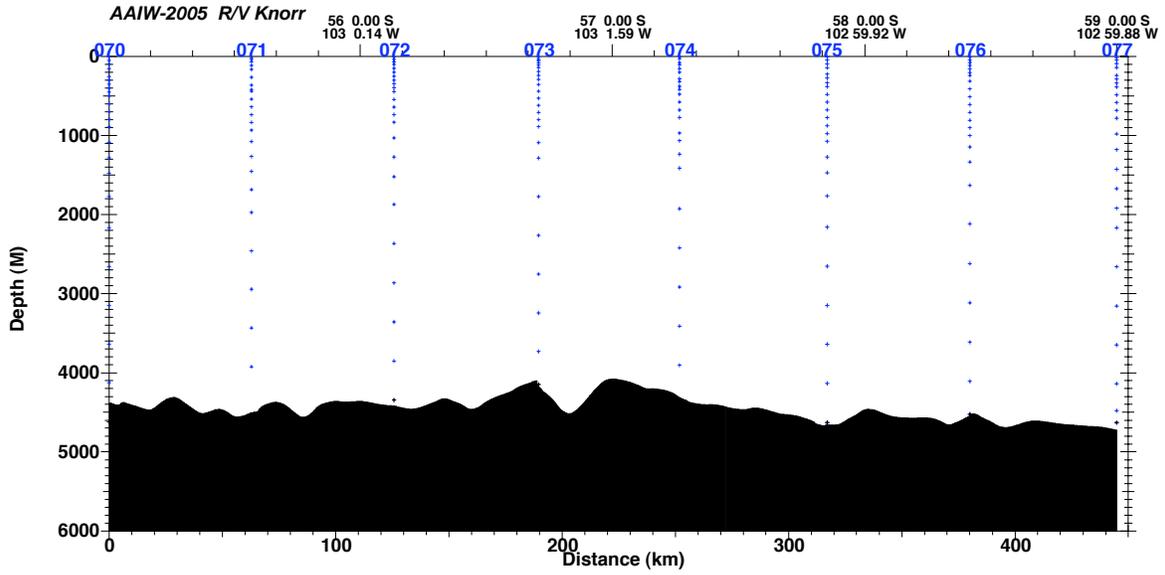


Figure 1.5 Sample distribution, stations 70-77.

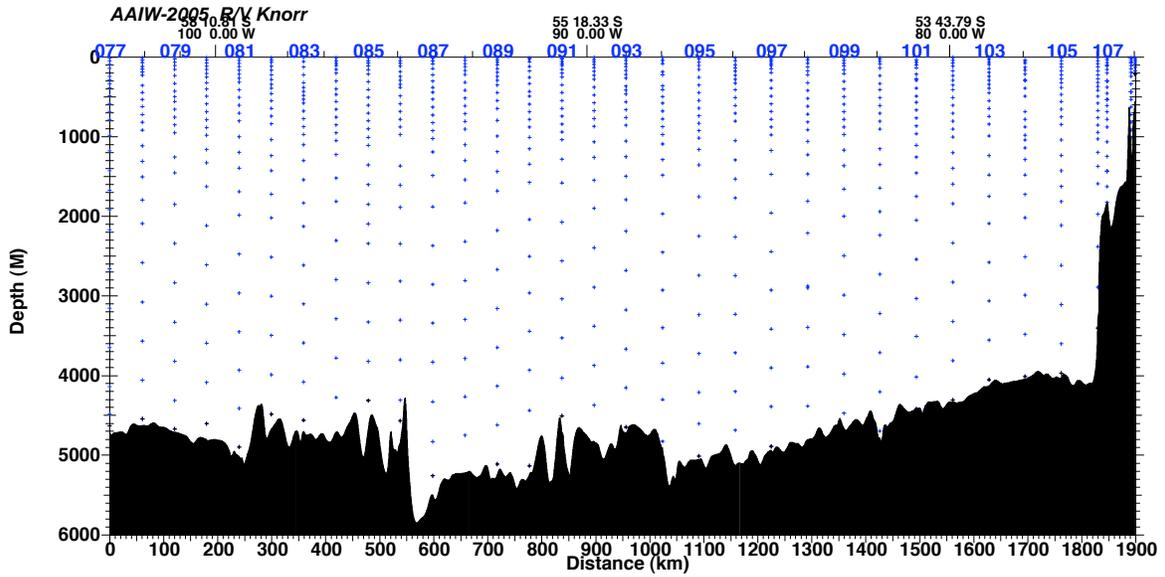


Figure 1.6 Sample distribution, stations 77-109.

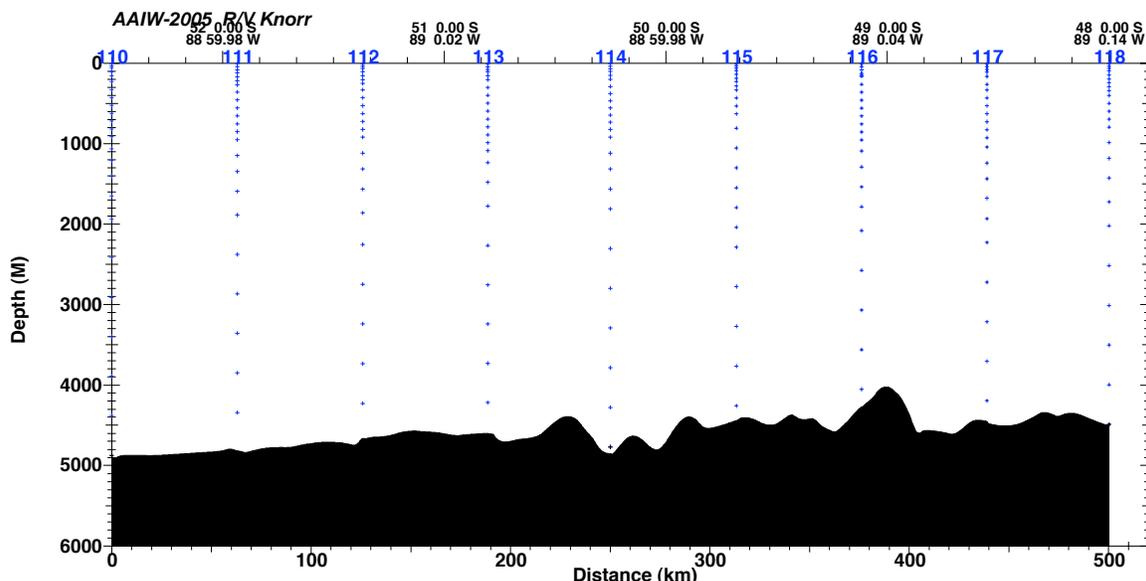


Figure 1.7 Sample distribution, stations 110-118.

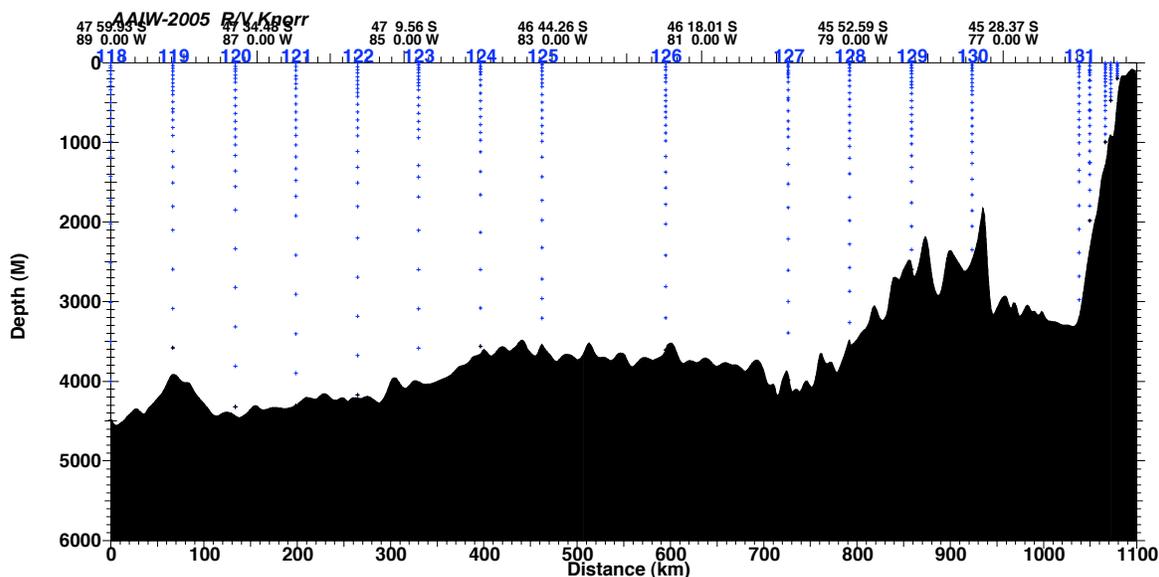


Figure 1.8 Sample distribution, stations 118-136.

### 1.1. Water Sampling Package

LADCP/CTD/rosette casts were performed with a package consisting of a 24-bottle rosette frame (ODF), a 24-place pylon (SBE32) and 24 10-liter Bullister bottles (ODF). Underwater electronic components consisted of a Sea-Bird Electronics (SBE) 9plus CTD (ODF #796) with dual pumps, dual temperature (SBE3plus), dual conductivity (SBE4), dissolved oxygen (SBE43) and transmissometer (Wetlabs C-Star); an SBE35RT Digital Reversing Thermometer, an RDI LADCP (Broadband 150kHz) and a Simrad altimeter.

The CTD was mounted vertically in an SBE CTD frame attached to the bottom center of the rosette frame. The SBE4 conductivity and SBE3plus temperature sensors and their respective pumps were mounted vertically as recommended by SBE. Pump exhausts were attached to inside corners of the CTD cage and directed downward. The entire cage assembly was then mounted on the bottom ring of the

rosette frame, offset from center to accommodate the pylon, and also secured to frame struts at the top. The SBE35RT temperature sensor was mounted vertically and equidistant between the T1 and T2 intakes. The transmissometer was mounted horizontally along the rosette frame adjacent to the CTD. The altimeter was mounted on the outside of the bottom frame ring. The LADCP was vertically mounted inside the bottle rings on the opposite side of the frame from the CTD. The locations of bottles 16, 17 and 18 were adjusted to accommodate the LADCP.

The rosette system was suspended from a UNOLS-standard three-conductor 0.322" electro-mechanical sea cable. The R/V Knorr's starboard-side Markey winch was used for all casts. It was discovered at the beginning of the cruise that the two sea cables on board had only a single functional conductor each. Sea cable reterminations were made prior to casts 22/1, 70/1, 71/1, 73/1 and 110/1. Cast 75/1 was aborted at 212m on the downcast due to sea conditions.

The deck watch prepared the rosette 10-20 minutes prior to each cast. The bottles were cocked and all valves, vents and lanyards were checked for proper orientation. Once stopped on station, the LADCP was turned on and the rosette moved into position under the starboard-side squirt boom using an air-powered cart and tracks. The CTD was powered-up and the data acquisition system in the main lab started when directed by the deck watch leader. Tag lines were threaded through the rosette frame, and syringes were removed from the CTD intake ports. The winch operator was directed by the deck watch leader to raise the package, the boom and rosette were extended outboard and the package quickly lowered into the water. The tag lines were removed and the package was lowered to 10 meters, by which time the sensor pumps had turned on. The winch operator was then directed to bring the package back to the surface (0 winch wireout) and to begin descent. The entry procedure was frequently modified as dictated by weather and sea conditions and for many casts no attempt was made to return close to the surface prior to descent.

Each rosette cast was usually lowered to within 10 meters of the bottom, using the altimeter to determine a safe distance.

On the up cast the winch operator was directed to stop at each bottle trip depth. The CTD console operator waited 30 seconds before tripping a bottle to insure the package wake had dissipated and the bottles were flushed, then an additional 10 seconds after receiving the trip confirmation to allow the SBE35RT temperature sensor time to make a measurement. The winch operator was then directed to proceed to the next bottle stop.

Sea conditions were sufficiently poor toward the end of several casts that no stops were made shallower than 200m. In these cases, the rosette was hauled at a constant rate (20m/min) and the remaining bottles closed "on-the-fly". These bottles have a quality code of "4" (did not trip correctly) associated with them and are well-documented.

Standard sampling depths were used throughout AAIW 2005, depending on the overall water depth (table 1.1.0). These standard depths were staggered every other station.

Recovering the package at the end of the deployment was essentially the reverse of launching, with the additional use of poles and snap-hooks to attach tag lines, and air-tuggers on the tag lines for added safety and stability. The rosette was moved into the forward hangar for sampling. The bottles and rosette were examined before samples were taken, and anything unusual noted on the sample log.

Each bottle on the rosette had a unique serial number. This bottle identification was maintained independently of the bottle position on the rosette, which was used for sample identification. Six bottles were replaced on this cruise, and various parts of bottles were occasionally changed or repaired.

