AAIW 2006

R/V KNORR, KN182-11
30 January 2006 - 14 March 2006
Puenta Arenas, Chile - Valpariso, Chile

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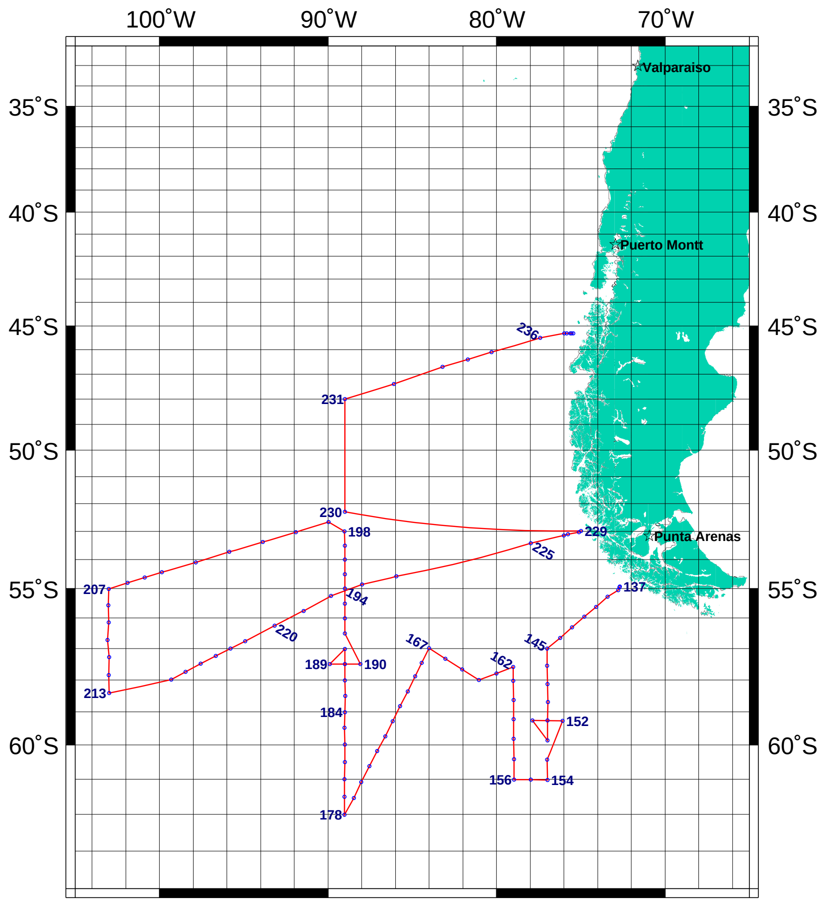

Cruise Report
13 March 2006

Data Submitted by:

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Summary

Bernadette Sloyan, CSIRO, CMAR

A hydrographic survey consisting of CTD/LADCP/rosette sections, underway shipboard ADCP, XCTD profiling, and float deployments in the southeast Pacific was carried out between January and March 2006. The R/V Knorr departed Punta Arenas, Chile on 30 January 2006. A total of 105 LADCP/CTD/rosette stations were occupied, 356 XCTDs were launched, and 3 APEX floats with oxygen sensors were deployed from 1 February - 11 March 2006. The ODF 36 bottle rosette was used successfully during the entire survey. Water samples for nutrient and oxygen analysis, LADCP, and CTD data were collected on each cast in most cases to within 10 meters of the bottom. Daily samples of pigments and DNA were collected on stations nearest local noon. Underway surface pCO2, N2O, temperature, conductivity, oxygen, and meteorological measurements were collected during the cruise. The cruise ended in Valparaiso, Chile on 14 March 2006.

Introduction

Antarctic Intermediate Water (AAIW) is a low salinity water mass that is formed in the southeast Pacific Ocean on the equatorward side on the Subantarctic Front (SAF). AAIW is subducted into the Atlantic, Indian and Pacific subtropical gyres at about 800 to 1000m depth. AAIW is thought to be the densest variety of Subantarctic Mode Waters (SAMW). This cruise (KN 182-11) is a followon from the late austral winter cruise that occupied a similar area of the southeast Pacific between August-October 2005. The goal of the austral winter and summer cruises is to characterize the formation processes and restratification of AAIW and SAMW in its formation region.

The science personnel and their responsibilities are listed below.

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Duties	Name	Affiliation	email
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Scientific Personnel AAIW 2006

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Principal Programs of AAIW 2006

Cruise Narrative

The RV Knorr departed Punta Arenas, Chile on Monday 30th January 2006 at 1300 local. Our original departure date and time (Sunday 29th January 0900 local) was delayed by 28 hours as we waited in port for the arrival of a critical box of chemicals that had failed to arrive on time. We left port as soon as possible after the delivery of the chemicals, two other chemical boxes that were delayed even longer were replaced with chemicals held in Raytheon's Office for Polar Programs storeroom in Punta Arenas. Two new winch wires were installed on the RV Knorr prior to our cruise. We used the starboard winch on which all three conducting cables were functioning to specification. The 36 bottle rosette with CTD and LADCP mounted in the center was used for the entire cruise, apart from 3 stations were only the CTD was deployed. A test station, to 200m, was performed in the Straits of Magellan. CTD station and XCTD profile numbering was continued from the end of the 2005 Austral winter cruise, i.e. first CTD station of the summer 2006 cruise was Station 137, and XCTD 407.

Many discussions were held between the Chief Scientist, Master of the RV Knorr, the SIO/STS/ODF Technician-in-Charge and the STS Electronic Technician (ET) about the use of the 36-place rosette. WHOI had a tension meter designed that they asked be placed just above the rosette. Scripps ODF designed a system to enable this tension information to be feed real time to the ship with the CTD data. This information was stored for each cast using the RV Knorr SEASAVE program and graphically displayed real-time with the wire tension at the sheave as the wire is feed to the boom. Normal wire speed (30m/min in upper 200m and 60m/min below 200m) with standard wire tension was achieved for a large percentage of the 105 stations occupied. However, as with any CTD/rosette operation in the Southern Ocean, winds, sea-state and multiple swell directions dictated much slower wire speed on some stations - 20-25 m/min to ~2000m and 60 m/min between ~2000m and bottom. At these stations the CTD and winch operators carefully monitored wire tension and adjusted wire speed to minimize the occurrence of low wire tension. During the cruise two complete re-terminations were performed. The conducting cables of the starboard wire were tested after the completion of the CTD/rosette program. All conductors were in the same order as when they we first tested in Punta Arenas.

During the 30 hour steam from Punta Arenas to our first station science personnel finished tying down their equipment in the Knorr's main science laboratory. Numerous problems were encountered with ODF CTD acquisition and database software during the first week of the cruise. As a result the first two CTD stations of the cruise were undertaken using the RV Knorr's Seabird (SEASAVE) data acquisition software. By CTD station 139 the ODF CTD acquisition software was running, and over the next few days the ODF database and website became operational.

CTD station spacing was roughly 50km for much of the southern portion of the survey region. In this region the SAF was crossed 6 times and the Polar Front (PF) once. Two intensive surveys, centered on the SAF were occupied during the cruise. These surveys were centered on Station 149 and Station 187. At each of these sites a diamond patterned was steamed with CTD stations occupied on the northern, southern, western and eastern corners. XCTDs were deployed along the diamond track with a spacing of approximately 8km.

Our delay in leaving Punta Arenas, weather and technical problems resulted in time losses that eventually required us to drop a large number of CTD stations in the northern portion of the survey region. Only 105 stations were completed of the planned 161 stations. Weather conditions deteriorated during the transit between Stations 140 and 141. Arriving at Station 141 the average wind speed was 35-45 knots and a short, steep sea had developed. We hove-to for 18 hours before conditions abated allowing for the resumption of CTD/rosette operations. At Station 177 the pump on the CTD unit failed and the cast was aborted so that the pump could be changed. Technical problems at station 183, data spikes, a large number of modulo error counts and freezing of the acquisition software resulted in this cast being brought directly to the surface from 2000m during the upcast. The technical problems were investigated during the transit to Station 184, and a possible cause for the problem isolated. However, problems continued on Station 184 and the initial cast was aborted. After each unsuccessful cast attempt further changes were made to the CTD setup and wire. These included: removal of WHOI load cell; new sliprings; new CTD cables; new cable between main laboratory and winch and connecting only one conductor to the CTD. Three attempts were made to complete Station 184 before the station was successfully completed using one conductor wire. A 12 hour delay resulted from these technical problems. Further investigations by the STS ET concluded that the data spike problem before and at station 184 was due to wire ringing. During the remainder of the cruise we successfully rotated CTD operations between the three conducting cables.

Slow station transits due to strong winds and rough seas on our leg from 89W to 103W resulted in further loss of time. As a result of time delays stations spacing was increased on the west-east legs at approximately 55S, on the northern portion of the 89W line and final leg into the coast at approximately 47S. The 54S east-west line from the Chilean coast to 89W was not occupied. However, station resolution was maintained at the eastern boundary in order to properly sample the complex coastal boundary currents. A deep low pressure system passed south of our position on our long west-east section from 103W to the Chilean coast. We began Station 224 but wire tension was not stable and the cast was stopped at 1500m. Bottles were tripped on the upcast. The weather deteriorated over the next 10 hours and three stations in the middle of the basin east of 89W were replaced with XCTD profiles. CTD/rosette operation resumed at the eastern edge of the basin. While transiting from the Chilean coast to 89W to resume the north-south section another low passed south of our position resulting in gale force winds and large seas. These conditions slowed our transit to 3-4 knots during 5-6 March. Although winds had weakened somewhat when we arrived at 89W the sea-state still prohibited the deployment of the 36-place rosette. At this point with limited time remaining on the cruise and the need to get full depth CTD data resolution we decided to re-configure rosette/CTD operations and deploy only the CTD with altimeter. In this mode we did not get any LADCP or bottle data. This configuration was used on stations 230, 231 and 232. We reverted back to the 36-place rosette with complete suite of measurements at station 233.

Three hundred and fifty-six XCTD were deployed during the cruise. In the southern part of the cruise track 3 XCTD's were deployed between each station with a resolution of 10-15 km. In the northern part of the XCTD's were used to fill gaps between stations that were eliminated due to time constraints. The resolution of the XCTDs in this region varied from 20 to 30km. Three APEX floats with temperature, salinity, pressure and oxygen sensors were deployed during the cruise west of 89W and north of the SAF.

