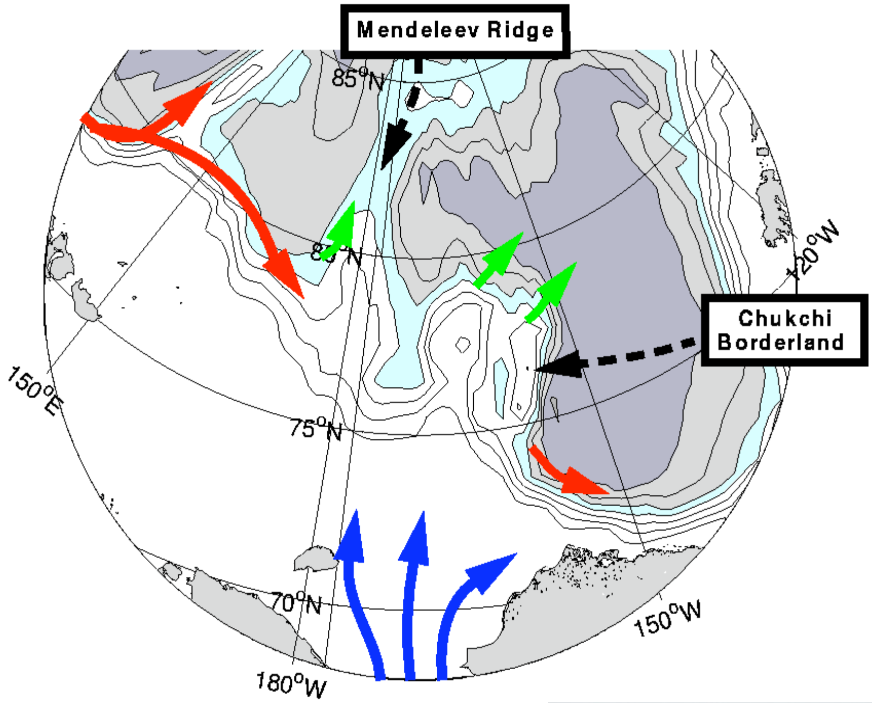
CHUKCHI BORDERLAND CRUISE
CBL 2002
Arctic West - Phase II (AWS-02-II)



USCGC Polar Star

Cruise Leader: Rebecca Woodgate, University of Washington

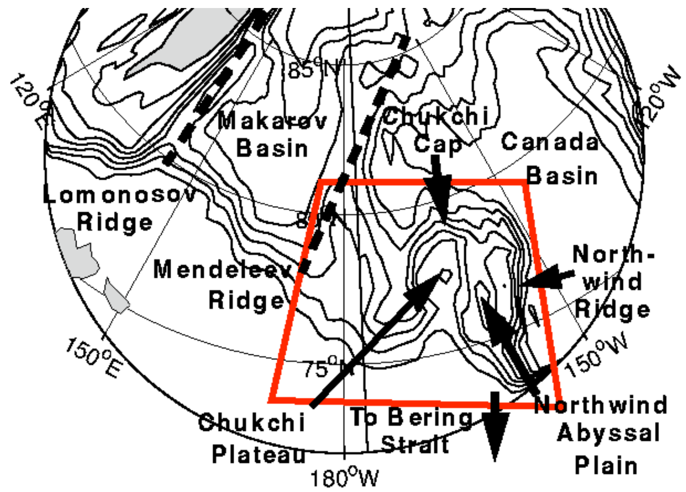
Barrow, Alaska, 19th August - Barrow, Alaska, 23rd September 2002

NSF Arctic Natural Sciences OPP-0117480

University of Washington, Scripps Institution of Oceanography
Lamont-Doherty Earth Observatory, Oregon State University

CBL2002 SUMMARY

Some 600 miles north of the Bering Strait, 800 miles south of the North Pole, the entrance into the Arctic Ocean is marked by a complex area of tortuous topography known as the Chukchi Borderland. This region of slopes, ridges, and deep-sea plateaus is an Arctic Crossroads, where waters from the Pacific and from the Atlantic meet.

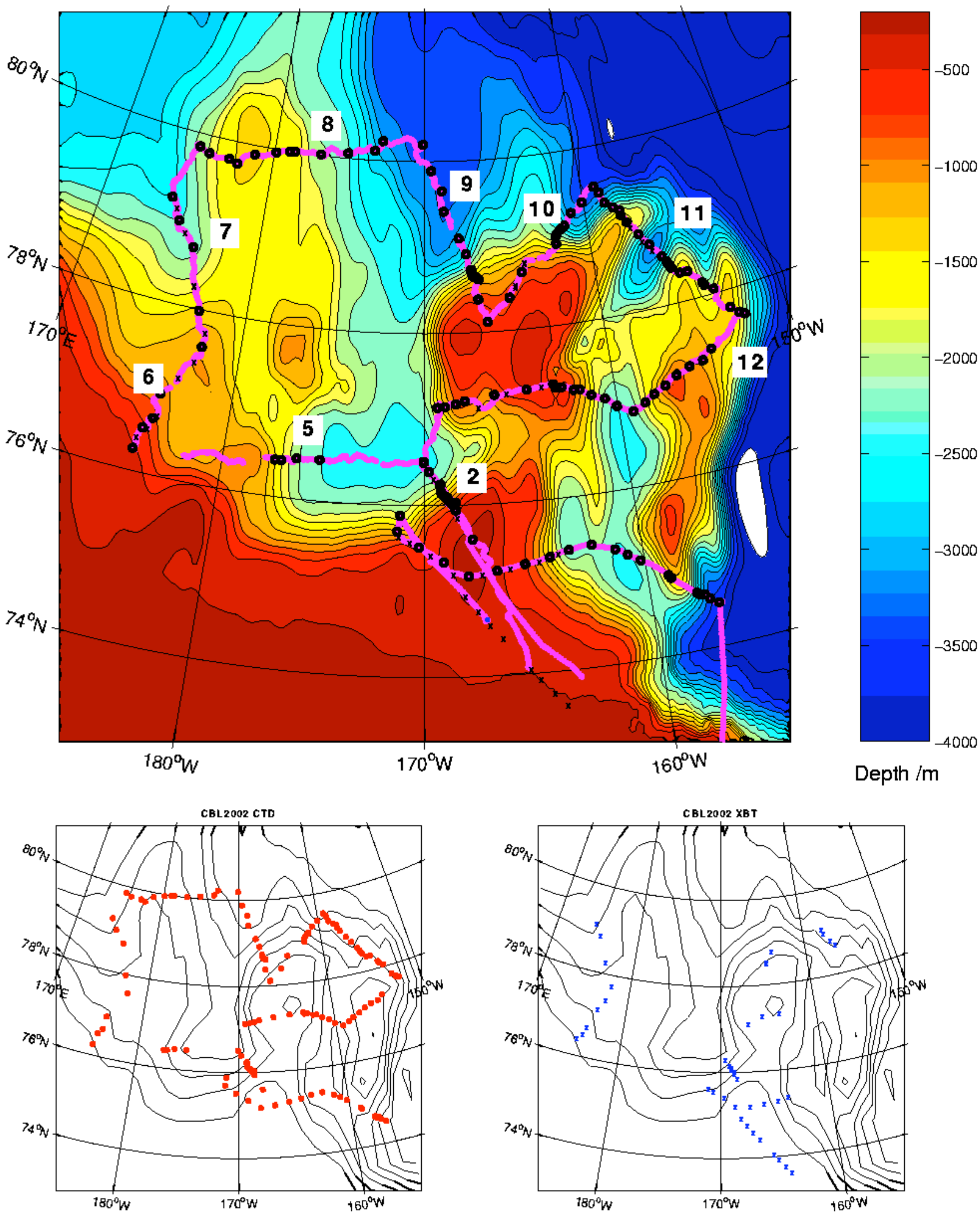


The Atlantic waters (warmer and saltier) flow cyclonically (anticlockwise) from Fram Strait and the Barents Sea around the edges of the Arctic Basins and approach the Mendeleev Ridge and the Chukchi Borderland from the west. The Pacific waters (colder, fresher and high in nutrients) enter at a shallower depth from the south via Bering Strait and the Chukchi Sea. Past measurements suggest that the pathways of both waters split in the Borderland region. Some waters continue cyclonically along the Beaufort slope, whilst some leave the boundary and head into the deep basin. The processes determining the splitting and the pathways, presumably depending upon the winds, the ice, the sea floor topography and thermohaline forcing, are neither well measured nor understood. The pathways of these waters have implications for local ecosystems (c.f. the nutrient-rich Pacific waters) and climate (c.f. the warm Atlantic layer), and also global ocean circulation issues (c.f. transit times through the Arctic Ocean).