Routine CTD maintenance included soaking the conductivity and DO sensors in fresh water between casts to maintain sensor stability. Rosette maintenance was performed on a regular basis. O-rings were changed as necessary and bottle maintenance was performed each day to insure proper closure and sealing. Valves were inspected for leaks and repaired or replaced as needed.

(1)	top bottle within sight of the surface
(2)	bottom bottle within 10 meters of bottom
(3)	0-about 500 meters: spacing no greater than 50-60 meters
(4)	500-800 meters: spacing no greater than 100 meters
(5)	800-1200 meters: spacing no greater than 200 meters
(6)	1200-2000 meters: spacing no greater than 350 meters
(7)	2000-bottom: spacing no greater than 500 meters
(8)	bottom of SAMW: resolve the property break with one bottle above and one below if the layer is obvious (within 50 meters of break)
(9)	AAIW if obvious salinity minimum (north of SAF): try to hit the minimum
(General)	Stagger the sampling so that sample depths are not exactly the same from one to the next.

**Table 1.1.0** AAIW 2005 water sampling guidelines.

## 1.2. Underwater Electronics Packages

CTD data were collected with a SBE9*plus* CTD (ODF #769). This instrument provided pressure, dual temperature (SBE3), dual conductivity (SBE4), dissolved oxygen (SBE43), transmissometer (Wetlabs SeaStar) and altimeter (Simrad 807 or 1007) channels. The CTD supplied a standard SBE-format data stream at a data rate of 24 frames/second (fps).

Sea-Bird SBE32 24-place Carousel Water Sampler	S/N 3223219-0320
Sea-Bird SBE35RT Digital Reversing Thermometer	S/N 35-0034
Sea-Bird SBE9 <i>plus</i> CTD	S/N 09P39801-0796
Paroscientific Digiquartz Pressure Sensor	S/N 98627
Sea-Bird SBE3 <i>plus</i> Temperature Sensor	S/N 03P-4486 (Primary)
Sea-Bird SBE3 <i>plus</i> Temperature Sensor	S/N 03P-4476 (Secondary)
Sea-Bird SBE4C Conductivity Sensor	S/N 04-3023 (Primary)
Sea-Bird SBE4C Conductivity Sensor	S/N 04-3002 (Secondary, 1/1-72/1)
Sea-Bird SBE4C Conductivity Sensor	S/N 04-2319 (Secondary, 73/1-136/1)
Sea-Bird SBE43 DO Sensor	S/N 43-0872 (1/1-32/1, 35/1)
Sea-Bird SBE43 DO Sensor	S/N 43-0185 (33/1-34/1, 36/1, 37/1-136/1)
Wetlabs Sea-Star Transmissometer	S/N 327DR (owned by TAMU)
Roll and Pitch Sensor	S/N SBE13-475
Accelerometer Sensor	S/N SBE13-471
Simrad 807 Altimeter	S/N 9711090
Simrad 1007 Altimeter	S/N 20174
RDI Broadband 150khz LADCP	S/N 1394
LADCP Battery Pack	

**Table 1.2.0** AAIW 2005 Rosette Underwater Electronics.

The CTD was outfitted with dual pumps. Primary temperature, conductivity and dissolved oxygen were plumbed on one pump circuit and secondary temperature and conductivity on the other. The sensors were deployed vertically. The primary temperature and conductivity sensors (T1 #03P-4486 and C1 #04-3023) were used for reported CTD temperatures and conductivities on all casts. The secondary temperature and conductivity sensors were used for calibration checks.

The SBE9*plus* CTD and SBE35RT temperature sensor were both connected to the SBE32 24-place pylon providing for single-conductor sea cable operation. The sea cable armor was used for ground (return). Power to the SBE9*plus* CTD (and sensors), SBE32 pylon, SBE35RT and Simrad 807 altimeter was provided through the sea cable from the SBE11*plus* deck unit in the main lab.

### 1.3. Navigation and Bathymetry Data Acquisition

Navigation data were acquired at 1-second intervals from the ship's C-Nav GPS receiver by one of the Linux workstations beginning August 21. Data from the ship's Knudsen 320B/R Echosounder (12 KHz transducer) were also acquired and merged with the navigation. The Knudsen bathymetry data were noisy and subject to washing out when the seas were choppy or the ship's bow thruster engaged.

Bathymetric data from the ship's multibeam echosounder system (Seabeam 2000) were also logged and archived independently.

### 1.4. CTD Data Acquisition and Rosette Operation

The CTD data acquisition system consisted of an SBE-11 *plus* (V2) deck unit and three networked generic PC workstations running Fedora Core Linux. Each PC workstation was configured with a color graphics display, keyboard, trackball and DVD+RW drives. One of the three systems also had 8 additional RS-232 ports via a Control Rocketport PCI serial controller. The systems were connected through a 100BaseTX ethernet switch, which was also connected to the ship's network. These systems were available for real-time operational and CTD data displays, and provided for CTD and hydrographic data management and backup.

One of the workstations was designated the CTD console and was connected to the CTD deck unit via RS-232. The CTD console provided an interface and operational displays for controlling and monitoring a CTD deployment and closing bottles on the rosette.

CTD deployments were initiated by the console watch after the ship had stopped on station. The watch maintained a console operations log containing a description of each deployment, a record of every attempt to close a bottle and any pertinent comments. The deployment and acquisition software presented a short dialog instructing the operator to turn on the deck unit, examine the on screen CTD data displays and to notify the deck watch that this was accomplished.

Once the deck watch had deployed the rosette, the winch operator would begin the descent. When permitted by sea conditions, the rosette was lowered to 10 meters, raised back to the surface then lowered for the descent. This procedure was adopted to allow the immersion-activated sensor pumps time to start and flush the sensors.

Profiling rates were frequently dictated by sea conditions but never exceeded 60m/minute.

The progress of the deployment and CTD data quality were monitored through interactive graphics and operational displays. Bottle trip locations were decided and transcribed on the console and sample logs. The sample log would later be used as an inventory of samples drawn from bottles.

The combination of altimeter distance, CTD depth, winch wire-out and echo-sounder depth provided reliable, precise control of package distance from the bottom and allowed routine approaches to within 10 meters.

Bottles were closed on the up cast by operating an on-screen control. The winch operator was given a target wire-out for the bottle stop, proceeded to that depth and stopped. Bottles were tripped at least 30 seconds after stopping to allow the rosette wake to dissipate and the bottles to flush. The winch operator was instructed to proceed to the next bottle stop at least 10 seconds after closing bottles to allow the SBE35RT calibration temperature sensor time to make a measurement.

After the last bottle was tripped, the console watch directed the deck watch to bring the rosette on deck. Once on deck, the console watch terminated the data acquisition, turned off the deck unit and assisted with rosette sampling.

### 1.5. CTD Data Processing

The shipboard CTD data acquisition was the first stage in shipboard processing. The raw CTD data were converted to engineering units, filtered, response-corrected, calibrated and decimated to a more manageable 0.5 second time-series. The laboratory calibrations for pressure, temperature and conductivity were applied at this time. The 0.5 second time-series data were used for real-time graphics during deployments, and were the source for CTD pressure and temperature associated with each rosette bottle. Both the raw 24hz data and the 0.5 second time-series were stored for subsequent processing

steps.

At the completion of a deployment a series of processing steps were performed automatically. The 0.5 second time-series data were checked for consistency, clean sensor response and calibration shifts. A 2 decibar pressure-series was then generated from the up cast. The up cast data were selected because of missing near-surface down cast data in many of the deployments due to sea conditions. Both the 2 decibar pressure-series and 0.5 second time-series data were then made available for downloading, plotting and reporting on the shipboard cruise website.

CTD data were routinely examined for sensor problems, calibration shifts and deployment or operational problems. The primary and secondary temperature sensors (SBE 3) were compared to each other and to the SBE35 temperature sensor. CTD conductivity sensors (SBE 4) were compared and calibrated by examining differences between CTD and check-sample conductivity values. The CTD dissolved oxygen sensor data were calibrated to check-sample data. Additional deep TS and theta- $O_2$  comparisons were made between down and up casts as well as with adjacent deployments. Vertical sections were made of the various properties derived from sensor data and checked for consistency.

A total of 136 casts were made (including 1 aborted cast). The 24-place 10-liter rosette and CTD #796 were used on all casts.

### 1.6. CTD Sensor Laboratory Calibrations

Laboratory calibrations of the CTD pressure, temperature, conductivity, dissolved oxygen and the SBE35RT Digital Reversing Thermometer sensors were performed prior to AAIW 2005 . The calibration dates are listed in table 1.6.0.

Sensor	S/N	Calibration Date	Calibration Facility
Paroscientific Digiquartz Pressure	98627	7-July-05	SIO/ODF
Sea-Bird SBE3 <i>plus</i> T1 Temperature	03P-4486	7-July-05	SIO/ODF
Sea-Bird SBE3 <i>plus</i> T2 Temperature	03P-4476	7-July-05	SIO/ODF
Sea-Bird SBE4C C1 Conductivity	04-3023	14-July-05	SBE
Sea-Bird SBE4C C2 Conductivity	04-3002	14-July-05	SBE
Sea-Bird SBE4C C2 Conductivity	04-2319	04-March-05	SBE
Sea-Bird SBE43 Dissolved Oxygen	43-872	N/A	SBE
Sea-Bird SBE43 Dissolved Oxygen	43-848	N/A	SBE
Sea-Bird SBE35RT Digital Reversing Thermometer	35-0034	18-May-05	SIO/ODF

**Table 1.6.0** AAIW 2005 CTD sensor laboratory calibrations.

### 1.7. CTD Shipboard Calibration Procedures

CTD #796 was used for all AAIW 2005 casts. The CTD was deployed with all sensors and pumps aligned vertically, as recommended by SBE. The primary temperature and conductivity sensors (T1 & C1) were used for all reported CTD data on all casts. The secondary temperature and conductivity sensors (T2 & C2) served as calibration checks for the primary sensors. The SBE35RT Digital Reversing Thermometer (S/N 35-0034) served as an independent calibration check. *In-situ* salinity and dissolved  $O_2$  check samples collected during each cast were used to calibrate the conductivity and dissolved  $O_2$  sensors.

#### 1.7.1. CTD Pressure

The Paroscientific Digiquartz pressure transducer (S/N 98627) was calibrated in July 2005 at the SIO/STS Calibration Facility. Calibration coefficients derived from the calibration were applied to raw pressures during each cast. Residual pressure offsets (the difference between the first and last submerged pressures) were examined to check for calibration shifts. All were < 0.5db, and the sensor exhibited < 0.2 db offset shift over the period of use. No additional adjustments were made to the calculated pressures.

### 1.7.2. CTD Temperature

A single primary temperature sensor (SBE 3, S/N 03P-4486) and secondary temperature sensor (SBE 3, S/N 03P-4476) served the entire cruise. Calibration coefficients derived from the pre-cruise calibrations were applied to raw primary and secondary temperatures during each cast.

Two independent metrics of calibration accuracy were examined. The primary and secondary temperatures were compared at each rosette trip, and the SBE35RT temperatures were compared to primary and secondary temperatures at each rosette trip.

Calibration accuracy was first examined by tabulating T1-T2 over a range of pressures (bottle trip locations) for each cast. These comparisons are summarized in figure 1.7.2.0.

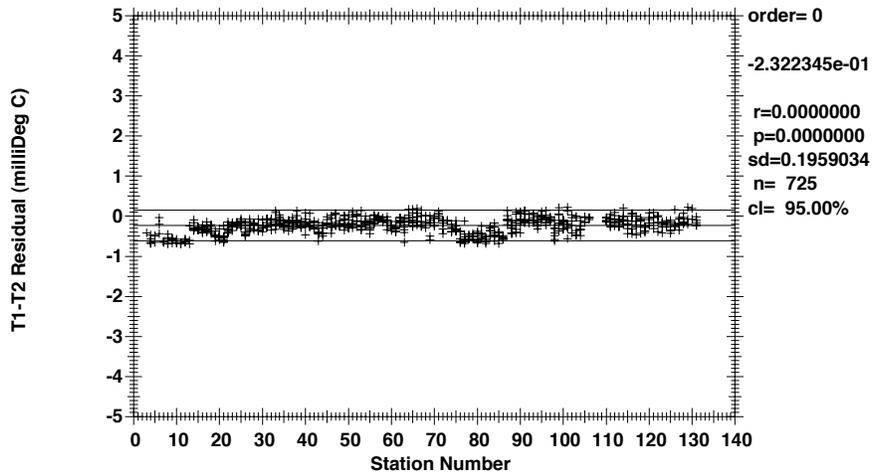


Figure 1.7.2.0 T1-T2 by station, p>2000db.

Although there appears to be a slight ( $<0.0003^{\circ}\text{C}$ ) drift between the sensors over the cruise, it is less than than the calibration accuracy. The 95% confidence limit for the mean differences is  $<0.0008^{\circ}\text{C}$ .