Science operations halted at 08:30 local time on 11 March 2006 to begin the 72 hour steam to Valparaiso. The science party and the officers and crew of the RV Knorr are commended for their hard work during the cruise. A CDROM of preliminary data obtained within the Chilean EEZ was produced and given to the Chilean observer/participating scientist, Luis Bravo.

Description of CTD/Hydrographic Measurement Techniques

Shipboard Technical Support/Oceanographic Data Facility
Shipboard Technical Support/Shipboard Electronics Group

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, and dissolved oxygen from CTD profiles. A total of 105 CTD/rosette stations were made usually to within 10 meters of the bottom. Prior to Station 184, "ringing" occurred in the CTD telemetry signal causing intermittent interference resulting in loss of CTD signal. SeaBird is aware of this but has no specific recommendation on conductor configuration other than to advise that the total loop resistance to below 350 ohms and in no case should it be greater than 400 ohms. Both single and 3-parallel wires meet this criterion. After 3 diagnostic casts on Station 184, this event was discovered and resolved by reterminating using a single conductor instead of 3 conductors. During the course of the next few stations, each conductor was used separately to verify that there was no problem with any one of the 3 conductors. The distribution of samples is illustrated in figure 1.0 - 1.6.

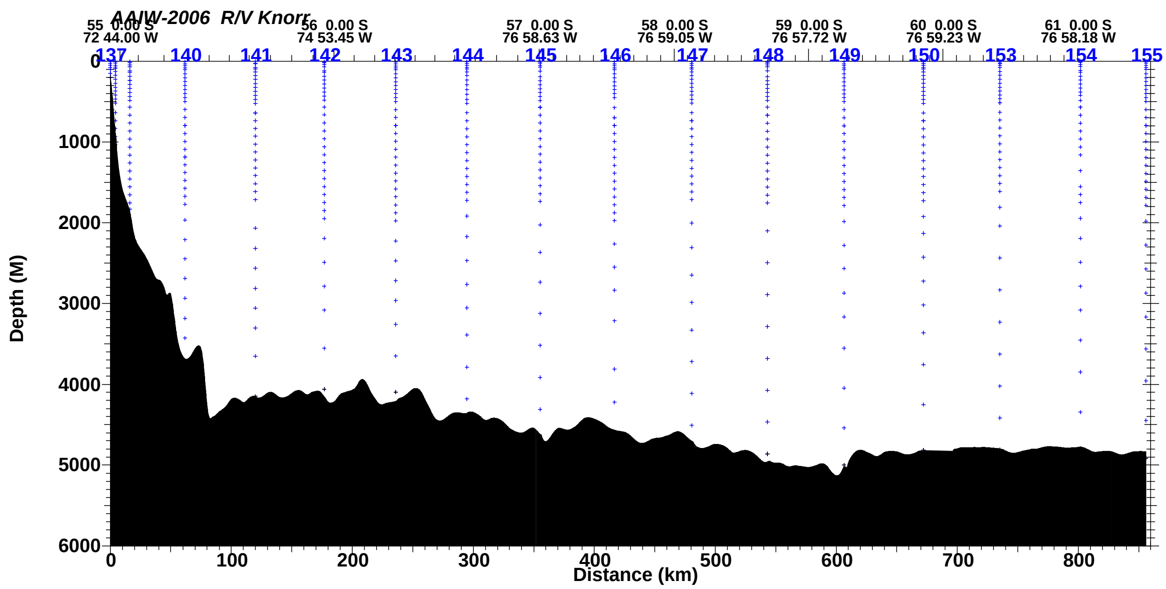

Figure 1.0 Sample distribution, stations 137-155.

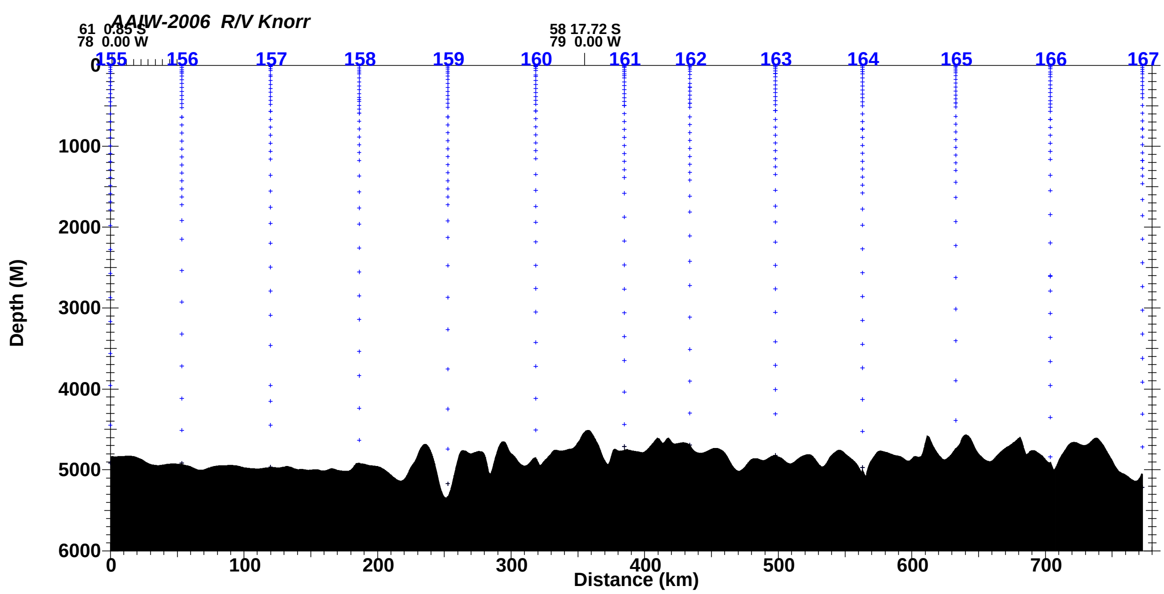

Figure 1.1 Sample distribution, stations 155-167.

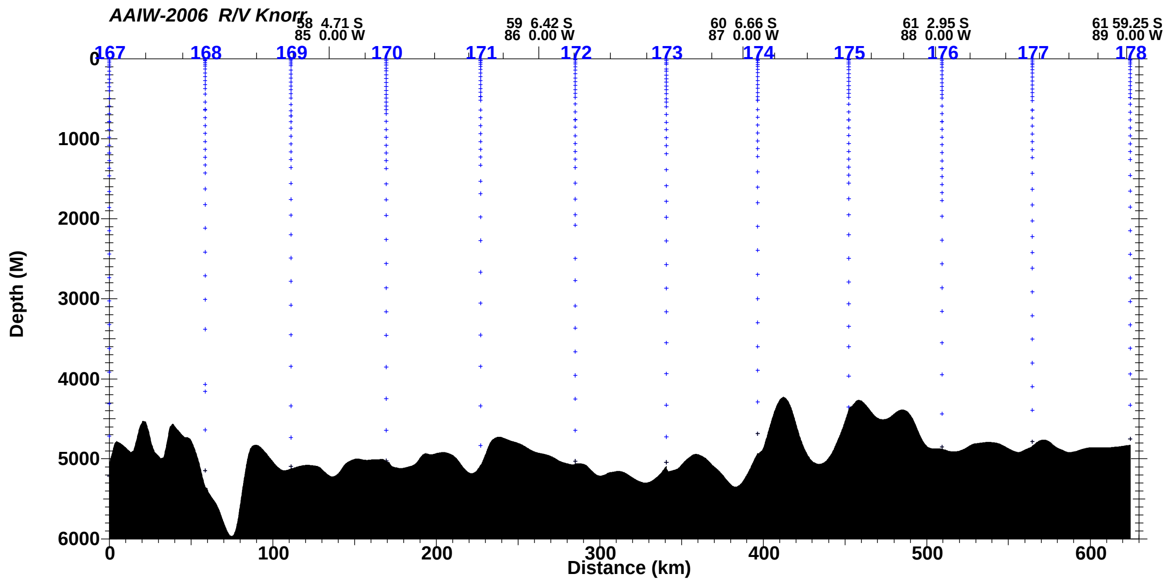

Figure 1.2 Sample distribution, stations 167-178.

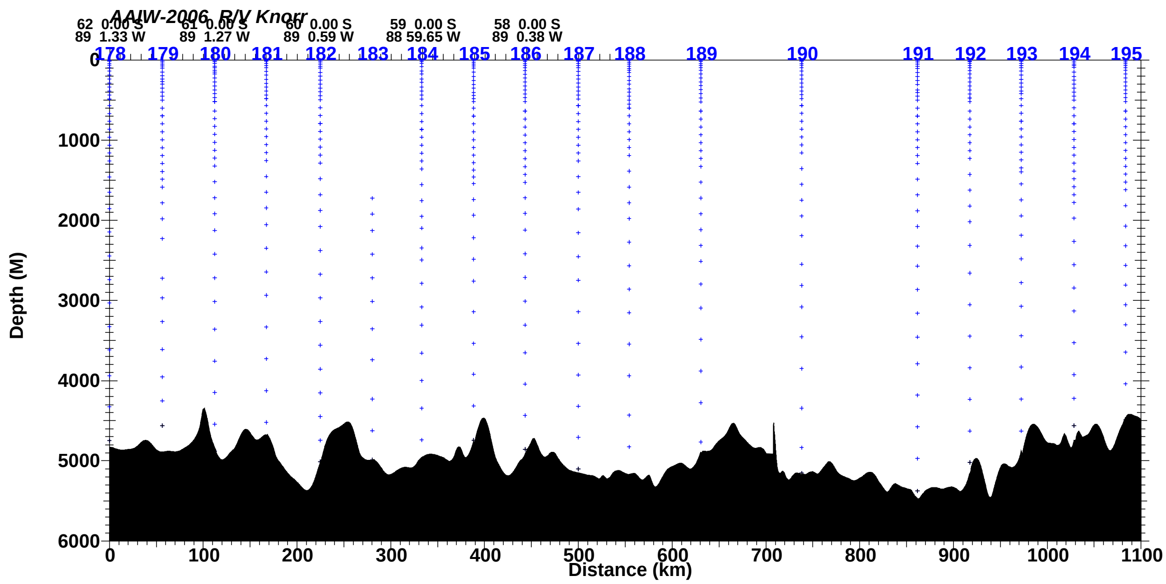

Figure 1.3 Sample distribution, stations 178-198.