A 35-day NSF-sponsored cruise aboard the USCGC Polar Star has studied in depth the physical oceanography of the Chukchi Borderland and Mendeleev Ridge regions. An extensive hydrographic survey (126 CTD casts) was conducted. In addition to CTD profiles of temperature, conductivity, oxygen, and light scatter and L-ADCP profiles of water velocity, bottle samples were taken for nutrients (2662 samples), dissolved oxygen (2999 samples), salinity (3066 samples) and tracers CFCs (F11, F12, F113, ca. 2500 samples), O18 isotopes (ca.1000 samples), Barium (ca.1000 samples), Helium (ca.108 samples), Iodine-129 (96 samples) and Cesium-137 (27 samples). Twenty-one denitrification (N:Ar ratio) samples were also taken. A total of 47 XBTs were used both to increase spatial coverage over the shelf and to increase spatial resolution in the slope regions. To better map the boundary current regime, 3 oceanographic moorings carrying current meters and temperature and salinity sensors were deployed across the boundary current for the ca. 1 month duration of the cruise.

During the cruise, via a website of daily updates from a High School teacher aboard the Polar Star and visits to schools in Barrow, we brought Arctic research into the classroom. Post-cruise a multi-institute team of scientists will study this extensive data set, with reference to previous (sparse) measurements, Canadian measurements taken this year in the Canadian Basin and near Northwind Ridge, and modeling results, to understand the role of this Arctic Crossroads in the circulation of the Arctic Ocean.

CBL2002 CRUISE TRACK



Upper map shows the cruise track in pink. Depth contours are "Terrainbase" and only approximate. Section numbering is as per proposal. Moorings are located on section 2. CTD stations are marked as black dots. XBTs are marked as black crosses.
Lower two figures show the CTD (red dots, right) and XBT (blue crosses, left) positions superimposed upon schematic topography.

CHUKCHI BORDERLAND CRUISE
CBL 2002
Arctic West - Phase II (AWS-02-II)

USCGC Polar Star
Cruise Leader: Rebecca Woodgate, University of Washington
Barrow, Alaska, 19th August - Barrow, Alaska, 23rd September 2002

NSF Arctic Natural Sciences OPP-0117480

University of Washington, Scripps Institution of Oceanography
Lamont-Doherty Earth Observatory, Oregon State University

INDEX

Cover Photo: Gail Grimes

1. PARTICIPANTS

Scientific Personnel:

Rebecca Woodgate (PI)	University of Washington	Chief Scientist
Knut Aagaard (co-PI)	University of Washington	Moorings and CTD
Jim Swift (co-PI)	SIO	CTD
Jim Johnson	University of Washington	Moorings
Ron Patrick	SIO	CTD (Technician in Charge)
Scott Hiller	SIO	CTD (salts)
John Calderwood	SIO	CTD (oxygens)
Susan Becker	SIO	Nutrients
Dave Muus	SIO	CTD Bottle samples
Mary Johnson	SIO	CTD data processing
Eugene Gorman	LDEO	CFCs
Guy Mathieu	LDEO	CFCs
Sarah Zimmermann	LDEO (UAF)	CFCs
Kevin Vranes	LDEO	CFCs
Kellie Balster	University of Washington	CTD (N:Ar, Cs, I)
Wendy Ermold	University of Washington	CTD (LADCP, He)
Marlene Jeffries	University of Washingon	CTD (O18 and Ba)
Gail Grimes	Lake Stevens High School	CTD, Educational outreach

Ship's Personnel:

CAPT Dave Mackenzie	Commanding Officer
CDR Bruce Toney	Executive Officer
LT Matthew Walker	Operations Officer
ENS Rebecca Albert	Marine Science Officer

MST1 El McFadden
MST3 Bryan Klostermeyer, Lee Brittle, April Dalton
BM3 Darrell Bresnahan, SM Megan Crawford

Science Participants not aboard:

Bill Smethie (co-PI)	LDEO	CFCs
Kelly Falkner (co-PI)	Oregon State University	O18, Ba
Peter Schlosser	LDEO	He
John Smith	Bedford Institute, Canada	Cs and I
Mark Ortmeyer	University of Washington	Website
Ed Carmack	IOS, Sidney, Canada	CTD
Fiona McLaughlin	IOS, Sidney, Canada	CTD
Al Devol	University of Washington	N:Ar

2. SCIENTIFIC BACKGROUND

The most important subsurface Arctic Ocean transport system, a cyclonic (here anticlockwise) boundary current, organized along the continental slopes and major trans-Arctic ridges, distributes waters, tracers and contaminants from the Atlantic (via Fram Strait and the Barents Sea) and the Pacific (via Bering Strait) around and into the deep Arctic basins. On its circum-Arctic pathway, parts of the topographically steered current are diverted away from the continental margin, generally along topographic ridges. The most complex obstacle the boundary current encounters is the Mendeleev Ridge/Chukchi Borderland complex, north of the Pacific entrance to the Arctic. This region is the cross-roads for Pacific-origin waters from the south and Atlantic waters carried from the west with the boundary current. The tortuous bathymetry offers many routes for a topographically steered current, and the spatial variability of the sparse data that exist clearly indicates the complexity of the region. These data also show significant interannual variability, in line with the major changes seen in the last decade throughout the Arctic, and they further suggest that the region diverts significant amounts of water into the deep basins, indicating this region's importance to shelf-basin exchange, deep basin ventilation, and circum- and trans-Arctic circulation (with feedback implications to the World Ocean circulation). Yet, the pathways and exchanges in this area are still unclear, both qualitatively and quantitatively, due to the lack of sufficiently concentrated observations.

The purpose of this research cruise was to conduct a high spatial resolution hydrographic and tracer survey, supported by short-term moored current and CTD measurements, in the region of the Chukchi Borderland and the southern end of the Mendeleev Ridge during August/September 2002.

Our objectives are to:

- delineate the pathways of the boundary current carrying the Atlantic water past the Mendeleev Ridge and through the Chukchi Borderland;
- ascertain the input from the boundary current and the shelves to the deep Arctic Ocean in the vicinity of the Mendeleev Ridge and the Chukchi Borderland;
- understand and quantify the pathways and transformations of the Pacific waters through this region;
- describe the horizontal and vertical structure of the boundary current, and estimate its transport; and
- quantify recent temporal changes in this region by combining the spatially sparse data extending through most of the past decade with new detailed synoptic measurements.

On the 35-day expedition on the USCGC Polar Star, we have measured temperature, salinity, dissolved oxygen, nutrients, CFCs, Ba and O18, on 14 sections that cross both the boundary flow and the Pacific inputs to the region before and after topographic junctions and hypothesized regions of flow diversion. Subsections of water samples were also taken for Helium, Cs-137, I-129, and N:Ar ratios. This tracer suite will allow us to identify the pathways of the boundary current and the Pacific-origin waters, and to quantify the different Atlantic and Pacific influences, as well as freshwater input from ice melt and different rivers. In addition, three moorings were deployed, spanning the boundary current for the duration of the cruise. Current meters and moored conductivity and temperature sensors quantify the vertical and horizontal extent of the boundary current, its structure and variability, and will yield an estimate of the transport and a description of eddies carried with or across the boundary current. To give a comprehensive picture of the system, the entire data set will be analyzed collectively and in tandem with hydrographic, tracer, and moored time series data from the last decade. Since the transit time of signals through this region is 2-4 years, the older data provide a temporal background for the new high spatial resolution data, whilst the newer data will supply an essential spatial framework for understanding the variability of the older surveys.

The work will yield a substantially increased understanding of the role of this region in the Arctic circulation, including a determination of pathways, a quantification of exchanges, and an assessment of temporal change. Its timing in 2002 provides a high quality hydrographic survey of the western Arctic at a time when the most dramatic changes ever observed in the Arctic are propagating through this region. The project will provide necessary background and mechanistic information to the SEARCH and Arctic-Subarctic Ocean Flux programs, and essential far-field information to the SBI Phase II field program in the Chukchi and Beaufort seas. Our cruise track also dovetails with the Canadian Arctic Expeditions this summer. In addition, the results will be pivotal to validating and improving high resolution computer and conceptual models of the Arctic, and will offer insights to physical mechanistic problems, such as the driving mechanism of the boundary current and the interaction of an equivalent barotropic current with steep and sharp topography.

3. HYDROGRAPHIC MEASUREMENTS PROGRAM

(Jim Swift, Knut Aagaard, Ron Patrick, Scott Hiller, Susan Becker, Mary Johnson, Dave Muus, John Calderwood, Kellie Balster, Marlene Jeffries, Wendy Ermold, Gail Grimes)

The hydrographic measurements program was run by the SIO group to WHP standards specifications or higher. Extracts from the preliminary report (Feb 2003) is included below.
In brief, 126 CTD/rosette casts were taken to within ca.10m of the bottom. Down- and up-cast profiles of temperatures, conductivity, pressure, dissolved oxygen and light scatter were recorded. Seabird sensors were used for T, C and oxygen. The light scattering sensor was made by WetLabs. Only the downcast data is presented in the final data. CTD data is good to 0.2 db, 0.0002deg C and 0.005 mS/cm.
Apart from winch interference issues on the early casts (causing some spiking in the CTD data), no major problems were encountered during the operation.
Water samples were taken from a 36 place rosette system, bottle depths being chosen with reference to the CTD and oxygen profiles. Samples were taken for CFCs, Helium, dissolved oxygen, salinity, O18 isotopes, barium, Iodine-129, Cesium-137 and N:Ar ratios. Not all samples were taken at all bottles or all casts.