The SBE35RT Digital Reversing Thermometer is an internally-recording temperature sensor that operates independently of the CTD. It is triggered by the SBE32 pylon in response to a bottle trip. According to the Manufacturer's specifications the typical stability is  $0.001^{\circ}\text{C}/\text{year}$ . The differences between the SBE35RT and T1 (primary CTD temperature) are summarized in figure 1.7.2.1, and between the SBE35RT and T2 (secondary CTD temperature) in figure 1.7.2.2.

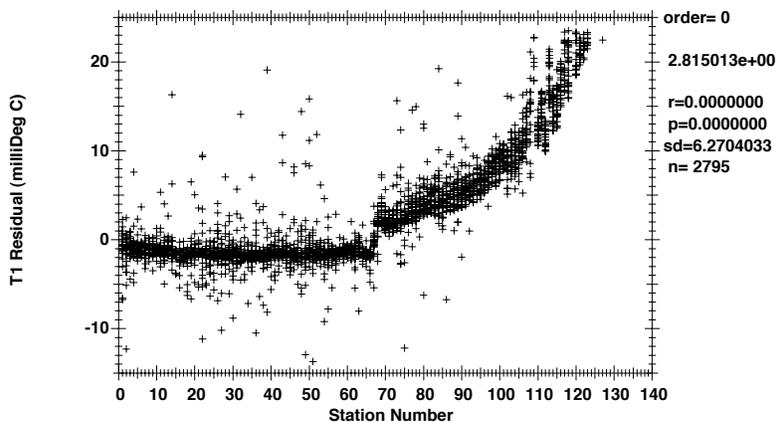


Figure 1.7.2.1 SBE35RT-T1 by station, p>2000db.

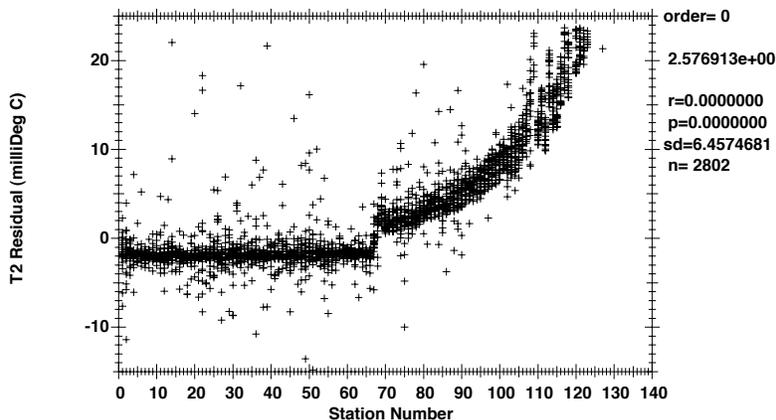


Figure 1.7.2.1 SBE35RT-T2 by station, p>2000db.

The SBE35RT used on AAIW 2005 was calibrated in May 2005 at which time it was reported to have < -0.0002°C correction over the entire operating range. The sensor was used for a 40-day cruise prior to AAIW 2005 during which it exhibited a -0.00082 °C offset relative to the CTD sensors. Evidently the SBE35RT began to drift significantly on 67/1. Examining casts 1/1-66/1, the mean differences are -0.0017988°C for SBE35RT-T1 and -0.0020826°C for SBE35RT-T2. Since T1 and T2 had been calibrated more recently (July 2005) than the SBE35RT, had not been used prior to AAIW 2005 since calibration and had a mean calibrated difference of -0.00023°C the SBE35RT differences were only used to check for calibration shifts. No additional corrections were applied to either T1 or T2 temperatures.

Post-cruise calibrations for all the temperature sensors are pending.

### 1.7.3. CTD Conductivity

A single primary conductivity sensor (SBE 4, S/N 04-3023) and two secondary conductivity sensors (SBE 4, S/N 04-3002 1/1-72/1, S/N 04-2319 73/1-136/1) served the entire cruise. Conductivity sensor calibration coefficients derived from the pre-cruise calibrations were applied to raw primary and secondary conductivities.

Comparisons between the primary and secondary sensors and between each of the sensors to check sample conductivities (conductivity calculated from bottle salinities) were used to derive conductivity corrections. None of the sensors showed any appreciable conductivity slope. The second C2 sensor used (04-2319) showed a slight (9.65e-8mS/cm/db) pressure slope. C1 was determined to have a slight drift amounting to a +0.0021 mS/cm offset change over the cruise. This drift correction was actually applied in 5 separate groupings as determined by secondary sensor and bottle conductivity differences. C2 #3002 had a constant offset of -0.0012mS/cm relative to corrected C1. C2 #2319 had a constant offset of -0.00012mS/cm for casts 73/1-109/1, and +0.00066mS/cm for 110/1-136/1 relative to corrected C1.

The comparison of the primary and secondary conductivity sensors by station, after applying shipboard corrections, is summarized in figure 1.7.3.0.

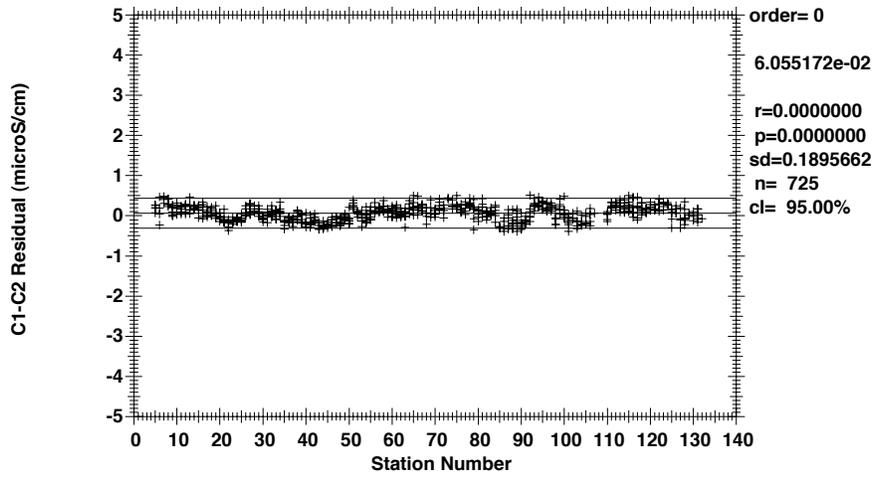


Figure 1.7.3.0 C1 and C2 conductivity differences by cast,  $p > 2000$ db.

Salinity residuals after applying shipboard T1/C1 corrections are summarized in figures 1.7.3.1 through 1.7.3.3.

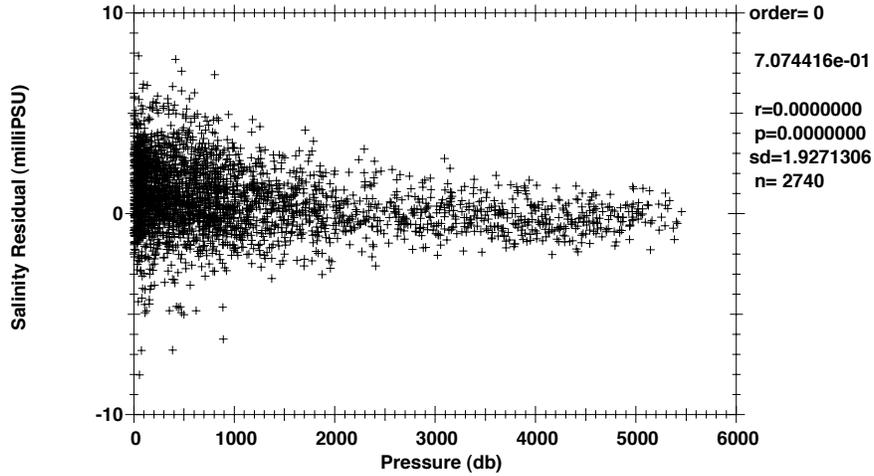


Figure 1.7.3.1 salinity residuals by pressure, all pressures.

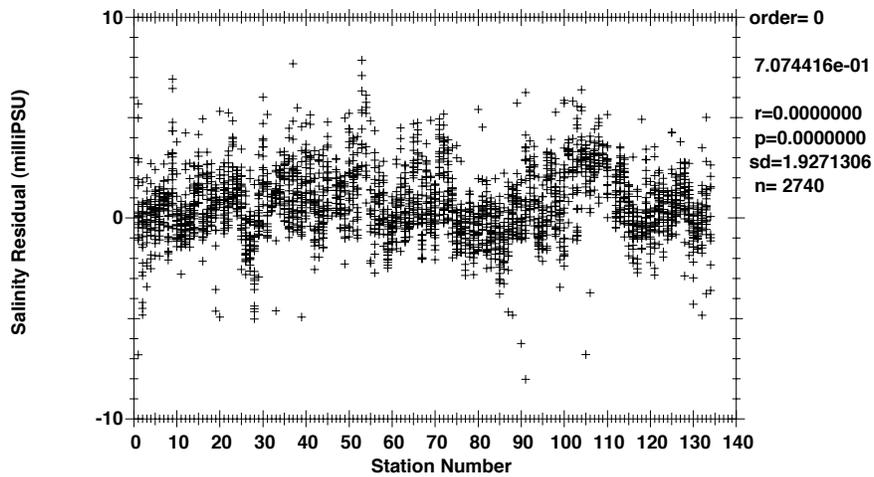


Figure 1.7.3.2 salinity residuals by cast, all pressures.

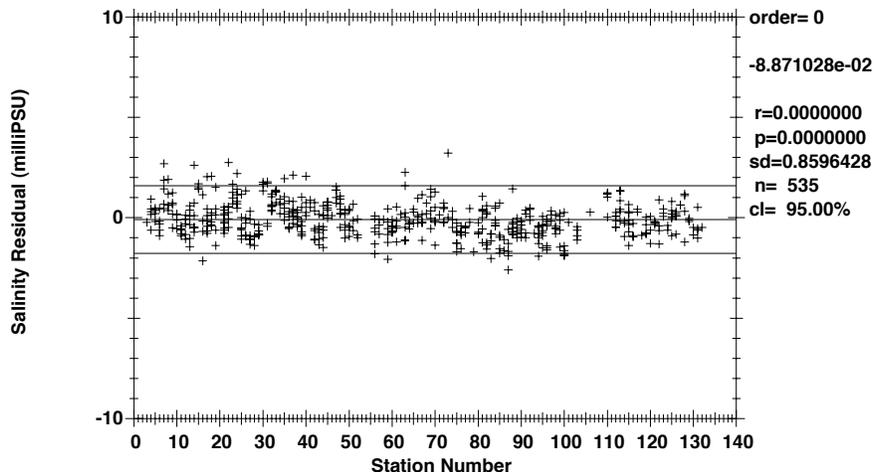


Figure 1.7.3.3 salinity residuals by cast,  $p > 2000$ db.

Figure 1.7.3.3 represents an estimate of the deep salinity accuracy on AAIW 2005. The 95% confidence limit is  $\pm 0.0018$  PSU relative to the bottle salts.

#### 1.7.4. CTD Dissolved Oxygen

Two SBE43 dissolved  $O_2$  (DO) sensor were used during this cruise: S/N 43-0872 (1/1-32/1, 34/1-35/1) and 43-0848 (33/1, 36/1-136/1). The sensor was plumbed into the primary T1/C1 pump circuit after C1. Sensor 0872 was replaced prior to 33/1 because of diminishing sensor response. Problems with the sensor cable on 33/1 rendered the DO data unusable, and 0872 was returned to service for two more casts.

The DO sensors were calibrated to dissolved  $O_2$  check samples at bottle stops by calculating CTD dissolved  $O_2$  then minimizing the residuals using a non-linear least-squares fitting procedure. The fitting procedure determined the calibration coefficients for the sensor model conversion equation, and was accomplished in stages. The time constants for the exponential terms in the model were first determined for each sensor. These time constants are sensor-specific but applicable to an entire cruise. Next, casts were fit individually to check sample data. The resulting calibration coefficients were then smoothed and held constant during a refit to determine sensor slope and offset.

Standard and blank values for bottle oxygen data were smoothed and the bottle oxygen recalculated prior to the final fitting of CTD oxygen.

The residuals are shown in figures 1.7.4.0-1.7.4.2.