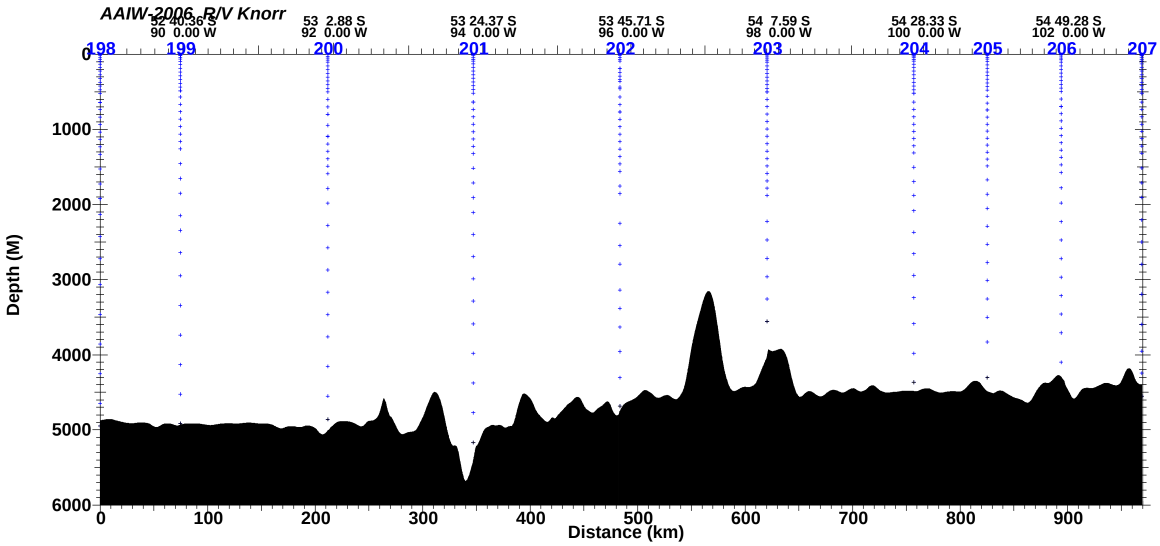

Figure 1.4 Sample distribution, stations 198-207.

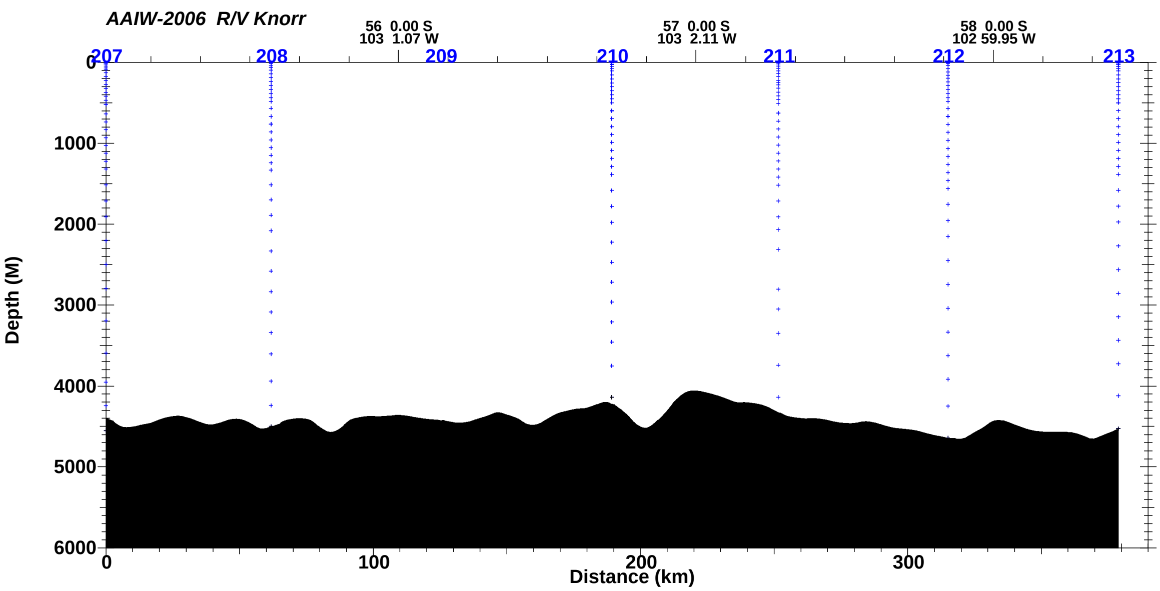

Figure 1.5 Sample distribution, stations 207-213.

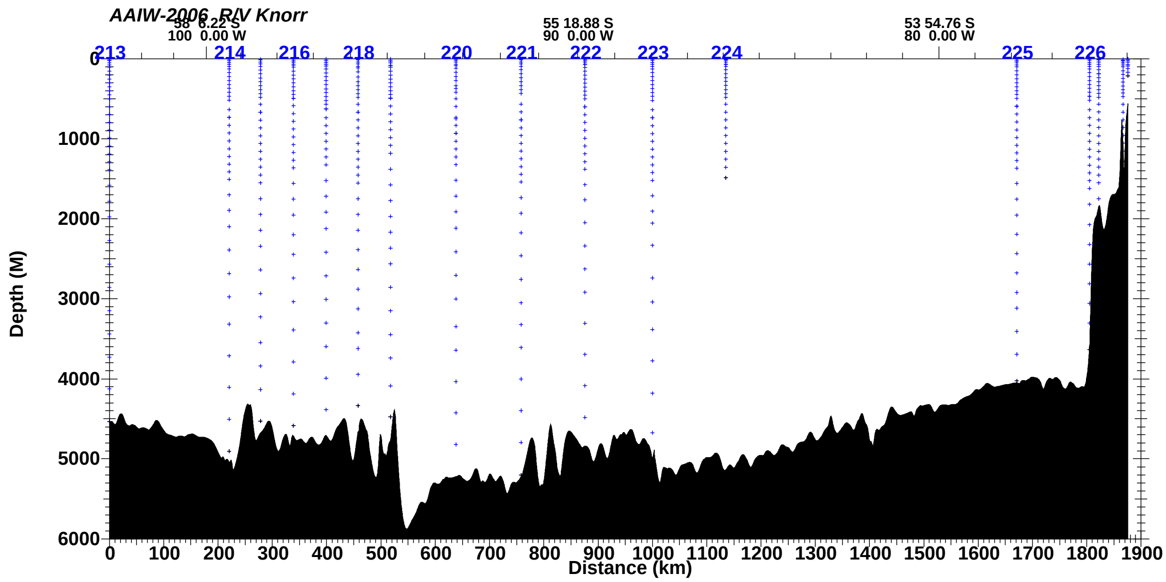

Figure 1.6 Sample distribution, stations 213-229.

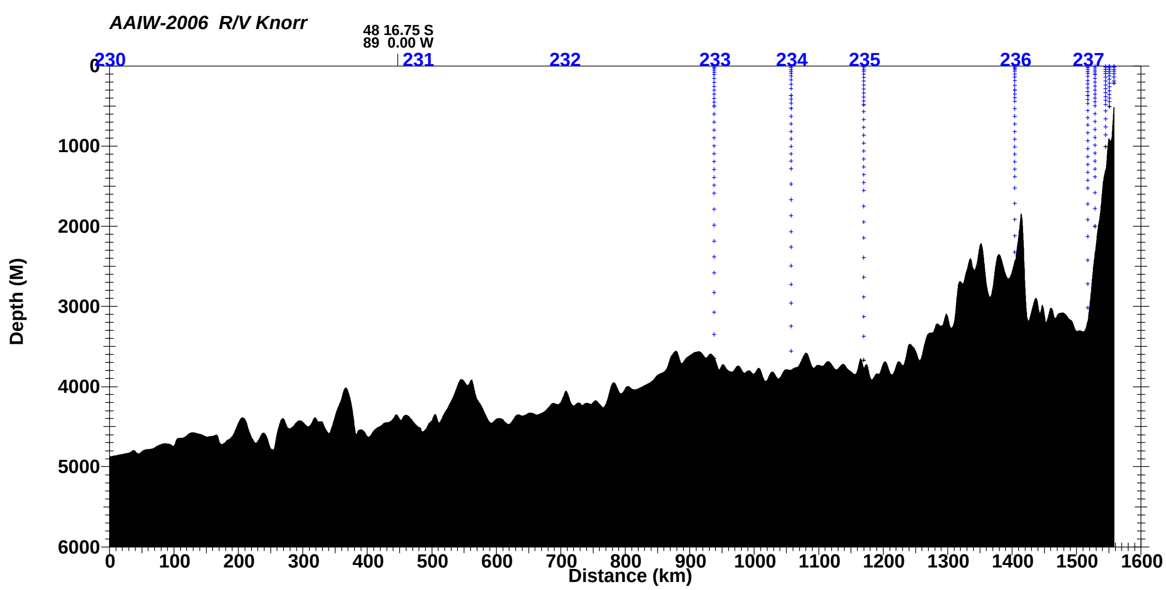

Figure 1.7 Sample distribution, stations 230-241.

1.1. Water Sampling Package

LADCP/CTD/rosette casts were performed with a package consisting of a 36-bottle rosette frame (ODF), a 36-place pylon (SBE32) and 36 10-liter Bullister bottles (ODF). Underwater electronic components consisted of a Sea-Bird Electronics (SBE) 9*plus* CTD (ODF #796, Stations 137-209, #401, Stations 210-241 with dual pumps, dual temperature (SBE3*plus*), dual conductivity (SBE4), dissolved oxygen (SBE43); and an SBE35RT Digital Reversing Thermometer, an RDI LADCP (Broadband 150khz) and a Simrad altimeter and 3PS, model LP-5k-2008, load pin force sensor.

The CTD was mounted vertically in an SBE CTD frame attached to the bottom center of the rosette frame. The SBE4 conductivity and SBE3*plus* 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 sensor was mounted horizontally, next to the intake of temperature sensor 2. The 3PS load pin force sensor owned by Woods Hole Oceanographic Institution (WHOI) was attached to the top of the rosette to measure loads at the package. The altimeter was mounted to 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 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. Sea cable reterminations were made prior to casts 171/1, 184/3 and 230/1. Station 184 casts 1, 2 and 3 were aborted because of electronics malfunctions, source was determined to be a "ringing" in the telemetry signal.