EXTRACT from ODF Preliminary Cruise Report

4. Description of Measurement Techniques

4.1. Hydrographic Measurements Program

The basic hydrography program consisted of salinity, dissolved oxygen and nutrient (nitrite, nitrate, phosphate and silicate) measurements made from bottles taken on CTD/rosette casts, plus pressure, temperature, salinity and dissolved oxygen from CTD profiles. 126 CTD/rosette casts were made, usually to within 10 meters of the bottom. One additional cast was aborted by the bridge (station 66 cast 1) at ~90 meters due to ice problems; it is not reported. No major problems were encountered during the operation. The distribution of samples is illustrated in figures 4.1.0-4.1.4.

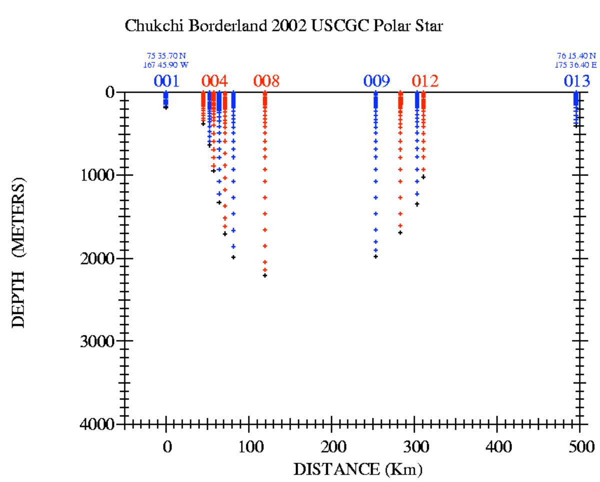


Figure 4.1.0 Sample distribution, stations 1-13.

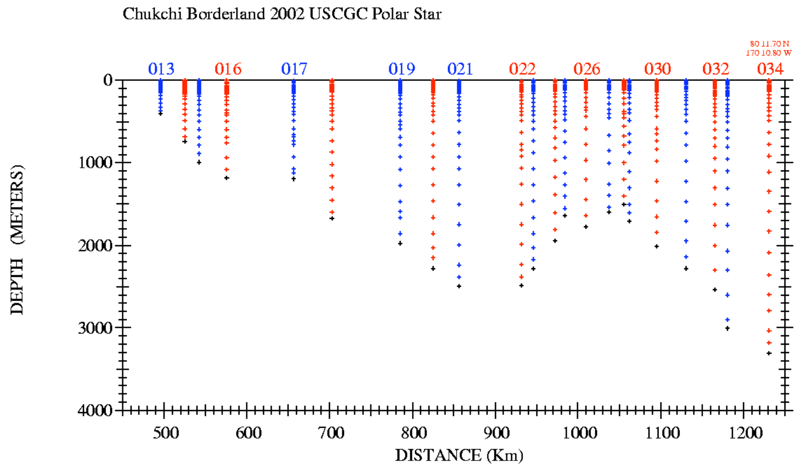


Figure 4.1.1 Sample distribution, stations 13-34.

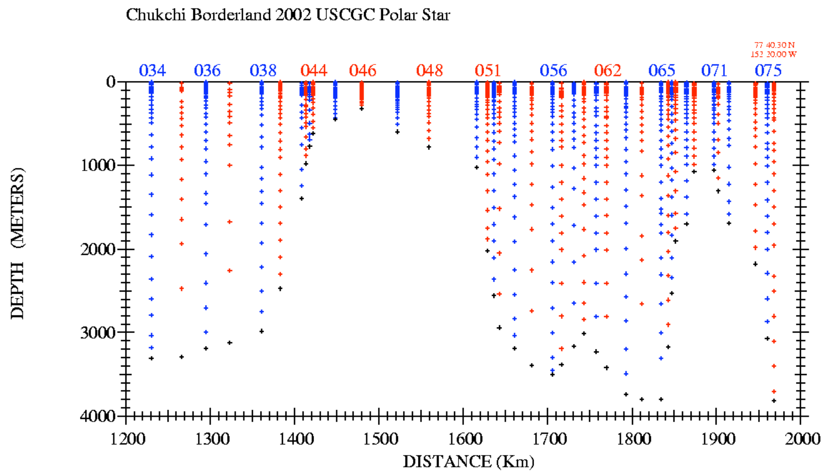


Figure 4.1.2 Sample distribution, stations 34-76.

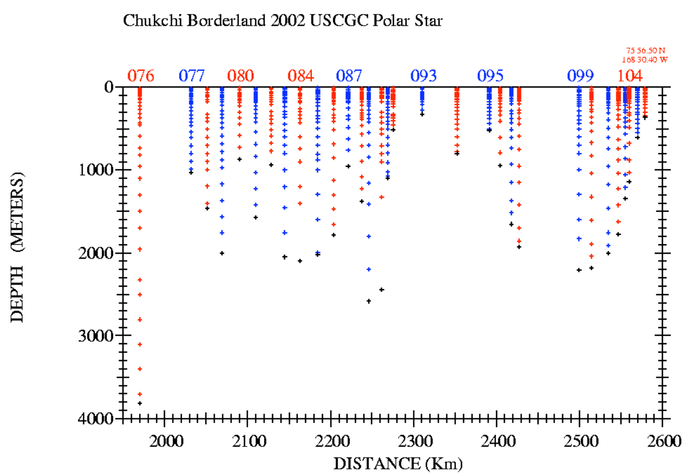


Figure 4.1.3 Sample distribution, stations 76-106.

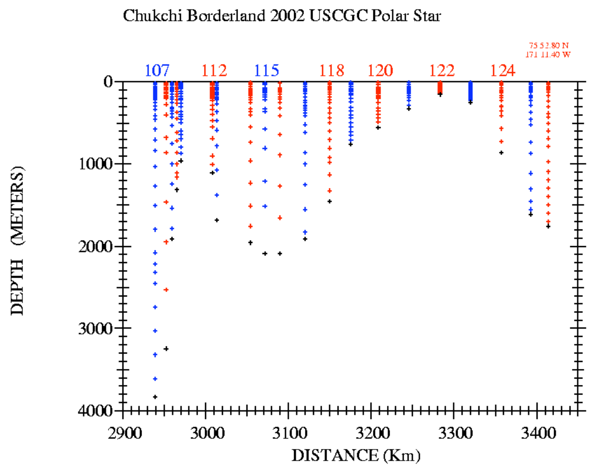


Figure 4.1.4 Sample distribution, stations 107-126.

4.2. Water Sampling Package

CTD/rosette casts were performed with a system consisting of a 36-bottle rosette frame (ODF), a 36-place pylon (SBE32) and 36 10-liter PVC bottles (ODF). Underwater electronic components consisted of a Sea-Bird Electronics (SBE) 9plus CTD (ODF #381) with dual conductivity and temperature sensors, SBE43 oxygen sensor, WetLabs Light Scattering Sensor (LSS), dual RDI LADCPs and Simrad altimeter.

36-bottle rosette frame	ODF	s/n unknown
Bullister 10-liter bottles	ODF	1-36
36-place Carousel Water Sampler	Sea-Bird SBE32	s/n 113
Deck Unit (in lab)	Sea-Bird SBE11	s/n 292 (USCG)
ODF CTD #381	Sea-Bird SBE9plus	s/n 09P9852-0381
Pressure	Paroscientific Digiquartz	s/n 58952
Temperature#1	Sea-Bird SBE3plus	s/n 03P-2505
Temperature#2	Sea-Bird SBE3plus	s/n 03P-2380
Conductivity#1	Sea-Bird SBE4C	s/n 04-1919
(stas 1-48) Conductivity#2	Sea-Bird SBE4C	s/n 04-2023
(stas 50-126) Conductivity#2	Sea-Bird SBE4C	s/n 04-1549
Oxygen Sensor	Sea-Bird SBE43	s/n 43-0185
Pump for T1/C1/Oxygen Sensors	Sea-Bird SBE5T	s/n unknown
Pump for T2/C2 Sensors	Sea-Bird SBE5T	s/n unknown
Light Scattering Sensor	WetLabs LSS	s/n CST-477
Altimeter	Simrad 807	s/n 9711091
LADCPs	RDI 300KHZ	s/n unknown
LADCP Battery Pack	WHOI	

Table 4.2.0 Underwater sampling package.

CTD #381 was mounted horizontally along the bottom of the rosette frame. The altimeter reported distance-above-bottom. The dissolved oxygen sensor and altimeter were interfaced with the CTD, and their data were incorporated into the CTD data stream. The two LADCPs were vertically mounted to the frame inside the bottle rings, one each at the top and bottom of the rosette, with upward- and downward-looking transducers. The rosette system was suspended from a three-conductor 0.322" electromechanical cable. Power to the CTD and pylon was provided through the cable from a SBE11plus deck unit in the lab. The USCGC Polar Star's portside InterOcean CTD winch was used throughout the leg.