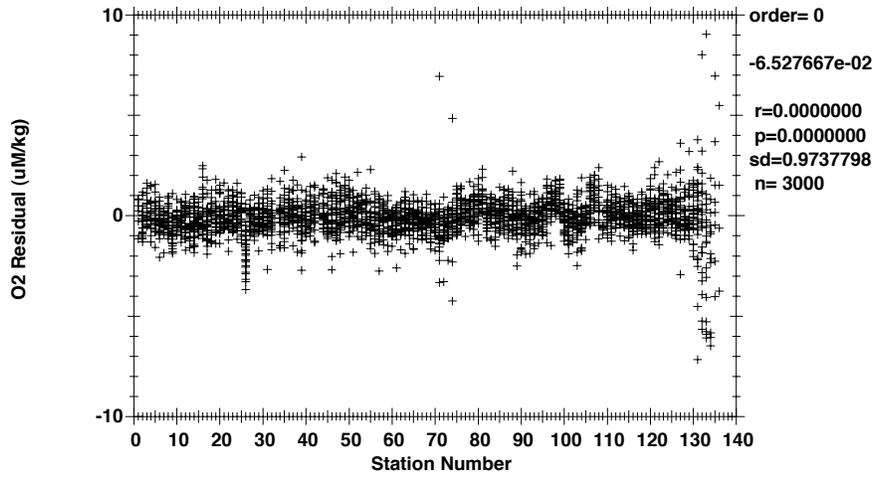


Figure 1.7.4.0 O<sub>2</sub> residuals by station number, all pressures.

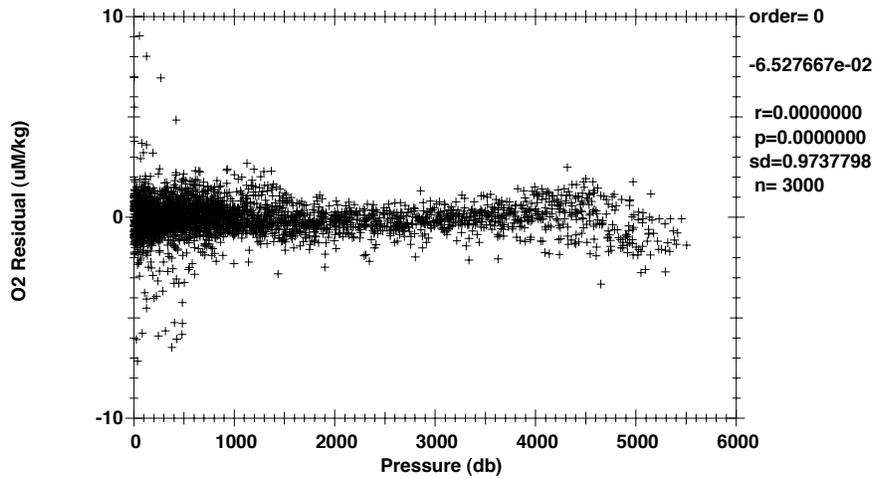


Figure 1.7.4.1 O<sub>2</sub> residuals by pressure, all pressures.

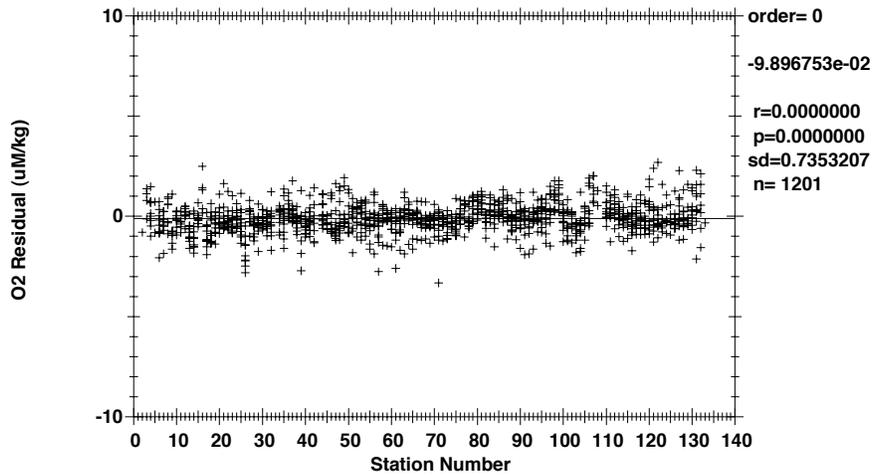


Figure 1.7.4.2 O<sub>2</sub> residuals by station number, p>1000db .

The standard deviations of 0.97 uM/kg for all oxygens and 0.74 uM/kg for deep oxygens are only presented as general indicators of goodness of fit. ODF makes no claims regarding the precision or

accuracy of CTD dissolved  $O_2$  data.

The general form of the ODF  $O_2$  conversion equation for Clark cells follows Brown and Morrison [Brow78] and Millard [Mill82], [Owen85]. ODF models membrane and sensor temperatures with lagged CTD temperatures and a lagged thermal gradient. *In-situ* pressure and temperature are filtered to match the sensor response. Time-constants for the pressure response  $\tau_p$ , two temperature responses  $\tau_{T_s}$  and  $\tau_{T_f}$ , and thermal gradient response  $\tau_{dT}$  are fitting parameters. The thermal gradient term is derived by low-pass filtering the difference between the fast response ( $T_f$ ) and slow response ( $T_s$ ) temperatures. This term is SBE43-specific and corrects a non-linearity introduced by analog thermal compensation in the sensor. The  $O_c$  gradient,  $dO_c/dt$ , is approximated by low-pass filtering 1st-order  $O_c$  differences. This gradient term attempts to correct for reduction of species other than  $O_2$  at the sensor cathode. The time-constant for this filter,  $\tau_{og}$ , is a fitting parameter. Dissolved  $O_2$  concentration is then calculated:

$$O_{2mll} = [c_1 O_c + c_2] \cdot f_{sat}(S, T, P) \cdot e^{(c_3 P_f + c_4 T_f + c_5 T_s + c_6 \frac{dO_c}{dt} + c_7 dT)} \quad (1.7.4.0)$$

where:

$O_{2mll}$	= Dissolved $O_2$ concentration in ml/l;
$O_c$	= Sensor current ( $\mu$ amps);
$f_{sat}(S, T, P)$	= $O_2$ saturation concentration at S,T,P (ml/l);
$S$	= Salinity at $O_2$ response-time (PSUs);
$T$	= Temperature at $O_2$ response-time ( $^{\circ}$ C);
$P$	= Pressure at $O_2$ response-time (decibars);
$P_f$	= Low-pass filtered pressure (decibars);
$T_f$	= Fast low-pass filtered temperature ( $^{\circ}$ C);
$T_s$	= Slow low-pass filtered temperature ( $^{\circ}$ C);
$\frac{dO_c}{dt}$	= Sensor current gradient ( $\mu$ amps/secs);
$\frac{dT}{dt}$	= low-pass filtered thermal gradient ( $T_f - T_s$ ).

## 1.8. Bottle Sampling

At the end of each rosette deployment water samples were drawn from the bottles in the following order:

- CFCs
- $O_2$
- Dissolved Inorganic Carbon (DIC)
- Total Alkalinity
- Nutrients
- Salinity
- Nitrous Oxide

The correspondence between individual sample containers and the rosette bottle position (1-24) from which the sample was drawn was recorded on the sample log for the cast. This log also included any comments or anomalous conditions noted about the rosette and bottles. One member of the sampling team was designated the *sample cop*, whose sole responsibility was to maintain this log and insure that sampling progressed in the proper drawing order.

Normal sampling practice included opening the drain valve and then the air vent on the bottle, indicating an air leak if water escaped. This observation together with other diagnostic comments (e.g., "lanyard caught in lid", "valve left open") that might later prove useful in determining sample integrity were routinely noted on the sample log. Drawing oxygen samples also involved taking the sample draw temperature from the bottle. The temperature was noted on the sample log and was sometimes useful in determining leaking or mis-tripped bottles.

Once individual samples had been drawn and properly prepared, they were distributed for analysis. Oxygen, nutrient and salinity analyses were performed on computer-assisted (PC) analytical equipment networked to the data processing computer for centralized data management.

## 1.9. Bottle Data Processing

Water samples collected and properties analyzed shipboard were managed centrally in a relational database (PostgreSQL-8.0.3) run on one of the Linux workstations. A web service (OpenAcs-5.1.5 and AOLServer-4.0.10) front-end provided ship-wide access to CTD and water sample data. Web-based facilities included on-demand arbitrary property-property plots and vertical sections as well as data uploads and downloads.

The Sample Log (and any diagnostic comments) was entered into the database once sampling was completed. Quality flags associated with sampled properties were set to indicate that the property had been sampled, and sample container identifications were noted where applicable (e.g., oxygen flask number). Each Sample Log was also scanned and made available as a JPEG file on the website.

Analytical results were provided on a regular basis by the various analytical groups and incorporated into the database. These results included a quality code associated with each measured value and followed the coding scheme developed for the World Ocean Circulation Experiment (WOCE) Hydrographic Programme (WHP) [Joyc94].

Sea conditions were sufficiently poor at the end of several deployments that no bottle stops were made shallower than 200m. In these cases, the rosette was hauled at a constant rate (20m/min) and the remaining bottles closed "on-the-fly". These bottles have a quality code of "4" (did not trip correctly) associated with them and are well-documented.

Various consistency checks and detailed examination of the data continued throughout the cruise. The individual sample comments are included in Appendix A.

## 1.10. Salinity Analysis

### Equipment and Techniques

Two Guildline Autosol Model 8400A salinometers (S/N 57-526 & S/N 53-503), located in the 01 lab, were used for all salinity measurements. The salinometers were modified by ODF to contain an interface for computer-aided measurement. The water bath temperatures were set and maintained at a value near the laboratory air temperature. They were set to 21°C for stations 1-92 and 118-124 analyses, then switched to 24°C for stations 92-117 and 121-134.

The salinity analyses were performed after samples had equilibrated to laboratory temperature, usually within 8-26 hours after collection. The salinometers were standardized for each group of analyses (usually 1-2 casts, up to ~48 samples) using at least two fresh vials of standard seawater per group. Salinometer measurements were made by computer, where the analyst was prompted by software to change samples and flush.

### Sampling and Data Processing

3114 salinity measurements were made and approximately 280 vials of standard water (SSW) were used. Salinity samples were drawn into 200 ml Kimax high-alumina borosilicate bottles, which were rinsed three times with sample prior to filling. The bottles were sealed with custom-made plastic insert thimbles and Nalgene screw caps. This assembly provides very low container dissolution and sample evaporation. Prior to sample collection, inserts were inspected for proper fit and loose inserts replaced to insure an airtight seal. The draw time and equilibration time were logged for all casts. Laboratory temperatures were logged at the beginning and end of each run.

PSS-78 salinity [UNES81] was calculated for each sample from the measured conductivity ratios. The difference (if any) between the initial vial of standard water and the next one run as an unknown was applied as a linear function of elapsed run time to the data. The corrected salinity data were then incorporated into the cruise database. Temperature control was somewhat problematic and a few runs were rendered unusable for calibration purposes because of a lack of temperature stability. The estimated accuracy of bottle salinities run at sea is usually better than  $\pm 0.002$  PSU relative to the particular standard seawater batch used. The 95% confidence limit for residual differences between the bottle salinities and calibrated CTD salinity relative to SSW batch P-145 was  $\pm 0.0037$  PSU for all

salinities, and  $\pm 0.0028$  PSU for salinities deeper than 1000db.

### **Laboratory Temperature**

The temperature in the salinometer laboratory varied from 17.0 to 24.0°C, during the cruise. The air temperature during any particular run varied from -7 to +4.5°C.

### **Standards**

IAPSO Standard Seawater (SSW) Batch P-145 was used to standardize for stations 1-122 salinity measurements and IAPSO Standard Seawater Batch P144 was used to standardize for stations 123-134.

## **1.11. Oxygen Analysis**

### **Equipment and Techniques**

Dissolved oxygen analyses were performed with an ODF-designed automated oxygen titrator using photometric end-point detection based on the absorption of 365nm wavelength ultra-violet light. The titration of the samples and the data logging were controlled by PC software. Thiosulfate was dispensed by a Dosimat 665 buret driver fitted with a 1.0 ml buret. ODF used a whole-bottle modified-Winkler titration following the technique of Carpenter [Carp65] with modifications by Culberson *et al.* [Culb91], but with higher concentrations of potassium iodate standard ( $\sim 0.012N$ ) and thiosulfate solution ( $\sim 55$  gm/l). Pre-made liquid potassium iodate standards were run once a day approximately every 4 stations, unless changes were made to system or reagents. Reagent/distilled water blanks were determined every day or more often if a change in reagents required it to account for presence of oxidizing or reducing agents. The auto-titrator performed well.

### **Sampling and Data Processing**

3126 oxygen measurements were made. Samples were collected for dissolved oxygen analyses soon after the rosette was brought on board. Using a Tygon and silicone drawing tube, nominal 125ml volume-calibrated iodine flasks were rinsed 3 times with minimal agitation, then filled and allowed to overflow for at least 3 flask volumes. The sample drawing temperatures were measured with a small platinum resistance thermometer embedded in the drawing tube. These temperatures were used to calculate  $\mu M/kg$  concentrations, and as a diagnostic check of bottle integrity. Reagents were added to fix the oxygen before stoppering. The flasks were shaken twice (10-12 inversions) to assure thorough dispersion of the precipitate, once immediately after drawing, and then again after about 20 minutes.