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. 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 2006 depending on the overall water depth (table 1.1.0). These standard depths were staggered every three stations.

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. One bottle was 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)	500-2000 meters: spacing no greater than 100 meters
(5)	2000-bottom: spacing no greater than 500 meters
(6)	bottom of SAMW: resolve the property break with one bottle above and one below if the layer is obvious (within 50 meters of break)
(7)	AAIW if obvious salinity minimum (north of SAF): try to sample the minimum.
(General)	Stagger the sampling so that sample depths are not exactly the same from one to the next. Three different scenarios were mapped and rotated from one station to the next to accomplish this.

Table 1.1.0 AAIW 2006 water sampling guidelines.

1.2. Underwater Electronics Packages

CTD data were collected with a SBE9*plus* CTD. This instrument provided pressure, dual temperature (SBE3), dual conductivity (SBE4), dissolved oxygen (SBE43) and altimeter (Simrad 807) channels. Additionally, a load pin for sensor, attached to the top of the rosette, provided load readings at the package for comparison with loads at the winch. The CTD supplied a standard SBE-format data stream at a data rate of 24 frames/second (fps).

Sea-Bird SBE32 36-place Carousel Water Sampler	S/N 3216715-0187
Sea-Bird SBE35RT Digital Reversing Thermometer	S/N 35-0011 (137-183,192-229)
Sea-Bird SBE9*plus* CTD	S/N 09P39801-0796 (137-209)
Sea-Bird SBE9*plus* CTD	S/N 09P11599-0401 (210-241)
Paroscientifi c Digiquartz Pressure Sensor	S/N 98627 (137-209)
Paroscientifi c Digiquartz Pressure Sensor	S/N 59916 (210-241)
Sea-Bird SBE3*plus* Temperature Sensor	S/N 03P-4486 (Primary)
Sea-Bird SBE3*plus* Temperature Sensor	S/N 03P-2165 (Secondary)
Sea-Bird SBE4C Conductivity Sensor	S/N 04-2112 (Primary, 137-208)
Sea-Bird SBE4C Conductivity Sensor	S/N 04-2659 (Primary, 209-241)
Sea-Bird SBE4C Conductivity Sensor	S/N 04-3058 (Secondary)
Sea-Bird SBE43 Dissolved Oxygen Sensor	S/N 43-0255 (137-241)
Sea-Bird SBE5T Pump	S/N 05-4128 (Primary/137-176)
Sea-Bird SBE5T Pump	S/N 05-4131 (Primary/177-183,208-241)
Sea-Bird SBE5T Pump	S/N 05-4132 (Primary/184-207)
Sea-Bird SBE5T Pump	S/N 05-4160 (Secondary)
Simrad 807 Altimeter	S/N 9711090
RDI Broadband 150khz LADCP	S/N 1394
LADCP Battery Pack	
3PS LP-5K-2008 Force Sensor	A0512124 (137-183,202-241)
SBE11*plus*-v.2 Deck Unit	S/N 11P21561-0518 (Shipboard)

Table 1.2.0 AAIW 2006 Rosette Underwater Electronics.

The CTD was outfi tted 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 SBE9*plus* CTD and SBE35RT temperature sensor were both connected to the SBE32 36-place pylon providing for single-conductor sea cable operation. The sea cable armor was used for ground (return). Power to the SBE9*plus* CTD was provide through the sea cable from the SBE11 deck unit in the main lab. All sensors, dual temperature and conductivity, oxygen, SBE32 carousel, SBE35RT and Simrad altimeter, received power from the CTD.

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 January 31. 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 Comtrol 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 on the stations with the rosette package. The stations that employed only the CTD, Stations 230-232, were brought up at 75m/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 onto 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.

The ship's CTD computer ran the SeaBird SeaSave software simultaneously with the STS/ODF acquisition system. This allowed the data from the load cell to be fed into the STS/ODF MET system for graphical display of wire tension at the winch and load tension at the rosette.

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, temperature and conductivity 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 generated from the down cast data whenever possible, where the CTD sensors saw the water before the rosette disturbed it. Only two casts had surface data extrapolated more than 8 decibars due to sea conditions and not being able to yoyo back to the surface after sensors stabilized. Both the 2 decibar pressure-series and 0.5 second time-series data were 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 (SBE3*plus*) were compared to each other and to the SBE35RT temperature sensor. CTD conductivity sensors (SBE4C) were compared with each other and with check-sample conductivity values to determine if any corrections were warranted. The CTD dissolved oxygen sensor (SBE43) data were calibrated to check-sample data. Additional deep theta-S and theta-O_2 comparisons were made between down and up casts as well as with adjacent deployments.

CTD data were collected successfully at all 105 stations occupied. A software update caused the serial ports to mentally "disappear" from the main acquisition computer just before the first station. The problem was fixed before station 139. Stations 137-138 data were collected with SBE software, and the SeaSave raw data were later imported into the usual STS processing software. The acquisition froze during stations 147 and 173 when a CTD signal spike killed the RawCTD display window. The raw data from the SeaSave simul-casts were imported post-cast to provide a more continuous data stream for these two stations. The cast at station 183 was stopped after 11 trips, when the acquisition window froze for a seventh time. The acquisition software was replaced with a 2-month older version (using the same underlying block-averaging program) after this cast, and never froze up again. Post-cast processing was performed on all casts with the same software.

The signal spiking problem (random spikes in random channels) was investigated prior to station 184, and water was found inside a damaged cable between the load cell and CTD. The load cell was removed prior to cast 1, which was aborted at 1230m after the signal spiked a second time during the down cast. Retermination and new slip rings did not resolve the spiking problem for cast 2, which was aborted at 1300m on the down cast. All cables between the CTD and sensors were replaced and the SBE35RT removed prior to cast 3; it was aborted at 680db on the down cast for excessive noise. New cable was installed between the lab and winch, a new primary pump was installed, and the wire terminated to use one conductor prior to cast 4, which was completed without spiking. A test of the conductors in the wire was run during the cast, and the remaining two cables had short-circuited at some point. Ultimately, the problem was traced to excessive attenuation of the Rochester sea cable due to the tri-conductor configuration of the wires. Reterminating the sea cable to the one-conductor configuration resolved the problem.

Two up casts were used for pressure-series instead of down casts (Stations 176 and 205) because the down casts were not usable. The pump for the primary sensors did not turn on until ~100db on the down cast of station 176, and the secondary conductivity sensor offset during the same cast. The problem was isolated at the start of station 177; the cast was aborted in the top 30m, and the primary pump was replaced before cast 2. The secondary sensors on the up cast were used for station 205 pressure-series data due to excessive noise in primary data after the sensors were fouled starting at 700db down, also causing a large ctd oxygen offset. The secondary sensors on the down cast were used for station 196 as well, due to fouling/offset of the primary sensors from ~800-1720db; its down cast oxygen (plumbed to the primary sensors) seemed to be unaffected.

Station 196 also began a series of casts with deep (2800+db), large spikes/cutouts affecting the primary conductivity (C1) sensor, but also causing smaller spikes in secondary conductivity (C2) and oxygen (O_2) sensors. The problem happened once or twice on stations 196 and 197, then not again until a single, brief "blip" on station 201, only in C1. The problem then affected each cast (down, up or both) except station 203, with C1 spiking and small C2 inversions lasting 6-60db, then O_2 returning to normal 30-40db later. An investigation of the raw data isolated the problem to C1: the signal from that one sensor apparently cut out, then both pumps turned off almost immediately because of the low conductivity signal (thinking they were out of water). About 5 seconds after C1 returned to normal, the pumps turned back on; O_2 fully recovered about 25 seconds later, due to its longer time constant. Since the cables between the CTD and its sensors were new and unlikely to be the problem, the C1 sensor was changed out before station 209 (from 04-2112 to 04-2659). The C1 signal cut out at 2245db on the down cast of station 209 and never returned; the cast was aborted at 3528db, since primary and secondary pumps were both off. The source was isolated to the C1 bulkhead connector on the CTD (#796). The backup CTD (#401) was installed before station 210, using the same temperature, conductivity and oxygen sensors as station 209. No more signal problems were encountered for the remainder of the cruise.

Extreme weather conditions and time constraints forced the use only the CTD in its cage with weights attached, minus rosette and extraneous instruments other than the altimeter, at Stations 230-232.

1.6. CTD Sensor Laboratory Calibrations

Laboratory calibrations of the SBE pressure, temperature, conductivity, dissolved oxygen and digital Reversing Thermometer sensors were performed prior to AAIW 2006 . The calibration dates are listed in table 1.6.0.

Sensor	S/N	Calibration Date	Calibration Facility
Paroscientific Digiquartz Pressure	98627	7-July-2005	SIO/STS
Paroscientific Digiquartz Pressure	59916	16-May-2005	SIO/STS
Sea-Bird SBE3*plus* T1 Temperature	03P-4486	12-Dec-2005	SIO/STS
Sea-Bird SBE3*plus* T2 Temperature	03P-2165	12-Dec-2005	SIO/STS
Sea-Bird SBE4C C1 Conductivity	04-2112	13-Dec-2005	SBE
Sea-Bird SBE4C C1 Conductivity	04-2659	10-Dec-2005	SBE
Sea-Bird SBE4C C2 Conductivity	04-3058	10-Dec-2005	SBE
Sea-Bird SBE43 Dissolved Oxygen	43-0255	(23-Dec-2005-N/A)	SBE
Sea-Bird SBE35RT Dig.Reversing Therm.	35-0011	15-Dec-2005	SIO/STS

Table 1.6.0 AAIW 2006 CTD sensor laboratory calibrations.

1.7. CTD Shipboard Calibration Procedures

CTD #796 was used for Stations 137-209 and CTD #401 was used on stations 210-241 on AAIW 2006. The CTD was deployed with all sensors and pumps aligned vertically, as recommended by SBE. The primary temperature and conductivity sensors (T1 and C1) were used for CTD data reported for all but two casts. The secondary temperature and conductivity sensors (T2 and C2) were used for stations 196 and 205 reported CTD data, but typically served only as calibration checks for the primary sensors. The SBE35RT Digital Reversing Thermometer (S/N 35-0011) served as an independent calibration check for temperature. *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 transducers (CTD796-Pressure S/N 98627 and CTD401-Pressure S/N 59916) were calibrated in July and May 2005 at the SIO/STS Calibration Facility. Coefficients derived from the calibration were applied to convert raw pressure frequencies to corrected pressures during each cast. Residual pressure offsets (the CTD pressures just before submersion and just after coming out of the water) were examined to check for calibration shifts. Offsets varied between 0.4-0.9db for the first sensor, and 0.0-0.4db for the second pressure sensor. An offset of -0.7db was applied to calculated pressures for stations 137-176, then reduced to -0.5db until the CTD/pressure sensor were changed before station 210. No adjustments were made to the calculated pressures for the replacement sensor. All final corrected residual pressure offsets were between -0.3 and +0.5db.