The deck watch prepared the rosette approximately 45 minutes prior to each cast. All valves, vents and lanyards were checked for proper orientation. The bottles were cocked and all hardware and connections rechecked. Time, position and bottom depth were logged by the console operator at arrival on station. The rosette was moved into position under a projecting boom from the port-side CTD hangar using an overhead trolley. Two stabilizing tag lines were threaded through rings on the frame, and CTD sensor covers were removed. As directed by the USCGC watch leader, the winch operator raised the package, extended the J-frame boom over the side of the ship and quickly lowered the package into the water; then the tag lines were removed.

Each rosette cast was lowered to within 7-20 meters of the bottom. Bottles on the rosette were identified with unique serial numbers. These numbers corresponded to the pylon tripping sequence 1-36, the first trip closing bottle #1. No bottles were changed out during the leg, although parts of bottles may have been replaced or repaired.

Averages of CTD data corresponding to the time of bottle closure were associated with the bottle data during a cast. CTD pressure, depth, temperature, salinity, density and oxygen were immediately available to facilitate examination and quality control of the bottle data as the sampling and laboratory analyses progressed.

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

Routine CTD maintenance initially included soaking the conductivity and CTD O2 sensors in distilled water between casts to maintain sensor stability. After station 27, the sensors were rinsed in discarded IAPSO standard seawater after each cast, but not soaked, due to problems with water freezing in the sensor pump tubing. After station 50, when the substitute secondary conductivity sensor was installed, tygon tubing was placed between the ducts and pumps of the primary and secondary sensor housings to keep the sensors and pump tubes warmer while on deck. The rosette was stored in the CTD hangar between casts to insure the CTD was not exposed to direct sunlight, wind or snow, in order to maintain the internal CTD temperature near ambient air temperature. A large space heater, which could be aimed at the sensors, was used as needed in the hangar after station 27 to keep the sensors and pump tubes from freezing.

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.

4.3. Underwater Electronics Packages

CTD data were collected with a SBE9plus CTD (ODF #381). This instrument provided pressure, temperature, conductivity, dissolved O2, LSS and altimeter channels, and additionally measured a second PRT temperature and conductivity as a calibration check and backup. CTD #381 supplied a standard Sea-Bird format data stream at a data rate of 24 frames/second (fps). The CTD sensor configuration is provided in Table 4.2.0 in the previous section.

The secondary CTD temperature and conductivity sensors were pumped separately from the primary sensors. They were mostly used as a calibration reference or to occasionally verify unusual T/S structures observed in the primary sensors. However, it was apparent after the cast that water was not being properly pumped past the primary sensors at the start of station 26, likely due to freezing problems discovered prior to station 27. The secondary sensor pair was used as the primary data source for station 26.

The secondary conductivity sensor was not working properly during station 48. It was removed before station 49, then replaced before station 50 with a backup sensor belonging to the USCG. The primary conductivity sensor appeared to be consistent throughout the cruise, although Sea-Bird reported that it was broken and not able to be calibrated post-cruise.

An SBE43 dissolved O2 sensor ducted to the same pump line as the primary CTD temperature and conductivity sensors.

The CTD system was configured for single-conductor operation by combining together the 3 sea cable conductors. An SBE32 36-place carousel was the water sampler control unit on the rosette. An SBE11plus deck unit located in the Polar Star's main wet lab supplied power and telemetry control for the rosette water sampler and Sea-Bird CTD. The binary data were fed into the main CTD acquisition computer. Bottle-trip commands were sent from this computer to the SBE11 deck box, which transmitted the commands down the cable to the SBE32 water sampler unit.

4.4. Navigation and Bathymetry Data Acquisition

Navigation data were acquired from an ODF Garmin 128 GPS receiver via RS-232. Data were logged automatically at 2- to 10-second intervals by the Linux computer beginning August 28. These data were merged with Ashtech GPS data stored by the ship's computer systems from earlier in the leg, to fill in gaps from before the ODF navigation acquisition was up and running.

Underway bathymetry was logged every 1-2 seconds by the ship's computer system, recording an uncorrected Knudsen echosounder depth. Depth data were not merged with ODF navigation data because of numerous erratic readings that might have distorted bottom profiles on vertical sections. However, the Knudsen data, eyeball-edited for repeatability, were used for start-, bottom- and end-of-cast bathymetry at each station.

4.5. CTD Data Acquisition and Real-Time Control System

The CTD data acquisition and real-time control system consisted of a generic PC workstation running RedHat 7.3 Linux, an SBE-11plus deck unit and a VCR recorder for real-time analog backup recording of the sea-cable signal. The Linux system consisted of a color display with 3-button trackball and keyboard (the CTD console), 10 RS-232 ports, 40-GB disk and CD-R drive. Two other Linux systems were networked to the data acquisition system, as well as to the rest of the networked computers aboard the Polar Star. These systems were available for real-time CTD data display and provided for CTD and hydrographic data management and backup. One HP 1200C/PS color inkjet printer provided hardcopy from any of the workstations.

The data stream from the CTD was fed into the CTD acquisition computer through through a bi-directional serial line from the deck unit. This allowed bottle trips to be initiated and confirmed by the ODF data acquisition software. A bitmapped color display provided interactive graphical display and control of the CTD rosette sampling system, including real-time raw and processed CTD data, navigation, winch and rosette trip displays.

The CTD data acquisition, processing and control system was prepared by the console watch a few minutes before each deployment. A console operations log was maintained for each deployment, containing a record of every attempt to trip a bottle as well as any pertinent comments. Most CTD console control functions, including starting the data acquisition, were initiated by pointing and clicking a trackball cursor on the display at icons representing functions to perform. The system then presented the operator with short dialog prompts with automatically-generated choices that could either be accepted as defaults or overridden. The operator was instructed to turn on the deck unit, then to examine a real-time CTD data display on the screen for stable data from the underwater unit. Once this was accomplished, the data acquisition and processing were begun and a time and position were automatically logged for the beginning of the cast. A backup analog recording of the CTD signal on a VCR tape was started at the same time as the data acquisition. A rosette trip display and pylon control window popped up, giving visual confirmation that the pylon was initializing properly. Various plots and displays were initiated. When all was ready, the console operator informed the deck watch by radio.

Once the deck watch had deployed the rosette and informed the console operator that the rosette was at the surface (also confirmed by the computer displays), the console operator or watch leader provided the winch operator with a target depth (wire-out) and maximum lowering rate, normally 60 meters/minute for this package. The package then began its descent, building up to the maximum rate during the first few hundred meters, then optimally continuing at a steady rate without any stops during the down cast.

There were problems at the beginning of the leg with erratic winch speeds (frequent abrupt braking at higher speeds during lowering), caused by the automatic winch controller. These were resolved by using manual winch controls beginning with station 12. Adjustment of winch gearing also improved lowering rates. Another problem was excessive signal noise, which disappeared after re-wiring the sea cable away from the winch power source before station 9, and by fixing a sea cable shield grounding problem prior to station 14.

The console operator examined the processed CTD data during descent via interactive plot windows on the display, which could also be run at other workstations on the network. Additionally, the operator decided where to trip bottles on the up cast, noting this on the console log. The altimeter signal was also monitored for bottom proximity.

Around 100-200 meters above the bottom, depending on bottom conditions, the altimeter typically began signaling a bottom return on the console. The winch speed was usually slowed to ~30 meters/minute during the bottom approach. The winch and altimeter displays allowed the watch leader to refine the target depth relayed to the winch operator and safely approach to within 10-20 meters of the bottom.

Bottles were closed on the up cast by pointing the console trackball cursor at a graphic firing control and clicking a button. The data acquisition system responded with the CTD rosette trip data and a pylon confirmation message in a window. All tripping attempts were noted on the console log. The console operator then instructed the winch operator to bring the rosette up to the next bottle depth. The console operator was also responsible for generating the sample log for the cast.

After the last bottle was tripped, the console operator directed the deck watch to bring the rosette on deck. Once the rosette was on deck, the console operator terminated the data acquisition and turned off the deck unit and VCR recording. The VCR tape was filed. Usually the console operator also brought the sample log to the rosette room and served as the sample cop.

4.6. CTD Data Processing

ODF CTD processing software consists of over 30 programs running under the Linux operating system. The initial CTD processing program (ctdba) is used either in real-time or with existing raw data sets to:

- Convert raw CTD scans into scaled engineering units, and assign the data to logical channels
- Filter various channels according to specified criteria
- Apply sensor- or instrument-specific response-correction models
- Decimate the channels according to specified criteria
- Store the output time-series in a CTD-independent format

Once the CTD data are reduced to a standard-format time-series, they can be manipulated in various ways. Channels can be additionally filtered. The time-series can be split up into shorter time-series or pasted together to form longer time-series. A time-series can be transformed into a pressureseries, or into a larger-interval time-series. The pressure, temperature and conductivity laboratory calibration corrections are applied during the creation of the initial time-series. Oxygen corrections and any adjustments to the pressure, temperature or conductivity corrections for the series are maintained in separate files and are applied whenever the data are accessed.