The samples were analyzed within 1-12 hours of collection, and the data incorporated into the cruise database.

Thiosulfate normalities were calculated from each standardization and corrected to 20°C. The 20°C normalities and the blanks were plotted versus time and were reviewed for possible problems.

The blanks and thiosulfate normalities for each batch of thiosulfate were smoothed (linear fits) in three groups during the cruise and the oxygen values recalculated.

A noisy endpoint was occasionally acquired during the analyses, usually due to small waterbath contaminations. These endpoints were checked and recalculated using STS/ODF designed software.

### **Volumetric Calibration**

Oxygen flask volumes were determined gravimetrically with degassed deionized water to determine flask volumes at STS/ODF's chemistry laboratory. This is done once before using flasks for the first time and periodically thereafter when a suspect volume is detected. The volumetric flasks used in preparing standards were volume-calibrated by the same method, as was the 10 ml Dosimat buret used to dispense standard iodate solution.

## Standards

Liquid potassium iodate standards were prepared in 6 liter batches and bottled in sterile glass bottles at STS/ODF's chemistry laboratory prior to the expedition. The normality of the liquid standard was determined at ODF by calculation from weight. Two standard batches were used during AAIW 2005. Potassium iodate was obtained from Acros Chemical Co. and was reported by the supplier to be 98% pure. The second standard was supplied by Alfa Aesar and has a reported purity of 99.4-100.4%. Tests at ODF indicate no difference between these 2 batches. All other reagents were "reagent grade" and were tested for levels of oxidizing and reducing impurities prior to use.

## 1.12. Nutrient Analysis

### Equipment and Techniques

Nutrient analyses (phosphate, silicate, nitrate and nitrite) were performed on an ODF-modified 4-channel Technicon AutoAnalyzer II, generally within one to two hour after sample collection. Occasionally samples were refrigerated up to 4 hours at  $\sim 4^{\circ}\text{C}$ . All samples were brought to room temperature prior to analysis.

The methods used are described by Gordon *et al.* [Gord92]. The analog outputs from each of the four colorimeter channels were digitized and logged automatically by computer (PC) at 2-second intervals.

Silicate was analyzed using the technique of Armstrong *et al.* [Arms67]. An acidic solution of ammonium molybdate was added to a seawater sample to produce silicomolybdic acid which was then reduced to silicomolybdous acid (a blue compound) following the addition of stannous chloride. Tartaric acid was also added to impede  $\text{PO}_4$  color development. The sample was passed through a 15mm flowcell and the absorbance measured at 660nm.

A modification of the Armstrong *et al.* [Arms67] procedure was used for the analysis of nitrate and nitrite. For the nitrate analysis, the seawater sample was passed through a cadmium reduction column where nitrate was quantitatively reduced to nitrite. Sulfanilamide was introduced to the sample stream followed by N-(1-naphthyl)ethylenediamine dihydrochloride which coupled to form a red azo dye. The stream was then passed through a 15mm flowcell and the absorbance measured at 540nm. The same technique was employed for nitrite analysis, except the cadmium column was bypassed, and a 50mm flowcell was used for measurement.

Phosphate was analyzed using a modification of the Bernhardt and Wilhelms [Bern67] technique. An acidic solution of ammonium molybdate was added to the sample to produce phosphomolybdic acid, then reduced to phosphomolybdous acid (a blue compound) following the addition of dihydrazine sulfate. The reaction product was heated to  $\sim 55^{\circ}\text{C}$  to enhance color development, then passed through a 50mm flowcell and the absorbance measured at 820nm.

Explicit corrections for *carryover* in nutrient analyses are not made. In a typical AutoAnalyzer system, sample to sample carryover is  $\sim 1$ -2% of the concentration difference between samples. This effect is minimized by running samples in order of increasing depth such that concentration differences between samples are minimized. The initial surface samples could be run twice or a low nutrient sea water sample run ahead of the surface sample since these samples generally follow standard peaks.

### Sampling and Data Processing

3126 nutrient samples were analyzed.

Nutrient samples were drawn into 45 ml polypropylene, screw-capped "oak-ridge type" centrifuge tubes. The tubes were cleaned with 10% HCl and rinsed with sample 2-3 times before filling. Standardizations were performed at the beginning and end of each group of analyses (typically one cast, up to 36 samples) with an intermediate concentration mixed nutrient standard prepared prior to each run from a secondary standard in a low-nutrient seawater matrix. The secondary standards were prepared aboard ship by dilution from primary standard solutions. Dry standards were pre-weighed at the laboratory at ODF, and transported to the vessel for dilution to the primary standard. Sets of 7 different standard concentrations were analyzed periodically to determine any deviation from linearity as a function of absorbance for each nutrient analysis. A correction for non-linearity was applied to the final nutrient concentrations when

necessary. A correction for the difference in refractive indices of pure distilled water and seawater was periodically determined and applied where necessary. In addition, a "deep seawater" high nutrient concentration check sample was run with each station as an additional check on data quality. The pump tubing was changed 3 times.

After each group of samples was analyzed, the raw data file was processed to produce another file of response factors, baseline values, and absorbences. Computer-produced absorbence readings were checked for accuracy against values taken from a strip chart recording. The data were then added to the cruise database.

Nutrients, reported in micromoles per kilogram, were converted from micromoles per liter by dividing by sample density calculated at 1 atm pressure (0 db), *in situ* salinity, and a per-analysis measured laboratory temperature.

Some stations showed small yet significant concentrations of NO<sub>2</sub> deeper than expected (i.e. ~0.01 uM below the thermocline). These stations were carefully reviewed and included in the final data report. It should be noted, however, that 0.01 uM is at the detection limit of the autoanalyzer system.

### **Standards**

Primary standards for silicate ( $Na_2SiF_6$ ) and nitrite ( $NaNO_2$ ) were obtained from Johnson Matthey Chemical Co.; the supplier reported purities of >98% and 97%, respectively. Primary standards for nitrate ( $KNO_3$ ) and phosphate ( $KH_2PO_4$ ) were obtained from Fisher Chemical Co.; the supplier reported purities of 99.999% and 99.999%, respectively. The efficiency of the cadmium column used for nitrate was monitored throughout the cruise and ranged from 99-100%.

No major problems were encountered with the measurements. The temperature of the laboratory used for the analyses ranged from 21.6°C to 25.8°C, but was relatively constant during any one station ( $\pm 1.5^\circ C$ ).

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## **Appendix A: Individual Sample Comments**

### **Appendix A**

This appendix contains remarks for samples and bottles having a quality code of other than "2" (no problem noted).

Individual Sample Comments

CFC-11, CFC-12, CFC-113, and CCl<sub>4</sub>  
*Analysts: Jim Happell and Kim VanScoy*

## **Sample Collection**

All samples were collected from depth using 10 liter Niskin bottles. None of the Niskin bottles used showed a CFC contamination throughout the cruise. All bottles in use remained inside the CTD hanger between casts. All spare bottles were stored on a spare rosette under a tarp, sitting on the Maindeck.

CFC sampling was conducted first at each station, according to WOCE protocol. This avoids contamination by air introduced at the top of the Niskin bottle as water was being removed. A water sample was collected directly from the Niskin bottle petcock using a 100 ml ground glass syringe which was fitted with a three-way stopcock that allowed flushing without removing the syringe from the petcock. Syringes were flushed several times and great care was taken to avoid contamination by air bubbles. One duplicate sample was taken on each station from random niskin bottles. Air samples, pumped into the system using an Air Cadet pump, were run about every 2 – 4 days from a Dekoron air intake hose mounted high on the foremast.

## **Equipment and technique**

Chlorofluorocarbons CFC-11, CFC-12, and CFC-113, and CCl<sub>4</sub> were measured on 134 stations for a total of 3,199 samples. Halocarbon analyses were performed on a gas chromatograph (GC) equipped with an electron capture detector (ECD). Samples were introduced into the GC-EDC via a purge and dual trap system. The samples were purged with nitrogen and the compounds of interest were trapped on a main Porapak N trap held at ~ -15°C with a Vortec Tube cooler. After the sample had been purged and trapped for several minutes at high flow, the gas stream was stripped of any water vapor via a magnesium perchlorate trap prior to transfer to the main trap. The main trap was isolated and heated by direct resistance to 140°C. The desorbed contents of the main trap were back-flushed and transferred, with helium gas, over a short period of time, to a small volume focus trap in order to improve chromatographic peak shape. The focus trap was also Porapak N and is held at ~ -15 °C with a Vortec Tube cooler. The focus trap was flash heated by direct resistance to 155 °C to release the compounds of interest onto the analytical pre-column. The pre-column was the first 5 meters of a 60 m Gaspro capillary column with the main column consisting of the remaining 55 meters. The analytical pre-column was held in-line with the main analytical column for the first 1.5 minutes of the chromatographic run. After 1.5 minutes, all of the compounds of interest were on the main column and the pre-column was switched out of line and back-flushed with a relatively high flow of nitrogen gas. This prevented later eluting compounds from building up on the analytical column, eventually eluting and causing the detector baseline signal to increase.

The syringes were stored in a flow-through seawater bath and analyzed within 8 -12 hours after collection. Bath temperature was recorded continuously for use in calculating the mass of water analyzed. Every 12 to 13 measurements were followed by a purge blank and a standard, gas 7.175ml. The surface sample was held after measurement and was sent through the process in order to “restrip” it to determine the efficiency of the purging process.

## **Calibration**

A gas phase standard, S39, was used for calibration. The concentrations of the CFCs and  $\text{CCl}_4$  in this standard are reported on the SIO 1998 absolute calibration scale. A calibration curve was run every 3-5 days. Estimated accuracy is +/- 2%. Precision for CFC-12, CFC-11, CFC-113 and  $\text{CCl}_4$  was less than 1%. Estimated limit of detection is 0.010 pM/kg for CFC-12 and CFC-113, and 0.005 pM/kg for CFC-11 and  $\text{CCl}_4$ .

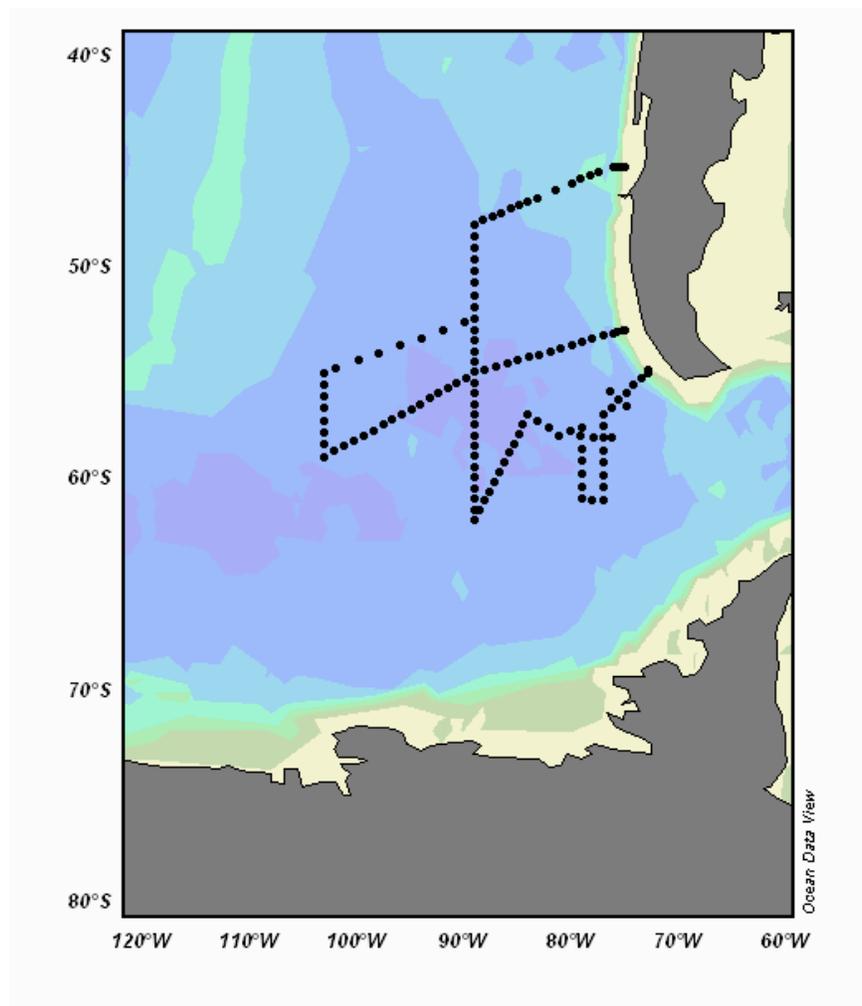
## **Technical Problems**

In large part, sample collection and measurement were very successful. The integration of the computer software with the GC-EDC system hardware made the procedure almost completely automated. Two stations, 38 and 39, were skipped to try and determine why instrument sensitivity dropped when changing the  $\text{MgClO}_4$  drying trap. During the first part of the cruise several changes of the drying trap resulted in sensitivity changes, while several did not. We were not able to determine the cause of the sensitivity drop at this time. During a drying trap change on station 99, the flow controller for the ECD makeup gas flow was mistakenly turned down when it was meant to turn down the purge gas flow. Lowering the makeup gas flow increased the sensitivity and it was therefore considered likely that the earlier sensitivity loss occurred when the makeup flow controller knob was bumped when turning down the purge gas flow during drying trap changes. The makeup flow was set to 60 ml/min and care was taken not to bump the controller throughout the remainder of the cruise. The sensitivity changes did not seem to affect the limit of detection, because instrument blanks and noise decreased when the sensitivity decreased.