1.7.2. CTD Temperature

The same SBE3*plus* primary and secondary temperature sensors (T1-S/N 03P-4486 and T2-S/N 03P-2165) served for the entire cruise. Calibration coefficients derived from the pre-cruise calibrations in December 2005 were applied to raw primary and secondary temperature data during each cast.

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° C/year. The SBE35RT used on AAIW 2006 (S/N 35-0011) was calibrated in December 2005, at which time its correction was reported to have drifted at most by -0.0010° C over the entire temperature range (-2 to 30° C) since May 2000.

The SBE35RT was not on the rosette for stations 184-191, and its internal battery died (thereby erasing its memory) while trying to upload data for stations 224-229. It was not used after station 229. Occasionally the SBE35RT's memory filled between uploads, preventing it from storing more data.

Two independent metrics of calibration accuracy were examined. T1 and T2 were compared, and the SBE35RT temperatures were compared to both T1 and T2 at each rosette trip.

Calibration accuracy was first examined by tabulating T1-T2 over a range of pressures (at bottle trip locations) for stations 137-108. The differences appeared to have a small drift with station number (time) at the start of the cruise. An examination of the SBE35RT-T1 differences showed that T1 drifted -0.00029° C over the first 35 casts, then stabilized for the rest of the leg. SBE35RT-T2 differences indicated T2 did not drift. The T1 drift was corrected by applying a smoothly changing offset over the first 35 casts to match T2, based on data below 1500db. Then a simple offset was applied to T1 data starting at station 171.

The normalized T1-T2 differences showed an approximate 0.001° C slope from surface to deep pressures. A comparison with SBE35RT data indicated that T1 was 0.002° C high at deep pressures (5500db), while T2 was 0.001° C high. T1 matched the SBE35RT at surface pressures, and T2 was offset +0.00027° C. Historical calibrations showed that the SBE35RT was more stable over time than the SBE3*plus* sensors. However, the response of either sensor type to large pressures has not been documented. Since the two SBE3*plus* sensors showed a relative slope, an offset was applied to T2 data to match the SBE35RT at surface pressures, and then a 2nd-order polynomial fit of T2-T1 differences as a function of CTD Pressure was generated to correct T1. This compromise brought both SBE3*plus* sensors within 0.001° C of each other and the SBE35RT at all pressures.

Temperature differences were rechecked for stations 210-241 using the corrections determined above. The sparse SBE35RT data for these casts did not show any notable differences. The overall drift between T1 and T2 from stations 171-241 was less than 0.0003° C, half of the shift in temperature routinely observed when the CTD changes direction during a cast. No further adjustments to temperature corrections were warranted.

The residual differences for all temperatures are summarized in figures 1.7.2.0 through 1.7.2.4.

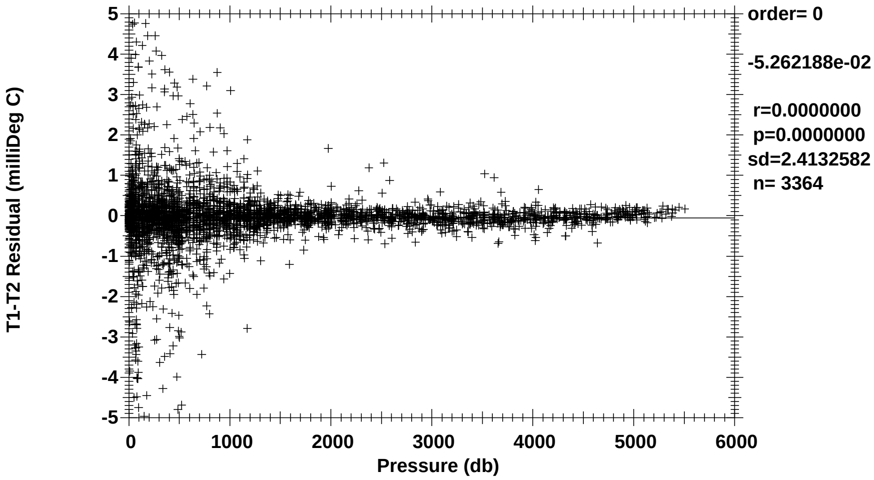

Figure 1.7.2.0 T1-T2 vs pressure, all pressures.

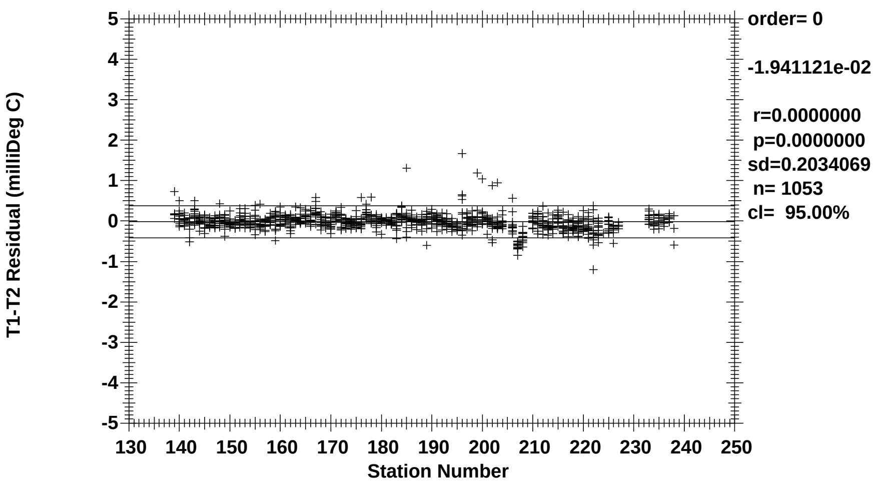

Figure 1.7.2.1 T1-T2 vs station, p>1500db.

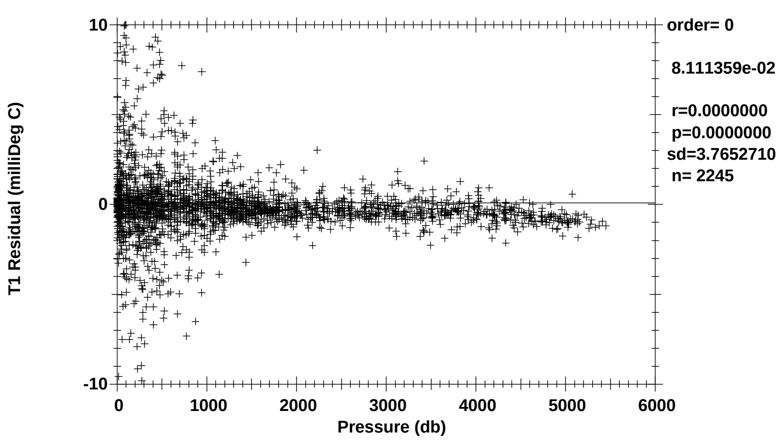

Figure 1.7.2.2 SBE35RT-T1 vs pressure, all pressures.

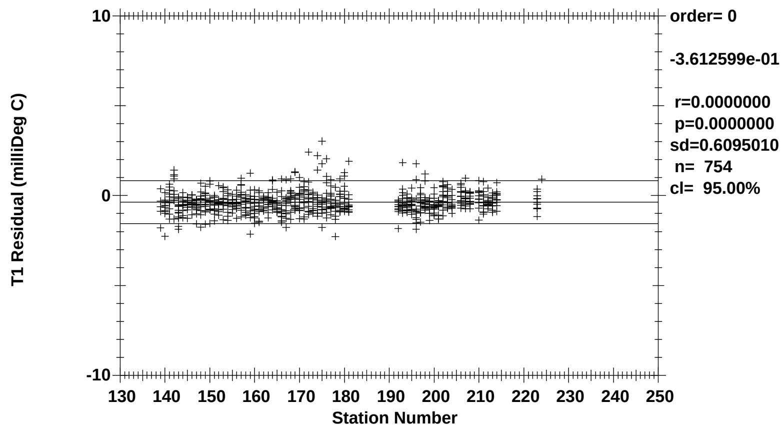

Figure 1.7.2.3 SBE35RT-T1 vs station, p>1500db.

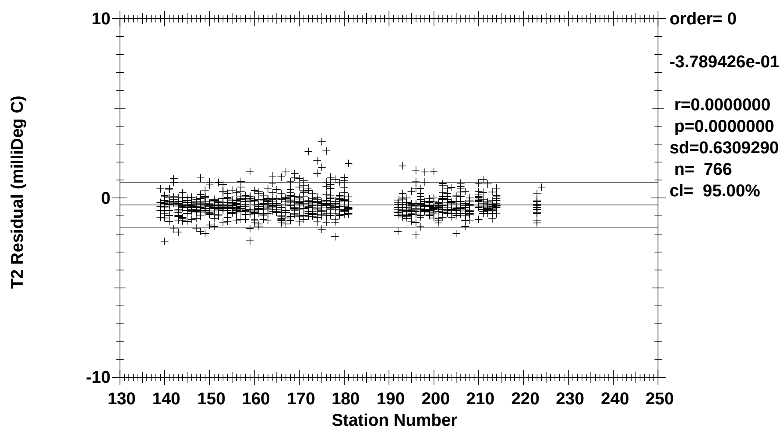

Figure 1.7.2.4 SBE35RT-T2 vs station, p>1500db.

The 95% confidence limit for the mean deep differences is ±0.0004° C for T1-T2, and ±0.0006° C for SBE35RT-T1.

1.7.3. CTD Conductivity

Two primary SBE4C conductivity sensors (C1A-S/N 04-2112 for stations 137-208, C1B-S/N 04-2659 for stations 209-241) and one secondary SBE4C conductivity sensor (C2-S/N 04-3058 for all casts) served for 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 sensor vs check sample conductivities calculated from bottle salinities, were used to derive conductivity corrections.