ODF data acquisition software acquired and processed the CTD data in realtime, providing calibrated, processed data for interactive plotting and reporting during a cast. The 24 fps data from the CTD were filtered, response-corrected and averaged to a 0.5-second time-series. Sensor correction and calibration models were applied to pressure, temperature, conductivity and O2. Rosette trip data were extracted from this timeseries in response to trip initiation and confirmation signals. The calibrated half-second time-series data, as well as the 24 fps raw data, were stored on disk and were available in real-time for reporting and graphical display. At the end of the cast, various consistency and calibration checks were performed, and a 2-db pressure-series of the down cast was generated and subsequently used for reports and plots.

CTD plots generated automatically at the completion of deployment were checked daily for potential problems. The two PRT temperature sensors were inter-calibrated and checked for sensor drift. The CTD conductivity sensor was monitored by comparing CTD values to check-sample conductivities, and by deep theta-salinity comparisons between down and up casts as well as adjacent stations. The CTD O2 sensor was calibrated to check-sample data.

Some casts were subject to noise in the data stream caused by sea cable, slip-ring or deck unit problems (especially prior to station 14); or by moisture in interconnect cables between the CTD and external sensors (i.e. O2). Intermittent noisy data were filtered out of the half-second time-series data using a spike-removal filter. A least-squares polynomial of specified order was fit to fixed-length segments of data. Points exceeding a specified multiple of the residual standard deviation were replaced by the polynomial value.

Density inversions can be induced in high-gradient regions by shipgenerated vertical motion of the rosette. Detailed examination of the raw data shows significant mixing can occur in these areas because of "ship roll". In order to minimize density inversions, a ship-roll filter was applied to all casts during pressure-sequencing to disallow pressure reversals. The pumps on the SBE9plus did not turn on until ~5 seconds after the CTD detected the in-water transition. The first few seconds of in-water data were excluded from the pressure-series data, since the sensors were still adjusting to the going-in-water transition.

Pressure intervals with no time-series data can optionally be filled by double-quadratic interpolation/extrapolation. The only pressure intervals missing/filled during this leg were at 0-4 db, caused by chopping off going-in-water transition data during pressure-sequencing.

There were two known casts with frozen sensor or pump-line problems at the start of the down casts, station 26 and station 47. Both were discovered after the cast was completed. The pump tubing was found frozen solid prior to station 27 and thawed prior to the cast, with no apparent damage to the sensors. Station 26 data showed some flow restriction at the start of the cast, so the secondary sensor pair was used for data processing. On station 47, there were indications of flow restriction on the primary conductivity sensor going into the water, and the secondary sensor was emitting bad data. The secondary conductivity sensor was removed for station 48, and replaced by a backup sensor belonging to the USCG prior to station 49.

When the down-cast CTD data have excessive noise, gaps or offsets, the upcast data are used instead. CTD data from down and up casts are not mixed together in the pressure-series data because they do not represent identical water columns (due to ship movement, wire angles, etc.). It was not necessary to use any up casts for Chukchi Borderland CTD data.

4.7. CTD Laboratory Calibration Procedures

Laboratory calibrations of the CTD pressure, temperature and conductivity sensors were used to generate Sea-Bird correction coefficients applied by the CTD data acquisition and processing software at sea. Pressure calibrations were last performed on CTD #381 at the ODF Calibration Facility (La Jolla) in May 2002, prior to Chukchi Borderland. The Paroscientific Digiquartz pressure transducer (s/n 58952) was calibrated in a temperature-controlled water bath to a Ruska Model 2400 Piston Gauge pressure reference. Calibration curves were measured at 5 temperatures from -2.06 to 32.36 deg.C to four maximum loading pressures (2086, 2774, 3463 and 2x6079 decibars). The SBE3plus sensors (primary/PRT1 s/n 03-2505, secondary/PRT2 s/n 03-2380) were calibrated to a NBIS ATB-1250 resistance bridge and Rosemount standard PRT. The SBE4 conductivity sensors (primary/C1 s/n 04-1919 and secondary/C2 s/n 04-2023) were calibrated in May 2002 at Sea-Bird Electronics. The C2 sensor was removed after station 48 because of damage from freezing. It was replaced by s/n 04-1549, owned by the USCG, from station 50 until the end of the expedition. This sensor was also calibrated in May 2002 and was used as the secondary conductivity on the preceding leg (AWS-02-I). After applying the pre-cruise calibration coefficients, CTD pressure, temperature and conductivity data were within +/-0.2 decibars, +/-0.0002 deg.C and +/-0.0005 mS/cm, respectively, compared to laboratory standard values.

Pressure and temperature calibration procedures were repeated post-cruise at ODF. Preliminary results indicate a pre- to post-cruise temperature difference of +/-0.0002 deg.C over the temperature ranges seen during the cruise. Post-cruise conductivity calibrations were carried out by SeaBird; the cell on the primary sensor was broken when it arrived at Sea-Bird and could not be calibrated until after repairs were made. Shipboard comparisons of CTD and bottle conductivities (see next section) indicate no problems with the primary sensor during the cruise. But the primary sensor data will be more closely compared to the secondary sensors for possible malfunctions before CTD salinity data are considered final.

4.8. CTD Shipboard Calibration Procedures

ODF SBE-CTD #381 was used for all Chukchi Borderland casts. A redundant PRT sensor was used on CTD #381 as a calibration check while at sea. CTD conductivity and dissolved O2 were calibrated to in-situ check samples collected during each rosette cast.

4.8.1. CTD #381 Pressure

Pre-cruise pressure calibration coefficients were applied to CTD #381 raw pressures during each cast. No additional adjustments were made to the calculated pressures. Residual offsets at the beginning and end of each cast (the difference between the first/last pressures in-water and 0) were monitored during the cruise to check for shifts in the pressure calibration. Almost all residual differences were 0.5 decibar or less; only 8 going-in pressures were between 0.5 and 1.0 decibar off. There was no apparent shift in pressure calibration during the cruise.

CTD pressure data will not be considered final until after the post-cruise laboratory calibrations have been completed and analyzed. Preliminary results of the post-cruise pressure calibration indicate a correction change of -0.3 to +0.1 decibar for the pressure and temperature ranges seen during this cruise.

4.8.2. CTD #381 Temperature

Pre-cruise laboratory calibration coefficients for the CTD #381 primary and secondary temperature sensors (PRT1 and PRT2) were applied to all shipboard CTD data. The two temperature channels were compared on all casts to monitor for drift. Preliminary corrected temperatures were compared for a series of standard depths from each CTD down-cast. Comparison of the two CTD #381 PRTs every 200 decibars at down-cast pressures 500 decibars and deeper showed the difference to be very stable during the cruise. Figure 4.8.2.0 summarizes the shipboard comparison between the primary and secondary PRT channels for CTD #381.

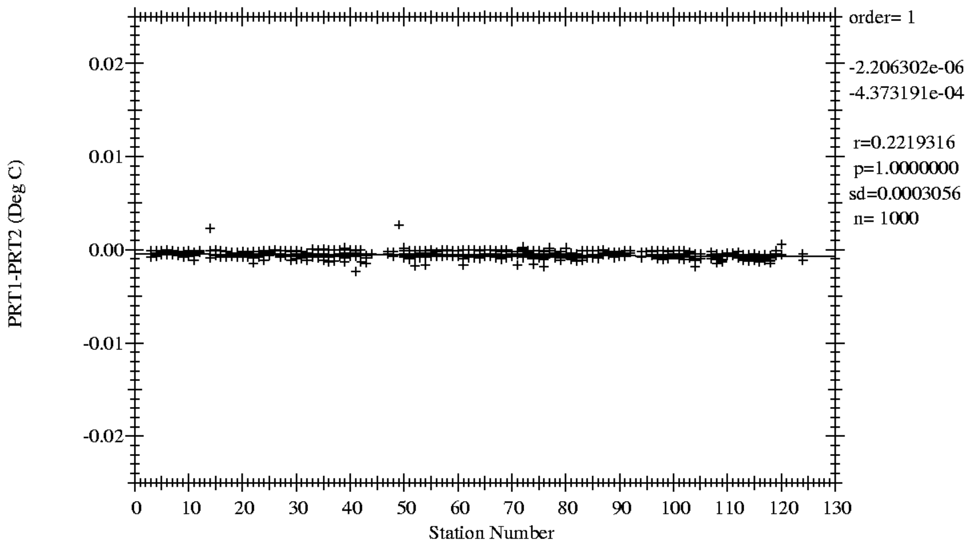


Figure 4.8.2.0 Shipboard comparison of CTD #381 dual PRTs, PRT1-PRT2, pressure>500db.