# AAIW 2005: Analyst's Report for Total Alkalinity and Dissolved Inorganic Carbon Measurements.

From August 21<sup>st</sup> to October 6<sup>th</sup> 2005, the R/V Knorr sailed on a NSF-funded oceanographic cruise off the coast of Southern Chile to collect physical and chemical data. Stations were occupied between ~45°S and ~62°S and ~75°W and ~105°W (see map below for station locations): the domain of the Polar and Subantarctic Fronts and the region where Antarctic Intermediate Water (AAIW) formation is suspected to occur. This report details the corrections that were made to the dissolved inorganic carbon ( $C_T$ ) and total alkalinity ( $A_T$ ) data and an assessment of these measurements' uncertainties. The symbol “ $\Delta\Delta\Delta$ ” precedes any paragraph that details an adjustment made to the data.

Prepared by Brendan Carter: [brcarter@ucsd.edu](mailto:brcarter@ucsd.edu)



**C<sub>T</sub>**: Estimated uncertainty: 1.7  $\mu\text{mol kg}^{-1}$   
*Analyzed by Justine Afghan, Brendan Carter, and Jeffrey Skacel.*

#### Sample Density and Measurement Technique:

Dissolved inorganic carbon (C<sub>T</sub>) analyses were made by coulometric titration with a SOMMA measurement apparatus and a UIC coulometer as described in SOP 2 of the Department of Energy's Carbon Dioxide System in Sea Water, Version 2 (DOE handbook).<sup>1</sup> Due to the length of time required to analyze a sample (~25min) many stations were not measured for C<sub>T</sub> at every depth for which water was collected. The pattern of every other station being sampled only for the shallowest half of the depths was adopted, though not rigorously adhered to when timing permitted otherwise. A total of 2,935 C<sub>T</sub> analyses were made including:

1. 189 measurements of Certified Reference Materials (CRM Batch 71, C<sub>T</sub> 2032.85 ± 0.40  $\mu\text{mol kg}^{-1}$ ).
2. 196 sets of duplicate measurements made on separate seawater samples collected from the same Niskin.
3. 86 measurements made on four separate batches of a reference material that were prepared at sea.
4. 25 rejected measurements of samples with known errors.
5. 2439 measurements of sample C<sub>T</sub> that are presented with quality control codes.

#### Data Quality Control and Applied Corrections:

CRMs:

Measurements on bottles of CRMs were used to calibrate the SOMMA system and the coulometer. A calibration factor (calfactor), expressed as the number of counts registered by the coulometer per  $\mu\text{mol}$  of carbon titrated, was obtained from each of the CRM measurements. These calfactors were used for all samples measured until another CRM was analyzed and a new calfactor was obtained. Measurements of CRMs were made at the beginning, middle, and end of a cell's life.

A control chart for the calfactor values was prepared (*Figure 1*) as described in SOP 22 of the DOE handbook. The mean and standard deviation for all data are  $4806.1 \pm 4.9$  counts/ $\mu\text{mol}$  of carbon. A number of changes were made to the system circa the 3<sup>rd</sup> of September including switching coulometers, and separate calfactor control charts were prepared for both the pre and post September 3<sup>rd</sup> CRM measurements (*Figures 2 and 3*). These subsets of the data can be shown to be statistically different from one another with greater than 99.9% confidence. For the pre-September 3<sup>rd</sup> data, the calfactor average and standard deviation are  $4809.4 \pm 3.5$  counts/ $\mu\text{mol}$ . For the post-September 3<sup>rd</sup> data, after excluding one known outlier, the average and standard deviation are  $4804.6 \pm 3.9$  counts/ $\mu\text{mol}$ .

### Duplicates:

While the CRM data provides a measure of the long-term reproducibility of the system, shorter-term reproducibility (sample to sample within a given cell) was estimated from measurements of duplicate samples (i.e. pairs of bottles filled with water from the same Niskin from a rosette cast). Duplicate measurements were made at the beginning, the midpoint, and end of a cast, and two duplicates with water from the same Niskin were never run consecutively.

A control chart was prepared using the duplicate data as described in SOP 22 of the DOE handbook (*Figure 4*). The average non-absolute difference ( $2^{\text{nd}} - 1^{\text{st}}$  in the order of analysis) was  $0.38 \mu\text{mol kg}^{-1}$  and the standard deviation was  $1.2 \mu\text{mol kg}^{-1}$ . The average value is statistically distinguishable from zero, where zero is the ideal result that would indicate all sources of error were random or independent of both time and the amount of carbon titrated within a given cell. It is thought that this error is related to the chemical evolution of the cell solutions with repeated titrations. However, since the exact nature of these cells' chemistry is not well-understood, no correction was made to account for this observation.

### Uncertified Reference Materials:

The uncertified reference materials collected at sea were the only inter-cell checks on reproducibility that were not used for calibration. The first measurement of such a reference material occurred on the 13<sup>th</sup> of September, and the practice was continued the rest of the cruise. Most often one uncertified reference material would be measured at the beginning of a cell and another at the end. The standard deviation for these reference material measurements is  $1.6 \mu\text{mol kg}^{-1}$ : a precision lower than the duplicate data. Subsequent tests have shown that the plastic bottles used to hold the reference materials may not form a proper seal, and this could easily account for some of the increase in variability.

### Samples:

With a gap in the data below 2000 meters at every other station and no samples collected from station 93 (which shared a location with station 58), there is no meaningful comparison of samples from a quality control perspective.

### Mercuric Chloride Dilution Correction:

**▲▲▲** A  $\sim 120 \mu\text{L}$  volume of 50% saturated mercuric chloride was added to the  $\sim 285 \text{ mL}$  samples prior to measurement. An upward adjustment of the final reported sample  $C_T$  values by a factor of 1.0004 was made to account for this dilution.

### Measurement Uncertainty:

The uncertainty for this measurement is a combination of the reproducibility of the system ( $\pm 1.6 \mu\text{mol kg}^{-1}$ , estimated from the deviation of post September 3<sup>rd</sup> calfactor data converted to  $\mu\text{mol kg}^{-1}$  using the certificate  $C_T$  for batch 71 CRMs) and the uncertainty in the certificate value to

which the system was calibrated ( $\pm 0.40 \mu\text{mol kg}^{-1}$ ). Adding these in quadrature yields a total uncertainty of  $\pm 1.7 \mu\text{mol kg}^{-1}$ .

**A<sub>T</sub>**: Estimated uncertainty:  $1.3 \mu\text{mol kg}^{-1}$   
*Analyzed by George Anderson, Justine Afghan, and Brendan Carter.*

#### Sample Density and Measurement Technique:

Total Alkalinity (A<sub>T</sub>) analyses were made using a two-stage, potentiometric, open-cell titration by coulometrically analyzed hydrochloric acid. The equivalence point was evaluated from titration points in the pH region 3.0 to 3.5 using a non-linear least squares procedure that corrects for reactions with sulfate and fluoride ions. A limited number of the Niskin samples that were not analyzed for C<sub>T</sub> due to time constraints were similarly not analyzed for A<sub>T</sub> to allow time for system diagnostics. A total of 3,837 A<sub>T</sub> analyses were made including:

1. 396 measurements of Certified Reference Materials (CRM Batch 71, alkalinity  $2254.50 \pm 0.71 \mu\text{mol kg}^{-1}$ ).
2. 251 sets of duplicate measurements made on separate seawater samples collected from the same Niskin.
3. 172 repeat measurements made to verify values, to check outliers, as system diagnostics, or when the system either was operated incorrectly or behaved abnormally.
4. 3018 values of samples A<sub>T</sub> that are presented with quality control codes.

#### Data Quality Control and Applied Corrections:

##### CRMs:

Measurements of bottles of CRMs were used to assess the system's reproducibility and accuracy at the beginning and end of each cast.

A control chart for the CRM A<sub>T</sub> values (*Figure 5*) was prepared as described in SOP 22 of the DOE handbook. The mean and standard deviation for all CRM analyses are  $2056.3 \pm 3.0 \mu\text{mol kg}^{-1}$ .

The control chart allows us to see that the series does not meet the control criteria early in the cruise. Using the 28<sup>th</sup> of August as a cutoff, it is statistically more than 99.9% likely that the data plotted before and after this date are distinct series. The two most likely causes for the change over time of the CRM results are a change in a calibrated syringe's volume (used for extracting the portion of seawater sample to be titrated) or a gradual change in the concentration of the acid used during titration. Gravimetric analyses of volumes of seawater collected from the syringe before and after this cutoff suggest that the syringe volume was constant.

▲▲▲ To determine whether a shift in the acid concentration could have produced the observed effect, a model was created to estimate how the analytical result of an  $A_T$  measurement of a CRM would vary when measured using acid of changing concentration. The model assumed that the acid reservoir, initially filled with HCl of one concentration, was repeatedly refilled by 200 mL portions of acid of another concentration every time the reservoir's acid volume decreased to 850 mLs. The actual dates of refilling were recorded by the operators, and these records were used to time the dilutions in the model. The modeled value expected for a measurement of a CRM using this acid of evolving concentration changed in a stepwise fashion that tracked an exponential (each step coinciding with a dilution) from 2254.25  $\mu\text{mol kg}^{-1}$  (an initial best guess) towards 2257.25  $\mu\text{mol kg}^{-1}$  (a best guess for the concentration given infinite dilutions). A chart was prepared that displays this evolution of the modeled CRM value as the acid concentration changed with successive dilutions (*Figure 6*). Since this seemed the more plausible cause of this change, and since the curve fit the observed changes reasonably well, the final values for the CRMs and samples have been recalculated to the values that would be obtained by the titration if the acid were of constant (initial best-guess) concentration. This correction was accomplished by multiplying the measured  $A_T$  by the ratio of the certificate CRM  $A_T$  over the modeled average CRM  $A_T$  expected for that time period. The CRM and sample data were then multiplied by a constant factor of 1.000118 to align the mean corrected value with the certified value.

The majority of the outliers on the control chart had lower  $A_T$  than the mean for all CRMs measured at sea. Subsequent laboratory experimentation has reproduced this trend and shown that the degree of deviation from the certified  $A_T$  is correlated with the amount of time that has elapsed since the CRM was sampled for  $C_T$  or  $A_T$ . This problem was unique to the CRMs, as only they were analyzed for more than one quantity:  $C_T$  and  $A_T$ . Data points that were subject to this deviation were labeled “suspect” and were excluded from any further calculation of standard deviation. This was done because the lower deviation obtained by excluding them would more accurately reflect the deviation of the collected station samples, as these samples were measured for only one quantity. The criterion for being labeled as “suspect” was that there had to be two consistent measurements of the same CRM bottle, the average  $A_T$  for which was more than two standard deviations below the inclusive mean. Prior to eliminating these data points the skew for the dataset was  $-3.4 \mu\text{mol kg}^{-1}$ . Afterwards it was  $-0.57 \mu\text{mol kg}^{-1}$ . The standard deviation excluding suspect points, but without making the correction for the acid evolution, was  $1.3 \mu\text{mol kg}^{-1}$ .

A final control chart was created following correction for the acid, exclusion of the suspect datapoints, and alignment of the mean corrected CRM value with the certified value (*Figure 7*). The final average and standard deviation for the measurement of the CRM's alkalinities are  $2254.5 \pm 1.1 \mu\text{mol kg}^{-1}$ .

Duplicates:

An estimate of the short term reproducibility of the alkalinity measurements made on this cruise was obtained from the duplicates. There were two pairs of duplicates measured per station: one drawn from the shallowest and one drawn from the deepest Niskin. One of each of the sets of duplicates was measured as the first station sample of a cast and the companion duplicates were

measured midway through and as the last. From these measurements a duplicate control chart was prepared (*Figure 8*) as described in SOP 22 of the DOE handbook. The standard deviation of duplicate measurements was  $0.84 \mu\text{mol kg}^{-1}$ , and the average non-absolute difference between all pairs of duplicate measurements ( $2^{\text{nd}}$  minus  $1^{\text{st}}$ ) was statistically indistinguishable from zero.