C1A-C2 differences showed a pressure slope of about -0.0005mS/cm from 0 to 5500db, with an average deep difference of +0.0004mS/cm. Bottle differences were more scattered, but indicated C1A was high and C2 was more nearly correct. A first-order pressure slope was applied to C1A, based on a fit of C2-C1A differences above 50db or below 1200db. C1B-C2 differences did not show any significant slope with pressure.

The first few stations displayed a greater change in offset with time, then the offsets stabilized. The C2 offsets started shifting slowly upward with time, with the shifting becoming a little more rapid after the sensors were moved to the second CTD before station 210. C1A, C1B and C2 offsets were adjusted in groups of stations based on observed shifts of one sensor vs the other in deep theta-salinity overlays of nearby stations for each sensor pair. Stations near crossover points in the track were also compared to ensure consistency.

Deep primary and secondary conductivity differences by station, after applying shipboard corrections, are summarized in figure 1.7.3.0.

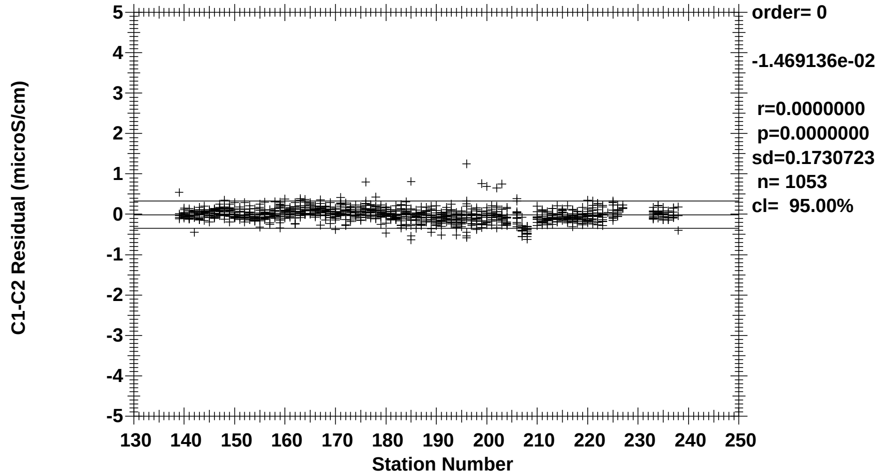

Figure 1.7.3.0 C1-C2 vs station, p>1500db.

Bottle minus CTD salinity residuals, after applying shipboard T1/C1 and T2/C2 corrections, are summarized in figures 1.7.3.1 through 1.7.3.3.

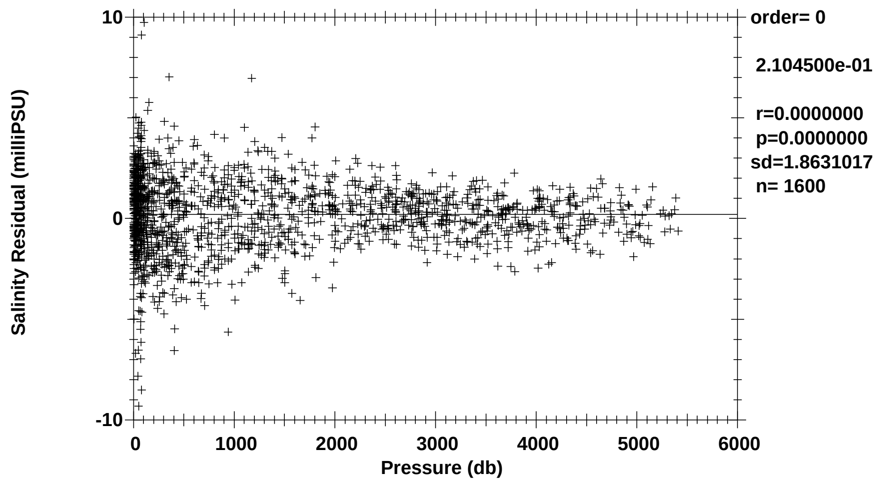

Figure 1.7.3.1 Salinity residuals vs pressure, all pressures.

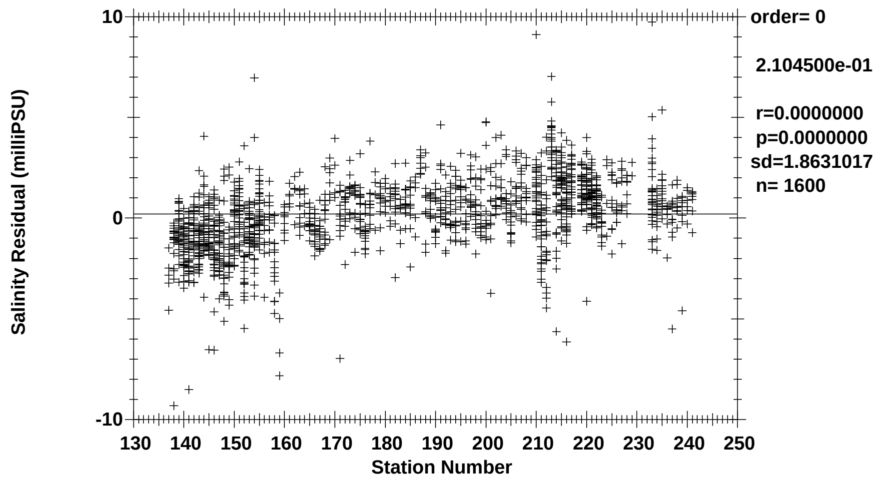

Figure 1.7.3.2 Salinity residuals vs station, all pressures.

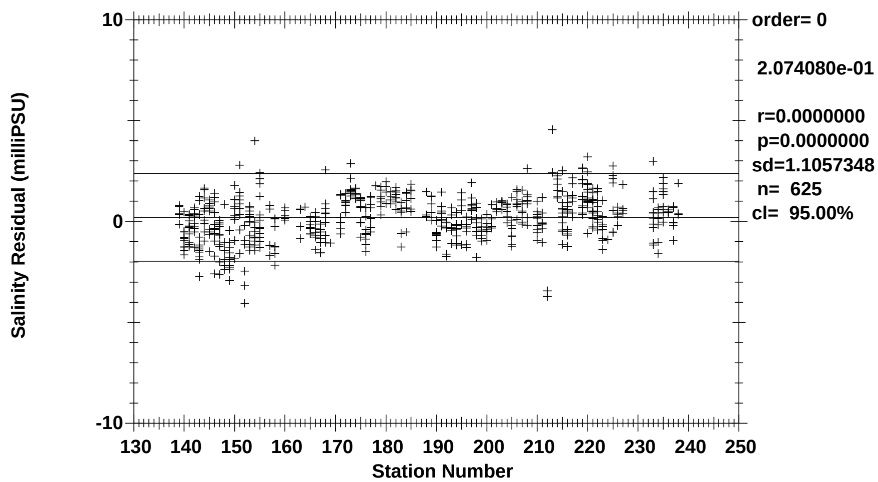

Figure 1.7.3.3 Salinity residuals vs station, p>1500db.

Figure 1.7.3.3 represents an estimate of the deep salinity accuracy on AAIW 2006. The 95% confidence limit is ±0.0022 PSU relative to the bottle salts.

1.7.4. CTD Dissolved Oxygen

One SBE43 dissolved O_2 sensor (DO-S/N 43-0255) was used during this cruise. The sensor was plumbed into the primary T1/C1 pump circuit after C1. Down cast data were used for all but two casts.

The DO sensor calibration method used for this cruise matched down cast pressure-series CTD O_2 data to up cast bottle trips along isopycnal surfaces. Residual differences between the *in-situ* check sample values and CTD O_2 were minimized 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 the sensor. These time constants are sensor-specific but applicable to an entire cruise. Next, casts were fit individually to check sample oxygen data. CTD data were refit if bottle oxygen data changed by 0.005ml/l or more after bottle data were recalculated with smoothed standards/blanks. Deep theta-O_2 overlays of nearby stations were compared to ensure data consistency. Down and up cast differences were also considered when bottle data in shallower areas disagreed. CTD O_2 data were converted from ml/l to umol/kg units after fitting.

Two up casts were processed instead of down casts, because of various problems with offsets in down cast salinity and/or oxygen data. These up cast time-series data were fit to bottle oxygens using the same time constants used on the down cast fits. The time-dependent corrections were updated before pressure-sequencing the data.

Four casts were acquired without bottle data at stations 209 and 230-232. A fifth cast at station 183 had no bottles shallower than 1748db. Bottle data from nearby casts were used to approximate the fits for stations 183, 209 and 230. The correction coefficients for station 233 were used for stations 231-232, since there were no nearby casts with similar features to use. CTD O_2 data for these stations may be acceptable, but are coded as "uncalibrated" because the bottle data were sparse or missing for such large sections.

Bottom bottle O_2 data were occasionally missing or coded "questionable" due to tripping, sampling or analytical problems. Deep theta-O_2 comparisons were used to estimate a bottom value for fitting where possible, typically helping to optimize the fit through other deep bottles. However, deep CTD O_2 data for stations 140-141 were coded questionable below their last "acceptable" deep bottles because it was unclear what value should be used to fit the bottom data.

Figures 1.7.4.0-1.7.4.2 show the residual differences between bottle and calibrated CTD O_2 where both CTD and bottle oxygen data are coded "acceptable".

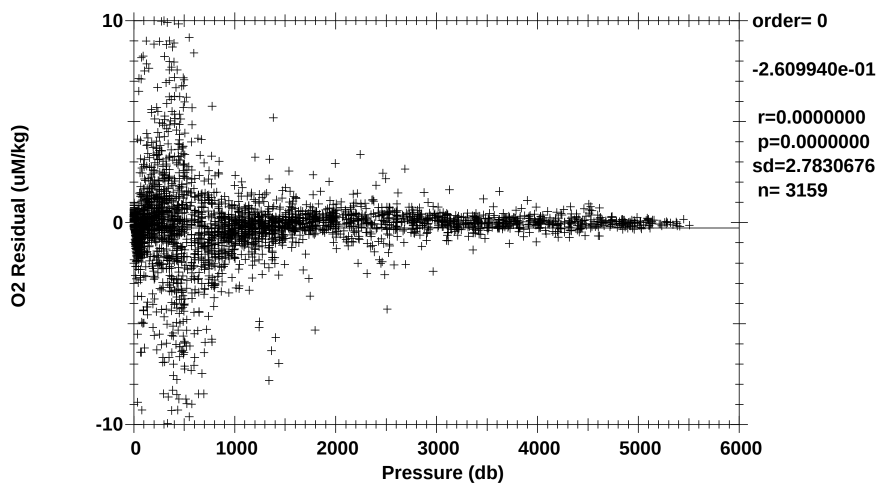

Figure 1.7.4.0 O_2 residuals vs pressure, all pressures.