CTD temperature data will not be considered final until after the post-cruise laboratory calibrations have been completed and analyzed. Preliminary results indicate a change of less than +/-0.0003 deg.C for temperatures in the range of this cruise.

4.8.3. CTD #381 Conductivity

Sea-Bird pre-cruise conductivity calibration coefficients were applied to primary and secondary conductivity sensors during each CTD cast. Corrected CTD rosette trip pressures and temperatures were used with bottle salinities to calculate bottle conductivities. Differences between the bottle and CTD conductivities were then used to derive a shipboard conductivity correction. The conductivity range and slope were both small, so it was decided to defer any slope correction until after station offsets were determined.

Bottle-CTD conductivity differences were biased on the high side in the thermocline. After closely analyzing a few CTD casts, it was determined that water dragged by the rosette and lack of motion by the ship (mostly in ice) prevented proper flushing of bottles and mis-matches of bottle and CTD data in high-gradient areas. Two flushing tests were done: on station 57, tripping 2 sets of 3 thermocline bottles 20 seconds, 1 minute and 2 minutes after stopping; and on station 61, tripping 2 sets of 2 thermocline bottles 20 seconds after stopping and after moving the rosette 2m up, 4m down and 2m up at the same level. Either the bottle differences were essentially the same, or they were the opposite sign and still large differences, in 4 out of 5 tests; so bottle sampling techniques were not modified. Instead, CTD conductivity offset values were calculated for all stations deep enough, using only bottle conductivities deeper than 500 db. Figure 4.8.3.0 illustrates the Chukchi Borderland preliminary shipboard conductivity offset values.

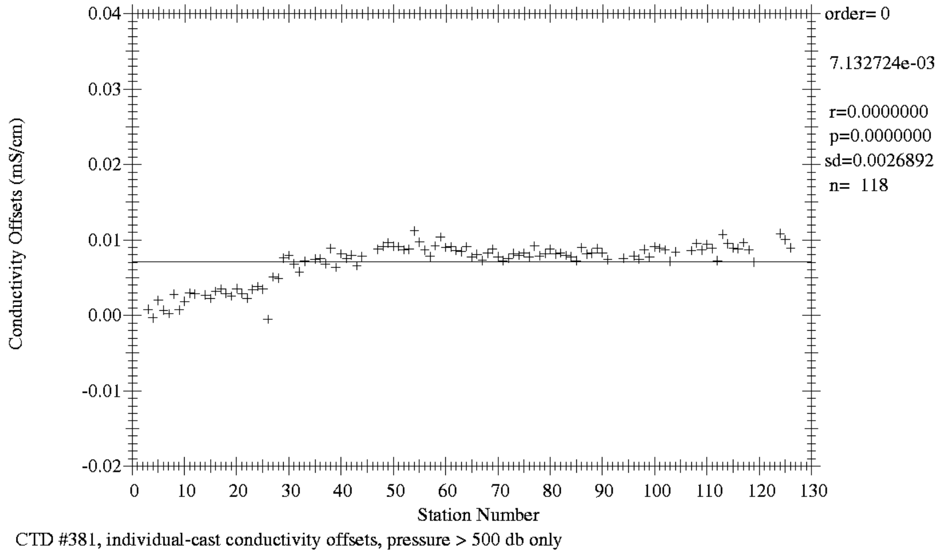


Figure 4.8.3.0 Chukchi Borderland CTD #381 preliminary shipboard conductivity offsets by station number.

Smoothed offsets were applied to each cast. Then conductivity differences above and below the thermocline were fit to CTD conductivity for all stations to determine a shipboard conductivity slope. A first-order fit was calculated, with outlying values (4,2 standard deviations) rejected. Figure 4.8.3.1 shows the data used to determine the Chukchi Borderland preliminary conductivity slope.

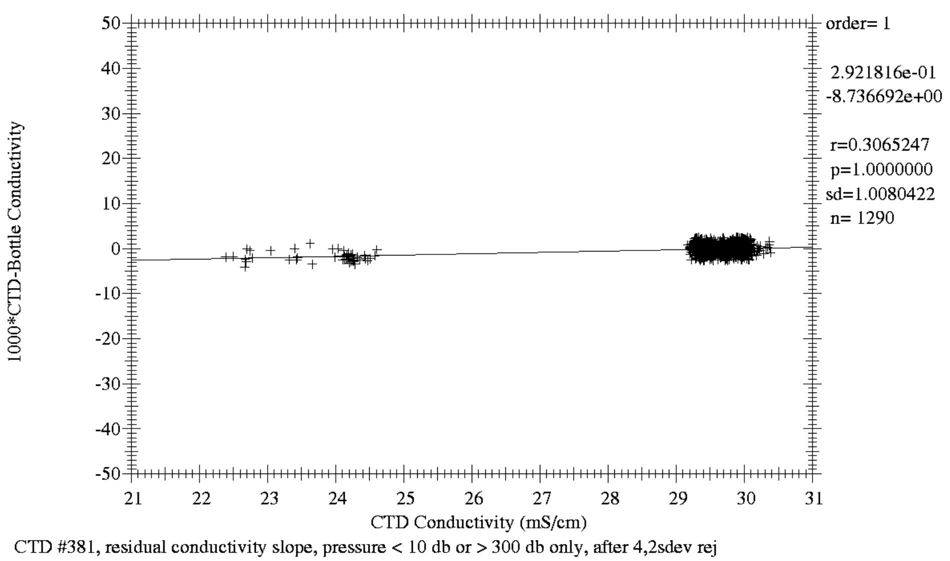


Figure 4.8.3.1 Chukchi Borderland CTD #381 preliminary shipboard conductivity slope.

Some offsets were manually adjusted to account for discontinuous shifts in the conductivity transducer response or bottle salinities, or to maintain deep theta-salinity consistency from cast to cast. Cast-by-cast comparisons showed minimal drifts in conductivity offset (less than 0.001 mS/cm), except between stations 25-30. The larger drift (~ 0.003 mS/cm total) in this area was attributed to frozen sensors at the start of stations 26 and 27. There were no apparent slope changes over the entire leg.

The standard salinity batch was changed from P-140 to P-136 beginning station 98 through the end of the cruise, due to a shortage of P-140 onboard. Although the two batches were inter-calibrated on-board and showed a small difference, the preliminary CTD theta-salinity comparisons did not warrant an additional offset based on batch differences. No adjustments to corrections were made for the standard batch change.
The final shipboard Chukchi Borderland conductivity slopes are summarized in Figure 4.8.3.2. Figure 4.8.3.3 summarizes the final shipboard conductivity offsets.

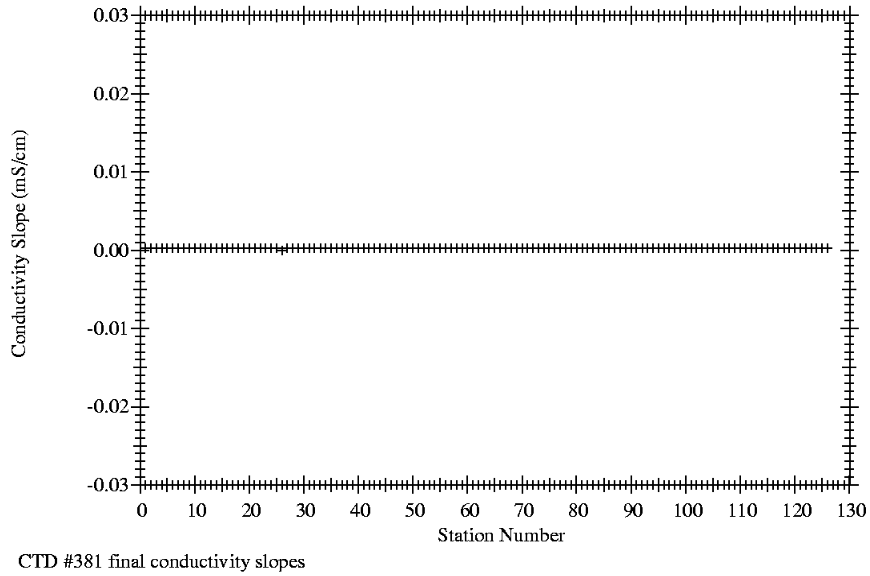


Figure 4.8.3.2 Chukchi Borderland CTD #381 shipboard conductivity slope correction by station number.