#### Samples:

Two sets of stations were near enough to be useful for comparison: stations and 15 and 27, and 9 and 28. Additionally, station 58 was reoccupied later in the cruise as station 93. Plots were prepared of the measured  $A_T$  vs. the potential density (relative to 4000 decibars) for each of these station pairs (*Figures 9, 10, and 11*). The plots agree with one another to the degree expected by measurements made several days or weeks apart, and, as expected, they agree most closely in the deep water where the effects of being near, and possibly straddling, the Southern Ocean's fronts would be minimal. Since sampling below 1000 meters was done with fairly large vertical spacing and there was vertical heterogeneity at these depths, no attempt was made to interpolate between points to allow for direct comparison of values.

#### Mercuric Chloride Dilution Correction:

**▲▲▲** A 57  $\mu\text{L}$  volume of 100% saturated mercuric chloride was added to the  $\sim 285$  mL samples prior to measurement. An upward adjustment of the final reported sample  $A_T$  values by a factor of 1.0002 was made to account for this dilution.

#### Uncertainty Estimate:

The uncertainty of these  $A_T$  values is due to a combination of the uncertainties in the short term reproducibility of the system ( $\pm 1.1 \mu\text{mol kg}^{-1}$  from CRM analyses) and in the certificate CRM concentration with which the technique was calibrated ( $\pm 0.71 \mu\text{mol kg}^{-1}$ ). Adding these two errors in quadrature yields an estimated total uncertainty of  $\pm 1.3 \mu\text{mol kg}^{-1}$ . More discussion of the uncertainty of the system employed can be found in *Dickson et al., 2003*.<sup>2</sup>

The variance of the CRM measurements was not found to be significantly affected by errors in the best-guess initial acid concentration used during the acid-reservoir concentration adjustment of the data. However, if an application for this dataset considers primarily data collected early in the cruise (before August 30<sup>th</sup>) then adopting a greater uncertainty may be appropriate given the larger relative affect errors in the best-initial-guess concentration would have for these points.

#### *References:*

- 1) DOE (1994) *Handbook of methods for the analysis of the various parameters of the carbon dioxide system in sea water; version 2*, A. G. Dickson & C. Goyet, eds., ORNL/CDIAC-74
- 2) Dickson, A. G., Afghan, J.D., Anderson, G.C., 2003. Reference Materials for Oceanic  $\text{CO}_2$  analysis: a Method for the Certification of Total Alkalinity. *Marine Chemistry* 80, 185-197

**AAIW: Preliminary XCTD Cruise Report**  
**Antarctic Intermediate Water Formation in the**  
**Southeast Pacific**  
**21 August to 6 October 2005**  
**by Teresa K. Chereskin**

# 1 AAIW XCTDs

During the Antarctic Intermediate Water (AAIW) winter cruise, dense underway profiling of upper ocean temperature and salinity was carried out with expendable conductivity-temperature-depth probes (XCTDs). The sampling at 15 to 20 km spacing supplemented the full-depth CTD stations that were spaced at approximately 50 km. Generally, three XCTDs were launched between CTD stations. Additionally, two intensive surveys were carried out in regions of deep mixed layers, steaming a diamond pattern centered on the main AAIW track, with dense XCTD sampling throughout and CTD stations at the corners. The first intensive survey began after CTD station 9 and ended with station 12 (Stations 8, 10, 6, and 11 are the corners). The second intensive survey began after CTD station 14 and ended with station 17 (Stations 14, 15, 12, and 16 are the corners). Surface drifters were deployed at the corners of the two diamond patterned intensive surveys.

## 1.1 Instrumentation

The XCTDs were digital TSK probes purchased from Sippican (Sippican, Inc.) and manufactured by TSK (The Tsurumi-Seiki Co.). The computer, deck unit, and launcher were supplied as standard ship's equipment on the Knorr. The deck unit was the Sippican MK-21 model.

## 1.2 Data acquisition

Data acquisition was on a pc computer with the Windows 2000 Professional operating system. (Minimum computer requirements for the Sippican software are a P3/700 with 64 MB of RAM, with W2000 or XP). Two copies of the data files were made; one on the pc hard disk and the second on either a networked drive or in a backup directory on the pc. The Sippican software versions were WinMK21 v2.1.2, MK21COEF v2.3.1, and MK21AL v2.5.1. The XCTD computer and the Sippican MK-21 deck unit were located in the computer rack in the main lab. The hand launcher and XCTDs were kept in the aft hangar, and the launches were staged from the hanger.

## 1.3 Launch Procedure

XCTD launching was a two person effort because the weather deck on the Knorr was secured while underway during most of the cruise, thus requiring two persons on deck and radio communication to the bridge. XCTD launch times were determined from the ETA time and range to station from the main ODF AAIW webpage. The bridge was notified via radio. One person opened the "New Launch" window of the MK-21 software while the second person went aft to load a new probe in the hand launcher. The software cycles through "Testing Probe", "Prepare to Launch", and "Launch Probe". If it is successful in reading the probe's EPROM, it will usually get through to the "Launch Probe" window. At this point both persons, in work vests and equipped with a handheld radio, would go out to launch the probe. There were four launch locations, and the choice was dictated by wind and seas. A permanent launch tube was located on the port side, just aft of the hangar. A second launch tube was tried in various locations; it was usually located on the rail on the port

side of the fantail. The third location was the starboard side of the fantail, and a fourth was the starboard side immediately across from the aft hangar. The fall rate is approximately 200 m/min, and a cast typically took 5 mins. If a launch tube was used, both persons would come back inside and monitor the launch on the computer. If the probe was hand-launched, one person would watch from the hangar where they could also view the computer screen if they moved to the doorway into the main lab. The spent canister was retrieved after the launch. The data file was inspected and serial number (SN), time, latitude, and longitude were recorded to logsheets and reported to the bridge.

## 1.4 Problems encountered

We launched 399 probes and had a total of 342 good casts (defined as casts to depths of at least 800 m) with an overall success rate of 86%. The main reasons for XCTD failures were 1) XCTD wire contacting the ship, usually due to wind, 2) XCTD launch not recognized by the software (despite the fact that the EPROM was read ok and the SN displayed correctly in the “Launch Probe” window), 3) a false splash (the software starts recording when the probe is in air, but the computer operator has gone aft to launch and does not know to abort the cast), 4) loading a probe too early while the software is running (operator error - we did not know that the batteries in the probe run down in about 15 min if the program is active). The table at the end of this section summarizes the XCTD performance. Also note that some casts did not profile to maximum depth, usually for unknown reasons.

Part of our launch procedure initially was to wet the end of the probe with Jet-Dry, to improve adhesion and thus decrease spiking near the surface. This technique is used for analog XCTDs, but it may have been the cause of some of our early false splash failures with the digital probes. After communication with Sippican, we stopped using Jet-Dry; however, we still encountered false launches and other failures. The system was examined for wiring defects such as ground loops. The launcher cable appeared to be wired correctly, after testing with an ohm meter between the launcher and the Sippican connector box at the computer. However, the computer chassis, monitor, and Sippican deck unit were all independently grounded, and we were advised by Justine Afghan and Glenn Pezzoli that floating all but one ground was considered critical for the setup of the XCTD systems that they install on the high resolution XBT container ships. We floated the computer and deck unit ground, using a single ground in the connector box. However the monitor, the GPS, and other computers in the rack all had independent grounds which we were unable to change, and these could be a potential problem. Our success rate improved dramatically (from 75% to 90% or 95%) after we floated the ground on the computer chassis and deck unit, until the last week of the cruise when we had a string of failures (mostly undetected launches). A loose ground wire was found on the connector box between the computer and the launcher and reconnected, but that did not solve the problem. The source of the failure turned out to be a broken wire in the stress-relief section of the launcher cable, located where it entered the hand launcher. Other things that were tried at this time were 1) rebooting the computer, power cycling the deck unit, and restarting the software before every cast, 2) installing the software on a new computer outside of the rack, 3) turning off virus detection software, 4) disconnecting from GPS, and 5) disconnecting from the network. We

had a Sippican digital test canister that did not detect the wiring problem, possibly because the wire ends still had intermittent contact. Continued testing by the Knorr's SSSG technician (Robbie Laird) indicated that the broken wire only had to make contact for an instant for the test canister to initiate a successful test cast. It is unknown whether the same is true for an actual XCTD cast.

XCTD Cast Statistics		
	No. of casts	Drop quality
Used probes	342	Good cast to depth > 800 m
	10	Good cast to depth < 800 m
	16	Bad or truncated cast due to wind or wire on deck
	17	Bad cast; failure to recognize launch
	9	Bad cast; reason unknown
	5	Bad cast; false splash
Unused probes	9	
Total	408	34 cases of 12

## 1.5 Data processing

The Sippican automated processing was the only processing that was applied. Two files exist for each cast: RDF (binary, raw) and EDF (ascii, edited by the Sippican autoprocessing). An example of a succession of good temperature casts to 1000 m is shown in Fig. 1.

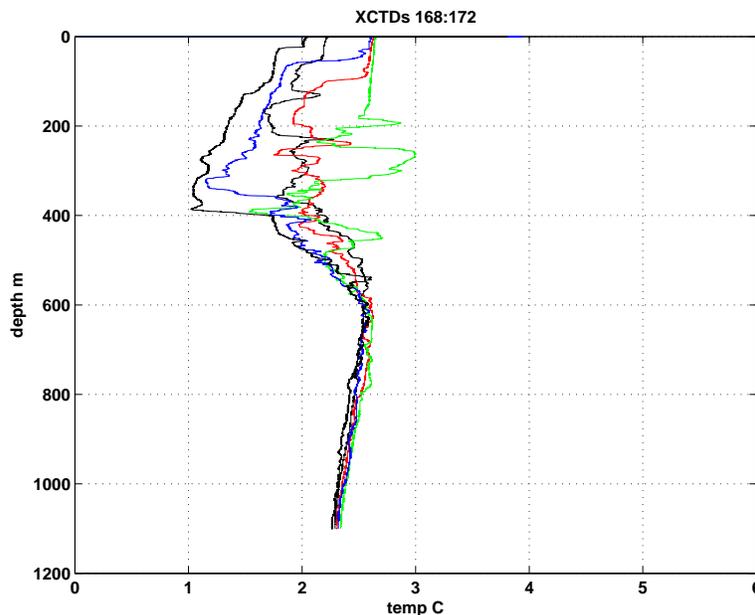


Figure 1: Sample of XCTD temperature profiles from casts 168 to 172

## 1.6 Recommendations

After diagnosing our final problem (broken wire in the launcher cable), we stopped the reboot/power cycle/restart routine, and we put the XCTD computer back on the network. We kept the virus software turned off, and we did not connect to the GPS. All of these things could potentially cause problems, but it is our assessment that they were probably not an issue in the Knorr setup. It is recommended to bring our own computer, cable, and launcher with a stable and tested version of the Sippican software installed. Then the science party has control with respect to: network, external inputs (GPS), grounding, and virus software. As long as time is accurate, the system does not need to be networked and does not need real-time GPS input.

Other recommendations for the summer cruise entail additional items to log for each cast that are helpful in assessing the quality of the cast and in diagnosing problems.

We suggest:

- Log whether spiking occurs in the profile and the maximum depth of the profile.
- Log the serial no. prior to deployment so that all probes get logged, even failures.
- Track the box number as well as serial no., in case the probe is part of a bad batch that needs to be reported to Sippican for a refund.
- Check whether the probes in a single box are all in sequence, again for tracking purposes.

## 1.7 Acknowledgements

Thanks to Justine Afghan and Glenn Pezzoli for advice during the AAIW winter cruise.

**AAIW: Preliminary ADCP/LADCP Cruise Report**

**Antarctic Intermediate Water Formation in the  
Southeast Pacific**

**21 August to 6 October 2005**

**by Teresa K. Chereskin**

# 1 Introduction

During the Antarctic Intermediate Water (AAIW) winter cruise, direct velocity measurements were made by the Chereskin lab group of Scripps Institution of Oceanography (SIO) from hull mounted shipboard acoustic Doppler current profilers (SADCPs) and from a Lowered Acoustic Doppler Current Profiler (LADCP).

## 2 Shipboard ADCPs

### 2.1 Instrumentation

Data was recorded from two shipboard ADCPs: an Ocean Surveyor 75 kHz phased array (OS75) and an RD Instruments 150 kHz narrowband ADCP (NB150).

The OS75 is standard ship's equipment on R/V Knorr. The OS75 ADCP transducer was mounted in an instrument well located near the center line of the ship and below the laundry room. The well is open to the sea, and the transducer is located at approximately 5 m depth, with beam 3 oriented 45 deg to starboard.