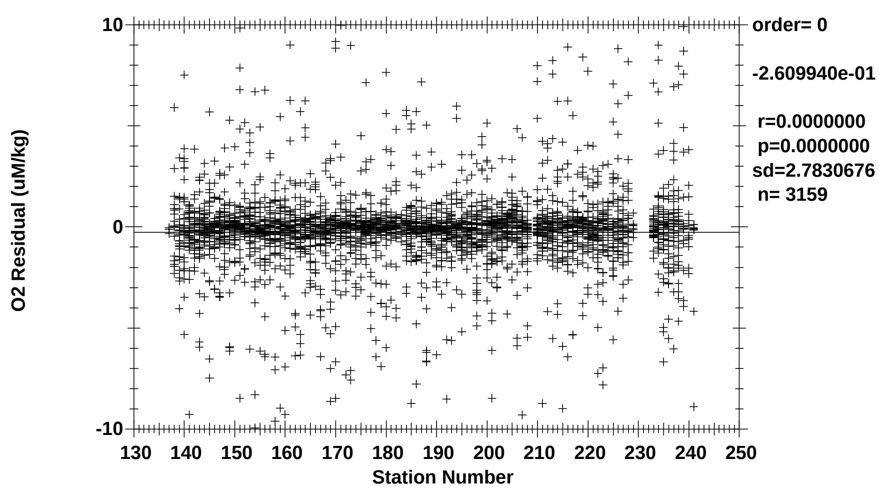

Figure 1.7.4.1 O_2 residuals vs station, all pressures.

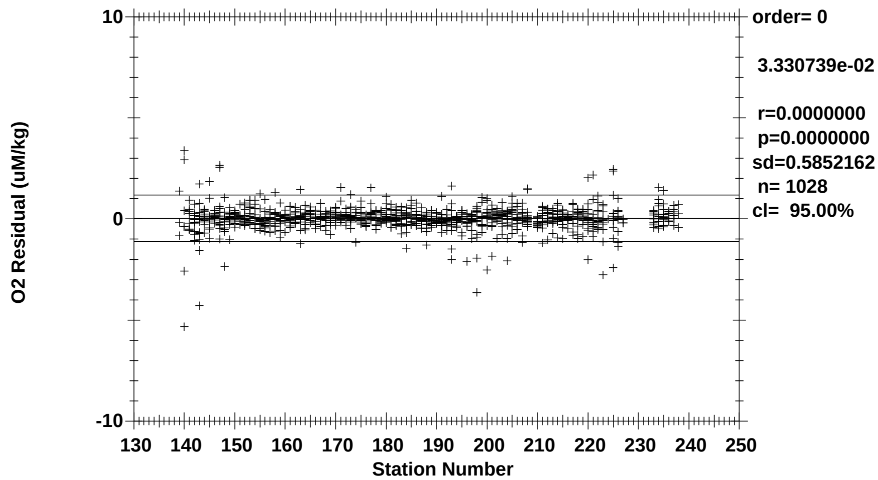

Figure 1.7.4.2 O_2 residuals vs station, p>1500db .

The standard deviations of 2.78 umol/kg for all oxygens and 0.585 umol/kg for deep oxygens are only presented as general indicators of goodness of fit. STS makes no claims regarding the precision or accuracy of CTD dissolved O_2 data.

The general form of the STS O_2 conversion equation for Clark cells follows Brown and Morrison [Brow78] and Millard [Mill82], [Owen85]. STS 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 τ_p, two temperature responses τ_{Ts} and τ_{Tf}, and thermal gradient response τ_{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, τ_{og}, is a fitting parameter. Dissolved O_2 concentration is then calculated:

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

where:

$O_{2ml/l}$	= Dissolved O_2 concentration in ml/l;
O_c	= Sensor current (μamps);
$f_{sat}(S,T,P)$	= 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 (° C);
P	= Pressure at O_2 response-time (decibars);
P_l	= Low-pass filtered pressure (decibars);
T_f	= Fast low-pass filtered temperature (° C);
T_s	= Slow low-pass filtered temperature (° C);
$\frac{dO_c}{dt}$	= Sensor current gradient (μamps/secs);
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:

- O_2
- Nutrients
- Salinity
- Phytopigments
- DNA

The 36-place 10-liter rosette was used on most casts. The latch which releases the lanyard and subsequently tripping the bottle in position 21 on the carousel malfunctioned early in the expedition. By Station 150, it was deemed unusable despite efforts to repair it. On Station 161, bottle 7 was replaced by bottle 37 until it could be properly serviced; bottle 7 was back on the rosette again by Station 162. Station 183 was aborted after 11 bottle trips after spiking in the CTD signal resulted in a seventh restart of the acquisition; there are no bottles shallower than 1748 db. No samples were collected during Station 209: the cast was discontinued during the down cast due to CTD problems. The CTD was deployed without the rosette or bottles at Stations 230-232.

The correspondence between individual sample containers and the rosette bottle position (1-36) 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. On two stations, 156 and 157, the oxygen draw temperature probe failed. In-situ temperatures are therefore used in the conversion of ml/l to uM/kg.

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 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 a few deployments that no bottle stops were made shallower than 50m. 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.

1.10. Salinity Analysis

Equipment and Techniques

Two Guildline Autosal Model 8400A salinometers (S/N 57-526 & S/N 53-503), located in the analytical lab, were used for all salinity measurements. Salinometer 53-503 was employed beginning with Station 190 when salinometer 57-527 was taken out of service due to unusual offsets in the Standard dial readings. The salinometers were modifi ed by ODF to contain an interface for computer-aided measurement. The water bath temperature was set at 24° C for the entire cruise and lab temperature was maintained at a value near 24° C +/- 2° C.

The salinity analyses were performed after samples had equilibrated to laboratory temperature, usually within 8-54 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

1911 salinity measurements were made and approximately 130 vials of standard water (SSW) were used. Salinity data was used as an additional calibration check for the CTD. After the initial comparison with the conductivity sensors, salinity was drawn from a few of the surface and bottom bottles.

Salinity samples were drawn into 200 ml Kimax high-alumina borosilicate bottles, which were rinsed three times with sample prior to fi lling. 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 fi t 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. The STD dial issue on salinometer 57-526 was problematic and a few runs were rendered unusable for calibration purposes. A new Chopper/conductivity printed circuit card was placed in this salinometer prior to the start of the cruise. It is suspected that the components deterioated on this card and that is the cause of the drift. Salinometer 53-503 also had problems, but with the Standby/Read switch: it introduced noise in the data and was replaced after Station 219. Diagnostics indicated that Stations 214-218 may have been affected from the switch problem and were deemed questionable with Station 218 unusable. The estimated accuracy of bottle salinities run at sea is usually better than ±0.002 PSU relative to the particular standard seawater batch used.

Laboratory Temperature

The temperature of the laboratory used for the analyses ranged from 21.6° C to 25.8° C. The air temperature during any particular run varied from -2.1 to +1.8° C. Most salinity runs had no or little lab temperature change.

Standards

IAPSO Standard Seawater (SSW) Batch P-146 was used to standardize Stations 138-189 and Batch P145 for stations 190-241.

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 LabView 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 (~0.012N) and thiosulfate solution (~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

3195 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 uM/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 1-2 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) 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 2006 . 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 ~4° 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 PO_4 color development. The sample was passed through a 15mm flowcell and the absorbence 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 absorbence 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 ~55° C to enhance color development, then passed through a 50mm flowcell and the absorbence measured at 820nm.

Explicit corrections for *carryover* in nutrient analyses are not made. In a typical AutoAnalyzer system, sample to sample carryover is ~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

3211 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 absorbence 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.

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 effi ciency 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 (±1.5° C).

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XCTD Operations

During the Antarctic Intermediate Water (AAIW) 2006 summer cruise, underway profiling of upper ocean temperature and salinity was carried out with expendable conductivity-temperature-depth probes (XCTDs). The sampling at 10 to 50 km spacing supplemented the full-depth CTD stations that were spaced at approximately 50-200 km. Generally, 3 XCTDs were launched between CTD stations for the southern portion of the survey region, with 2-5 XCTD's for the northern survey area where CTD station spacing was generally greater than 70 km. Additionally, two intensive surveys were carried out near the Subantarctic Front (SAF), 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 was centered on CTD station 149 and ended with station 152 (Stations 148,150,151, and 152 are the corners). The second intensive survey was centered on CTD station 187 and ended with station 190 (Stations 186, 188, 189, and 190 are the corners).

Instrumentation

The XCTDs were digital TSK probes purchased from Sippican (Sippican, Inc.) and manufactured by TSK (The Tsurumi-Seiki Co.). The science party supplied computer, deck unit, and launcher were used throughout the cruise, while the standard ship's equipment was a backup to our system. The deck unit was the Sippican MK-21 model.

Data acquisition

Data acquisition was on a pc computer with the Windows 2000 Professional operating system. Two copies of the data files were made: one on the pc hard disk; and the second on a backup directory on the pc. The Sippican software version was WinMK21 SURFACE. The hand launcher and XCTDs were kept in the aft hangar, and the launches were staged from the hanger.

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 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 two launch locations, and the choice was dictated by wind and seas. Permanent launch tube was located on the port side, just aft of the hangar and on the starboard side rail of the fantail. The fall rate is approximately 200 m/min, and a cast typically took 5 mins. Once the probe was launched using the tube, both persons would come back inside and monitor the launch on the computer. 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.

Data processing and quality

The Sippican automated processing was the only processing that was applied to the profiles. Two files exist for each cast: RDF (binary, raw); and EDF (ascii, edited by the Sippican autoprocessing). Three hundred and fifty-six (356) XCTD probes were launched during the cruise. The statistics of probe launches were: 346 completely successful (cast depth greater than 800m); 6 good data but limited depth (profile depth between 800m and 100m); 4 failed (profile depth < 100 m or failed outright).

Problems

During the cruise the ships deck crew cleaned and painted the aft hanger. During rough seas on the 8th of February planks on scaffolding in the hanger fell onto the XCTD launchers bending the metal yoke. XCTDs would not fit into the yoke once it was bent. The Knorr SSSG replaced the metal yoke with the same part from the Knorr launcher. The Knorr has ordered a replacement part for our equipment and will send the new part to Scripps.