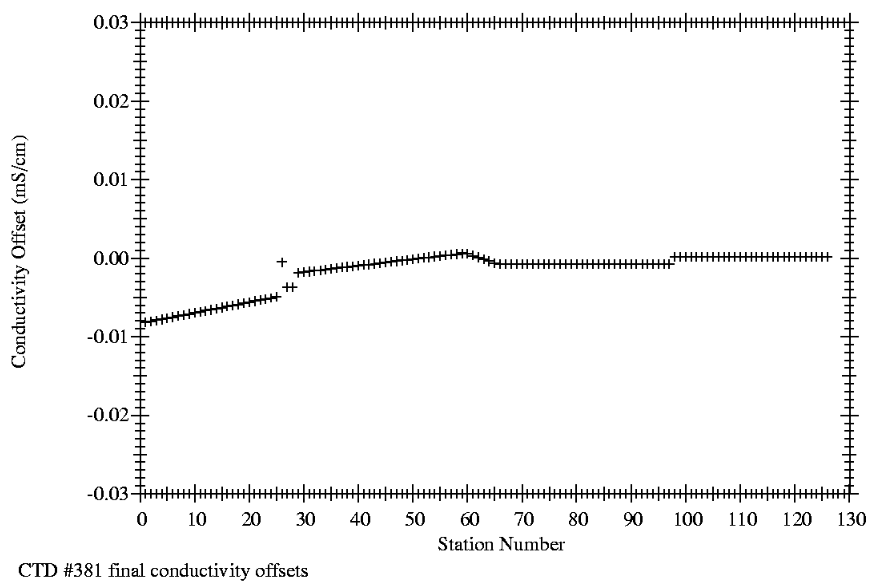


Figure 4.8.3.3 Chukchi Borderland CTD #381 shipboard conductivity offsets by station number.

Summary of Residual Salinity Differences

Figures 4.8.3.4, 4.8.3.5 and 4.8.3.6 summarize the Chukchi Borderland differences between bottle and CTD salinities after applying the shipboard conductivity corrections. Only CTD and bottle salinities with quality code 2 (acceptable) were used to generate these figures and statistics. Residual differences exceeding +/-0.025 PSU are included in the calculations for averages and standard deviations, even though they are not plotted. The large/high thermocline differences from lack of proper bottle flushing are evident on the first two plots, which include all data,

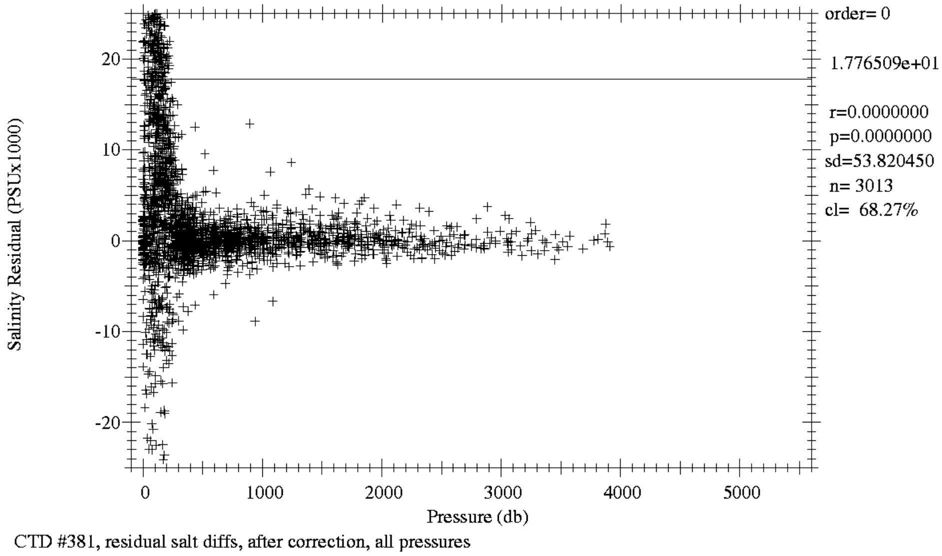


Figure 4.8.3.4 Salinity residual differences vs pressure (after correction).

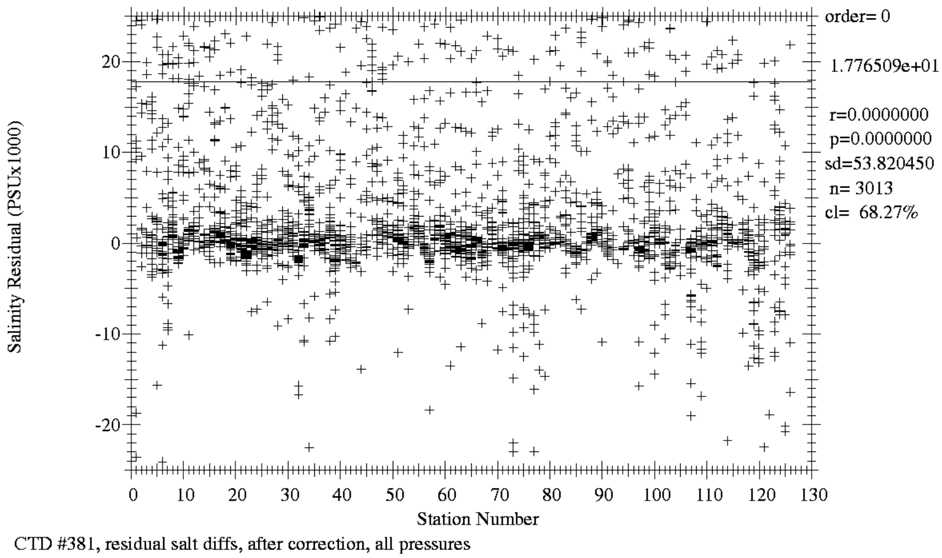


Figure 4.8.3.5 Salinity residual differences vs station # (after correction).

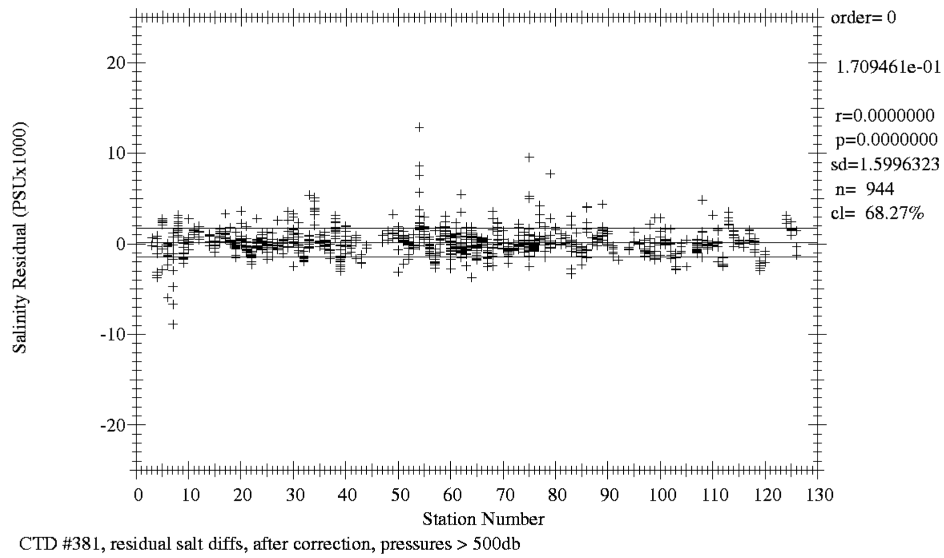


Figure 4.8.3.6 Deep salinity residual differences vs station # (after correction).

The CTD conductivity calibration represents a best estimate of the conductivity field throughout the water column. 3-sigma from the mean residual in Figures 4.8.3.5 and 4.8.3.6, or +/-0.0807 PSU for all salinities and +/-0.0024 PSU for deep salinities, represents the limit of repeatability of the bottle salinities (Autosal, rosette, operators and samplers). This limit agrees with station overlays of deep theta-salinity. Within most casts (a single salinometer run), the precision of bottle salinities appears to be better than 0.001 PSU. The precision of the CTD salinities appears to be better than 0.0005 PSU.

Tabulation of pressure, temperature and conductivity correction coefficients and historical data comparisons will be included in the final Chukchi Borderland report, after corrections are finalized.

4.8.4. CTD Dissolved Oxygen

A single pumped SBE43 dissolved O2 sensor was used for the entire cruise.

There were a number of problems with the response characteristics of SensorMedics O2 sensors typically used with NBIS MKIII CTDs, the major ones being a secondary thermal response and a sensitivity to profiling velocity. Stopping the rosette for as little as half a minute, or slowing down for a bottom approach, could cause shifts in the CTD O2 profile as oxygen became depleted in water near the sensor. This was still an apparent problem on the Nordic Seas cruise in Summer 2002, despite using an SBE43 pumped sensor with an NBIS MKIII CTD.

This was the first time the pumped SBE43 sensor was used with a SBE9plus CTD by ODF with its Unix/Linux acquisition system. The typical profiling velocity problems seen with the non-pumped SensorMedics O2 sensors, paired with NBIS Mark III CTDs, were still somewhat apparent, but at a much smaller magnitude.

Raw oxygen data were offset when it was apparent that the signal shifted due to slowdowns for a bottom approach; all deep shifts were less than 0.2 percent. Surface mixed-layer oxygen data were often affected by the goingin-water transition on most casts; raw surface oxygens were offset to a match a deeper mixed-layer value below this transition area to help the surface fits match the bottles better. Any changed data levels are coded as "despiked" (code 7) in the data files (see Bottle Data Processing section).