The NB150 is an obsolete instrument, no longer supported by the manufacturer, that was installed by WHOI on request from the PI specifically for the AAIW cruise in order to profile currents at higher resolution and at shallower depths than the OS75. The NB150 ADCP transducer was mounted in an instrument well located below the lower lab at frame 85, about 8 feet starboard of the center line. The well is open to the sea, and the transducer is located at approximately 5 m depth, with beam 3 oriented 45 deg to starboard. The NB150 that was installed in Miami for AAIW failed prior to the ship's arrival in Punta Arenas, Chile. A second complete system was sent via air freight. Although the system had checked out satisfactorily at WHOI, it reported error messages after installation on Knorr. In actual use, the problem was very low signal on beam 2 (unsuitable for a 4-beam velocity solution). We collected NB150 data with the intention of implementing a 3-beam solution.

### 2.2 Data acquisition

Single ping ADCP data from both instruments and ancillary navigation streams (GPS, gyrocompass, and POS/MV) were collected on a Dell 1-U rack-mounted server running the Linux operating system (Mandrake 10.2) using UHDAS, a data acquisition and processing software suite written by Eric Firing and Jules Hummon, University of Hawaii. The data were processed in real-time on the Linux server (currents.knorr.who.edu) and were recorded in duplicate on a pair of internal, mirrored hard disks. Data were copied to Mac G4 laptops via a network (Samba) exported filesystem for further processing. The primary heading source was the ship's gyrocompass, and heading corrections were made using the POS/MV. After applying the heading corrections, the overall additional calibration was an amplitude of 1.0 and a phase of 0.0 degrees. This calibration will be refined in post-processing.

## **2.3 Sampling parameters**

The NB150 operating parameters used during AAIW were 50 depth bins and an 8 m blank, range bin, and pulse length. The OS75 ADCP was configured to collect data in narrowband mode. The OS75 operating parameters were 70 depth bins and a 16 m blank, range bin, and pulse length.

## **2.4 Data processing**

Overall, the quality of the OS75 ADCP and navigation data acquired during AAIW was excellent. High precision GPS was available throughout the cruise, with an estimated single position fix accuracy of 1 m. The estimated accuracy of the POS/MV heading corrections is  $0.1^\circ$  (King and Cooper, 1992). The overall error in absolute currents is estimated at  $1\text{-}2\text{ cm s}^{-1}$  (Chereskin and Harris, 1997). The main problems encountered were bubble sweepdown when the bow thruster was used to maintain station and during rough weather and heavy seas. The maximum profiling range of the OS75 was about 850 m, but this depth range was drastically curtailed when bubbles were severe.

The NB150 data were processed using a 3-beam solution. Where the data overlap with the OS75, they are of higher resolution. Unlike the OS75, the NB150 was not affected by bubbles from the bow thruster. It was negatively affected by bubble sweepdown during rough weather and heavy seas. The maximum range was about 225 m; typical range was 180 m.

# **3 Lowered ADCP**

## **3.1 Instrumentation**

The lowered ADCP was Chereskin's 150 kHz RDI Phase 3 broadband ADCP, serial number 1394, firmware versions 1.16 (XDC), 5.52 (CPU), 3.22 (RCDR), and C5d3 (PWRTIM). The LADCP has custom  $30^\circ$  beam angles. It was mounted on the outer edge of the CTD rosette, about 1 inch above the bottom of the frame. A rechargeable lead acid gel cell battery in an oil-filled plastic case (SeaBattery, Ocean Innovations, La Jolla, CA) was mounted in a steel box that was hose-clamped to the bottom of the rosette frame.

## **3.2 Data acquisition**

A Mac G4 laptop computer running OSX (Panther 10.3.9) was used to upload an LADCP command set prior to each cast, using serial communication and a python terminal emulator (rdterm.py). Data acquired during the cast were stored internally on a 20 MB EPROM recorder. Data recovery used the terminal emulator, a public domain ymodem program (lrb), and a shell script to change the baud rate (change\_baud) once the ymodem transfer was initiated.

### 3.3 Sampling protocol

Commands were uploaded from a file for deployment. The profiler was instructed to sample in a 2 ping burst every 2.6 seconds, with 0 s between pings and 1 s between (single-ping) ensembles, resulting in a staggered ping cycle of [1 s, 1.6 s]. Other relevant setup parameters were 16x16 m bins, 16 m blank, 16 m pulse, bandwidth parameter WB1, water mode 1, and an ambiguity velocity of  $330 \text{ cm s}^{-1}$ . Data were collected in beam coordinates.

The battery pack was recharged after every cast, using an AmRel linear programmable power supply. The power supply was set to 57.31 V constant voltage and 1.8 A maximum current. Typically, at the end of a cast, the power supply was current-limited at the maximum current. The power supply switched within about 10 min to constant voltage as the current level dropped. Charging was stopped nominally at 0.6 A in order to minimize the chance of overcharging, although the power supply resorts to trickle charging as the battery approaches full charge. Since lead acid gel cells outgas small amounts of hydrogen gas when overcharged/discharging, it is necessary to vent the pressure case. The pressure case was vented every few casts. There was a small but noticeable amount of outgassing.

### 3.4 Data processing

The LADCP provides a full-depth profile of ocean current from a self-contained ADCP mounted on the CTD rosette. Using the conventional “shear method” for processing (e.g., Fischer and Visbeck, 1993), overlapping profiles of vertical shear of horizontal velocity are averaged and gridded, to form a full-depth shear profile. The shear profile is integrated vertically to obtain the baroclinic velocity and the resulting unknown integration constant is the depth-averaged or barotropic velocity. This barotropic component is then computed as the sum of the time-averaged, measured velocity and the ship drift (minus a small correction, less than  $1 \text{ cm s}^{-1}$ , to account for a nonconstant fall rate) (Fischer and Visbeck, 1993; Firing, 1998). Errors in the baroclinic profile accumulate as  $1/\sqrt{N}$  where  $N$  is the number of samples (Firing and Gordon, 1990). This error translates to the lowest baroclinic mode and, for a cast of 2500 m depth, it is about  $2.4 \text{ cm s}^{-1}$  (Beal and Bryden, 1999). The barotropic component is inherently more accurate, because the errors result from navigational inaccuracies alone. These are quite small with P-code GPS, about  $1 \text{ cm s}^{-1}$  (2 to  $4 \text{ cm s}^{-1}$  without). Comparisons with Pegasus suggest that the LADCP can measure the depth-averaged velocity to within  $1 \text{ cm s}^{-1}$  (Hacker et al., 1996). The rms difference between Pegasus and LADCP absolute profiles are within the expected oceanic variability, 3-5  $\text{cm s}^{-1}$  (Send, 1994), due primarily to high frequency internal waves.

In previous experiments the interference layer, which results from the previous ping reflecting off the bottom, has caused a large data gap in the LADCP profile, causing an uncertain velocity offset (several  $\text{cm s}^{-1}$ ) between the parts of the profile on either side of the gap. For this experiment bottom velocities were greatly improved by using Chereskin’s instrument which pings asynchronously, thereby avoiding complete data loss in the interference layer. A second problem with data loss arises at the bottom of a CTD/LADCP cast, when the package is held 10 m above the sea bed for bottle sampling. At this distance the instrument is ‘blind’ since the blank after transmit

is order 20 m, and a time gap in the data stream will result in an uncertainty in the absolute velocity. We attempted to minimize the stop at the bottom of the cast to keep this gap to a minimum.

Initial processing was done with the University of Hawaii CODAS software. The method is the traditional shear method outlined in Fischer and Visbeck (1993) as implemented by Eric Firing in the UH CODAS LADCP software. CTD time series data were available immediately following the cast which provided more accurate depth than from integrating LADCP vertical velocity as well as calculated sound speed at the transducer. Typically LADCP casts were analyzed through to absolute velocity, including CTD data, prior to the next station.

During the cruise, the casts were also processed with Martin Visbeck's LADCP Matlab processing routines, version 8a. The method (Visbeck, 2002) differs from the shear method in that an inverse technique is used which includes two additional constraints, the bottom velocity estimate and the average shipboard ADCP profile during the cast. In principle, the Firing shear and Visbeck inverse methods should agree when no additional constraints are included in the inverse, but at the moment the methods have shown unexplained differences on some data sets (Brian King, pers. comm.) Qualitatively, the absolute currents computed between the 2 methods agreed reasonably well. Detailed comparisons will be made in post-processing. Preliminary comparisons of shipboard and lowered ADCP data also showed fairly good agreement and suggest that the shipboard data will be a useful constraint in the inverse method utilized by Visbeck.

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**LADCP section:  
station K009 to K020**

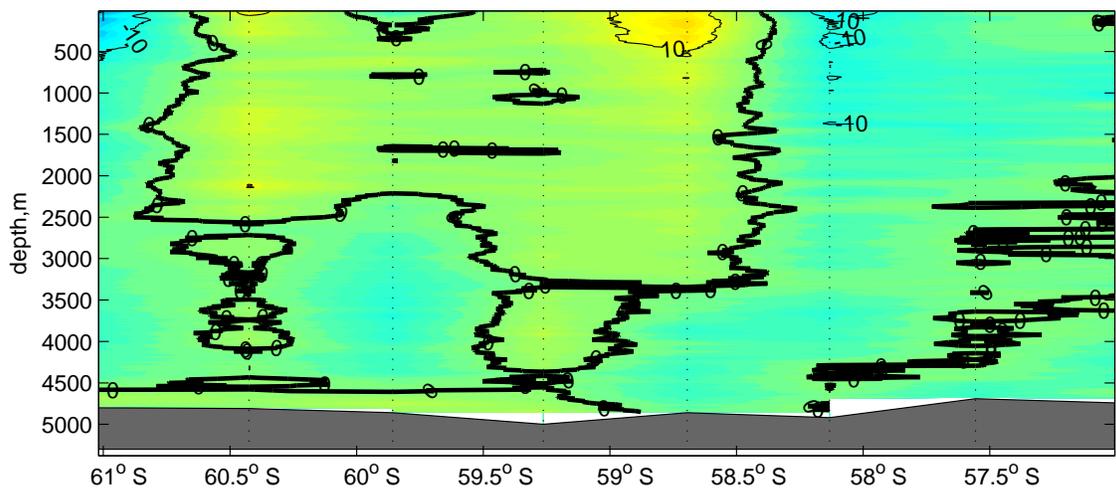
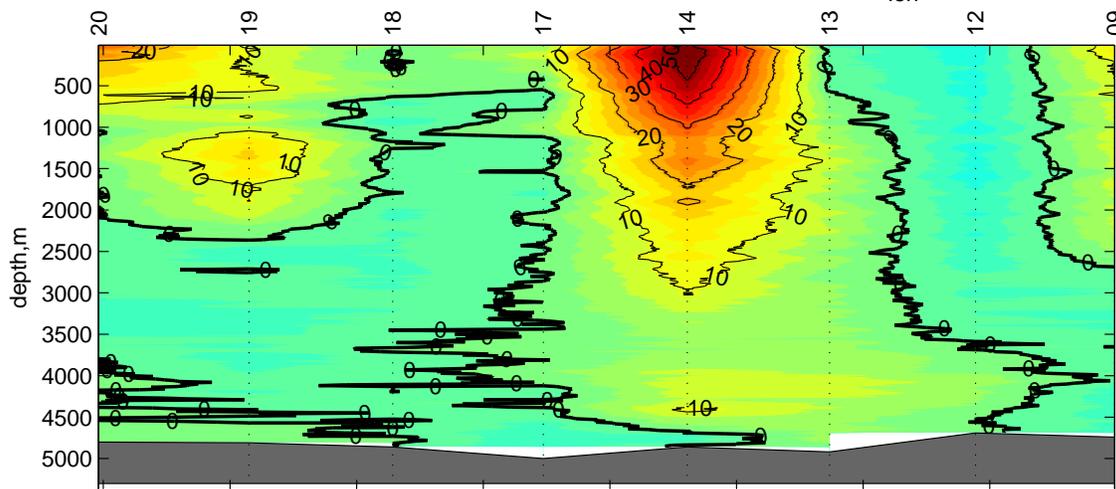
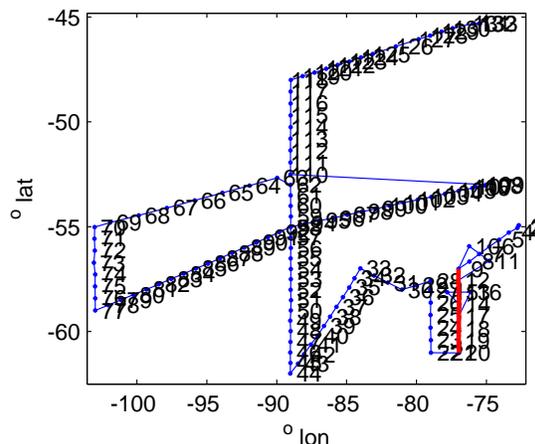


Figure 1: LADCP section across the Subantarctic Front, stations 009 to 020. Upper panel is eastward current (cm/s). Lower panel is northward current (cm/s). Red line on station map indicates location of section.