APEX FLOATS

Three APEX floats were deployed during the cruise. The floats were equipped with a SEABIRD 41 temperature, conductivity and pressure sensor and an Aanderaa Oxygen Optone 3830 sensor. The APEX floats were shipped directly to Punta Arenas from Webb Research, Falmouth MA. All floats passed the final test procedure prior to our departure from Punta Arenas.

The floats were launched at the end of a CTD stations. Launch location and time were:

Float	Date/Time (UTC)	Latitude	Longitude
2604	21 Feb 22:17	53 1.49S	91 55.59W
2605	22 Feb 20:28	53 43.8S	95 51.0W
2606	01 Mar 06:15	55 47.2S	91 28.90W

Each float was functioning and reporting temperature, salinity, pressure and oxygen profiles via ARGOS at the end of the cruise

Problems

Upon inspection of the shipping crates it was noted that the shockwatch warning device of the box housing float 2606 was red. The float passed the final test procedure that was undertaken before leaving port. Upon reset for actual deployment it gave only one ARGOS transmission, but all other reset functions worked as per the manual. ARGOS transmissions were received every 45 seconds for the period in which the air pump was operating during the reset. The float was deemed to be in working order and deployed as planned.

Underway PCOs/NO2

Underway PCO2/NO2 measurements were taken during the cruise by Osvaldo Ulloa and Laura Ferrias from the University of Concepcion, Chile. The system was monitored by Heather Bouman during the cruise.

Problems

The system was turned off due to low flow rate at different times during the cruise.

ADCP/LADCP
Teresa Chereskin

Introduction

During the Antarctic Intermediate Water (AAIW) summer 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).

Shipboard ADCPs

Instrumentation

Data were 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 cruises in order to profile currents at higher resolution and at shallower depths than is possible with the OS75. The NB150 ADCP transducer was mounted in an instrument well located below the lower laboratory 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 prior to the AAIW 2005 austral late winter /spring cruise. However it 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 4beam velocity solution). We collected NB150 data with the intention of implementing a 3beam solution.

Data acquisition

Single ping ADCP data from both instruments and ancillary navigation streams (GPS, gyrocompass, and POS/MV) were collected on a Dell 1U rackmounted 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 realtime on the Linux server (currents.knorr.whoi.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 postprocessing.

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.

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^{o} (King and Cooper, 1992). The overall error in absolute currents is estimated at 12 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 3beam 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.

Lowered ADCP

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^o beam angles. It was mounted on the interior 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 hoseclamped to the bottom of the rosette frame.

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 (rditerm.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). LADCP data were not collected on stations 230, 231 and 232 when only the CTD was deloyed.

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 (singleping) 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 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.

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 cm s^{-1}, to account for a nonconstant fall rate) (Fischer and Visbeck, 1993; Firing, 1998). Errors in the baroclinic profile accumulate as 1/ (*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 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 Pcode GPS, about 1 cms^{-1} (2 to 4 cm s^{-1} without). Comparisons with Pegasus suggest that the LADCP can measure the depthaveraged velocity to within 1 cm s^{-1} (Hacker et al., 1996). The rms difference between Pegasus and LADCP absolute profiles are within the expected oceanic variability, 35 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 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, versions 8a and 9a. 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 postprocessing. 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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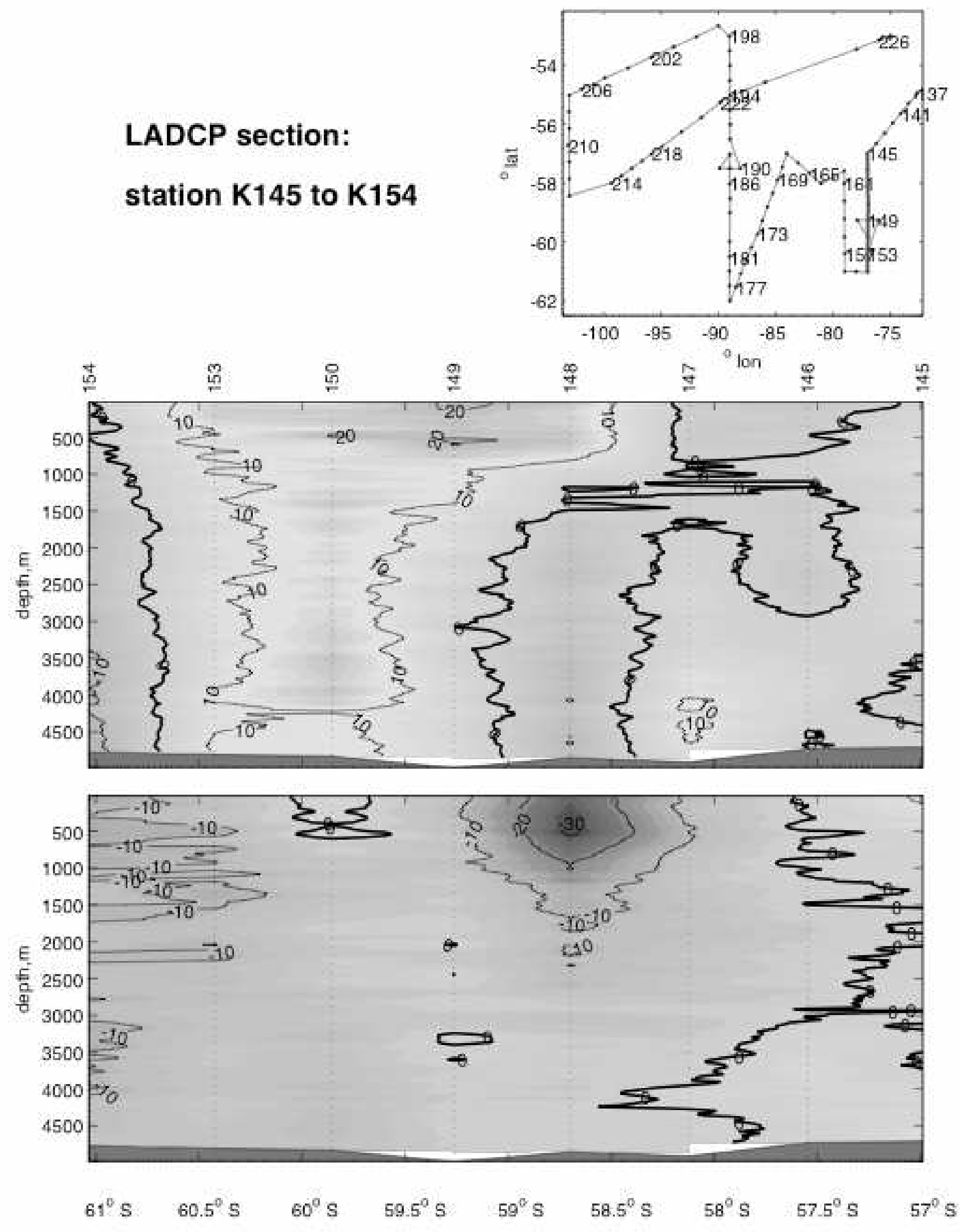

Figure 1: LADCP section across the Subantarctic Front, stations 145 to 154. Upper panel is eastward current (cm/s). Lower panel is northward current (cm/s). Red line on station map indicates location of section.

Phytoplankton

Heather Bouman (Univerisity of Concepcion, Chile)

To assess phytoplankton community structure during the Antarctic Intermediate Water (AAIW) 2006 summer cruise, seawater was collected daily to assess pigment composition, cell abundance and DNA. In addition, samples were collected to assess the population structure of cyanobacteria using Fluorescence *In Situ* Hybridization (FISH). Samples were collected daily at the sea surface for validation of remotely-sensed estimates of pigment concentration, and occasionally at multiple depths within the top 100m of the water column to assess vertical variability in phytoplankton community structure.

High Performance Liquid Chromatography Analysis (HPLC)

Between 0.5 and 1.5 liters of seawater were filter through a 25 mm GF/F filter. Filters were then placed in liquid nitrogen and then transferred to a –80ºC freezer. Samples will be processed in the laboratory. Concentrations of chlorophyll-a and accessory pigments will be used to assess the relative abundance of phytoplankton taxa.

Flow Cytometry

At each station 1.35 ml of seawater was placed in a 2 ml cryovial and preserved with 0.15 ml of 1% gluteraldehyde solution. Samples were then placed in liquid nitrogen and transferred to a –80ºC freezer for later analysis. Phytoplankton and bacteria cells will be enumerated based on their scattering and fluorescence properties using a FACSCalibur Flow Cytometer (Bection Dickinson, San Jose, CA).

DNA

Between 5 and 8 liters of seawater was filtered sequentially onto 3.0 and 0.20 um filters and placed into 5 ml cryotubes containing 1.5 ml lysis buffer. Samples were then immediately placed in liquid nitrogen and transferred to a –80ºC freezer. DNA extraction and amplification will be conducted at the University of Concepcion. Amplified DNA will be used to examine the genetic composition of the cyanobacteria community.

Fluorescence *In Situ* Hybridization (FISH)

Between 100 and 150 ml of seawater was filtered onto a 0.2 um GTTP filter. Filters were then air-dried and placed in 1% paraformaldehyde solution for 2 hours at room temperature. Filters were then sequentially transferred into 50, 80 and 100 % ethanol for approximately 5 minutes. Filters were then dried and stored at –80ºC in plastic petrislides for later analysis in the laboratory. Fluorescent probes specific for various genotypes of cyanobacteria will be used to assess the genetic structure of natural populations.

Particulate Absorption

Between 0.3 and 1.5 liters of seawater was filtered through a 25 mm GF/F filter. Samples were placed immediately into liquid nitrogen and then stored at 80ºC for later analysis. Absorption of total particulate and phytoplankton will be determined using a Shimadzu spectrophotometer with integrating sphere according to the method of Kishino et al. (1985). These data will be entered into a bio-optical databased used to develop ocean color algorithms for open ocean waters off Chile.

Particulate Organic Carbon

Between 1 and 1.5 liters were filtered onto 25 mm precombusted GF/F filters. Samples were then dried and stored for later analysis using a HCN analyser.

Problems

On March 7 and 8 seawater was obtained using the vessel’s flow through system, since bottles were removed from the CTD rosette.