Because of the signal-drop problems still evident with the SBE43 during package stops or slowdowns, up-cast CTD rosette trip data cannot be optimally calibrated to O2 check samples.

Instead, down-cast CTD O2 data are derived by matching the up-cast rosette trips along isopycnal surfaces. The differences between CTD O2 data modeled from these derived values and check samples are then minimized using a non-linear least-squares fitting procedure.

The down- and up-cast time-series oxygen profiles are fairly similar when viewed using the corrections generated during the pressure-series fits, not typical of the Sensormedics sensors previously used. However, down-cast extrema in higher-gradient areas of the top 1000 decibars are often 10-20 meters deeper than the same features on the up-cast, as with the Sensormedics sensors. This is probably due to a combination of water being dragged by the rosette and slow sensor response not accounted for by lags.

Figures 4.8.4.0 and 4.8.4.1 show the residual differences between the corrected CTD O2 and the bottle O2 (ml/l) for each station. Only CTD and bottle oxygens with quality code 2 (acceptable) were used to generate these figures and statistics. Residual differences exceeding +/-0.5 ml/l are included in the calculations for averages and standard deviations, even though they are not plotted.

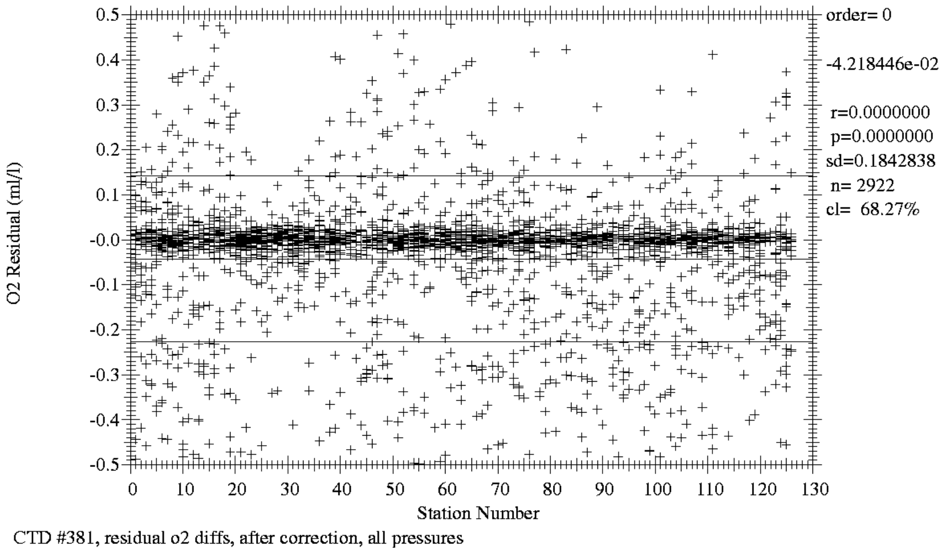


Figure 4.8.4.0 Chukchi Borderland O2 residual differences vs station # (after prelim. correction).

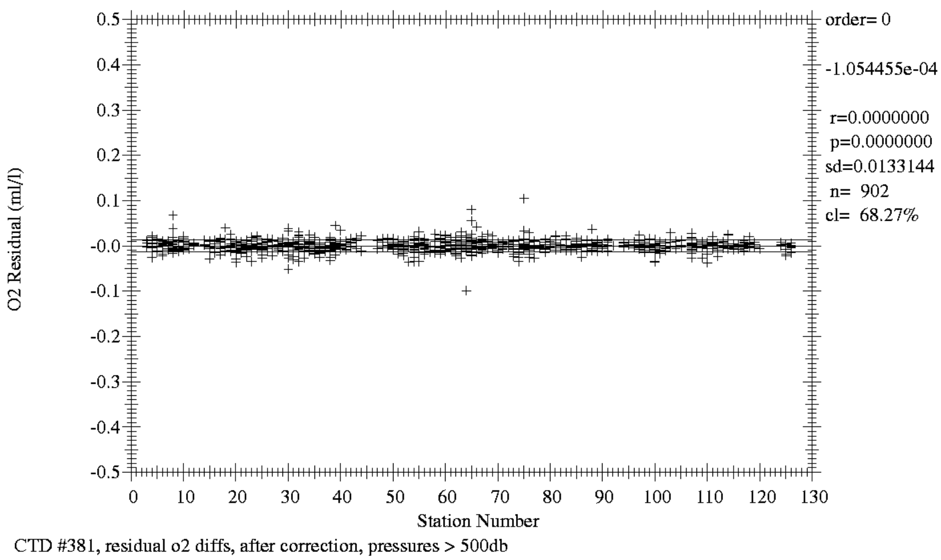


Figure 4.8.4.1 Chukchi Borderland Deep O2 residual differences vs station # (after prelim. correction).

The standard deviations of 0.184 ml/l for all oxygens and 0.013 ml/l for deep oxygens are only intended as indicators of how well the up-cast bottle and down-cast CTD O2 values match up. ODF makes no claims regarding the precision or accuracy of CTD dissolved O2 data. As with other CTD properties, the CTD dissolved O2 data are not considered final until after post-cruise pressure and temperature calibrations have been completed and analyzed.

The general form of the ODF O2 conversion equation follows Brown and Morrison [Brow78] and Millard [Mill82], [Owen85]. ODF does not use a digitized O2 sensor temperature to model the secondary thermal response but instead models membrane and sensor temperatures by low-pass filtering the PRT temperature. Insitu pressure and temperature are filtered to match the sensor response. Time-constants for the pressure response Taup, and two temperature responses TauTs and TauTf are fitting parameters. The Oc gradient, dOc/dt, is approximated by low-pass filtering 1st-order Oc differences. This gradient term attempts to correct for reduction of species other than O2 at the cathode. The time-constant for this filter, Tauog, is a fitting parameter. Oxygen partial-pressure is then calculated:

$$Opp=[c1*Oc+c2]*fsat(S,T,P)*e**(c3*Pl+c4*Tf+c5*Ts+c6*dOc/dt) \quad (4.8.4.0)$$

where:

Opp = Dissolved O2 partial-pressure in atmospheres (atm);
Oc = Sensor current (uamps);
fsat(S,T,P) = O2 saturation partial-pressure at S,T,P (atm);
S = Salinity at O2 response-time (PSUs);
T = Temperature at O2 response-time (deg.C);
P = Pressure at O2 response-time (decibars);
Pl = Low-pass filtered pressure (decibars);
Tf = Fast low-pass filtered temperature (deg.C);
Ts = Slow low-pass filtered temperature (deg.C);
dOc/dt = Sensor current gradient (uamps/secs).

Tabulation of oxygen correction coefficients will be included in the final Chukchi Borderland report, after corrections are finalized.

4.8.5. CTD Quality Codes

Preliminary quality coding of Chukchi Borderland CTD data was done using a coding scheme developed for the World Ocean Circulation Experiment (WOCE) Hydrographic Programme (WHP). WHP CTD quality codes were assigned as defined in the WOCE Operations Manual [Joyc94] with the following interpretations:

l

2 l Acceptable measurement.

3 l Questionable measurement. Typically, there were problems with noise, calibration, pumps, etc., which made the data suspect.

6 l Extrapolated/Interpolated data. Missing levels filled by double-quadratic interpolation/extrapolation of adjacent data.

7 l Despiked. The CTD data have been filtered to eliminate a spike or offset.

Explanations of CTD data coded "3", or any large segments of data coded "7", will be included with the final documentation.

4.9. Bottle Sampling

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

- o CFCs

- He-3
- O2

The remaining water samples were drawn in arbitrary order:

- Ba
- O-18
- Nutrients
- I-129
- Salinity

Note that some properties were subsampled by cast or by station, so the actual sequence of samples drawn was modified accordingly. Not all sample types were drawn at each station. Some stations had several additional bottles tripped just for Cs-137 or N:Ar samples. Salinity check samples were drawn after sampling Cs-137, and O2 check samples were drawn before and after each N:Ar sample.

The correspondence between individual sample containers and the rosette bottle 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 to their respective laboratories for analysis. Oxygen, nutrients and salinity analyses were performed on computer-assisted (PC) analytical equipment networked to the data processing computer for centralized data analysis. The analysts for each specific property were responsible for insuring that their results were updated into the cruise database.

5. Bottle Data Processing

Bottle data processing began with sample drawing, and continued until the data were considered to be final. One of the most important pieces of information, the sample log sheet, was filled out during the drawing of the many different samples. It was useful both as a sample inventory and as a guide for the technicians in carrying out their analyses. Any problems observed with the rosette before or during the sample drawing were noted on this form, including indications of bottle leaks, out-of-order drawing, etc. Additional clues regarding bottle tripping or leak problems were found by individual analysts as the samples were analyzed and the resulting data were processed and checked by those personnel.

The next stage of processing was accomplished after the individual parameter files were merged into a common station file, along with CTDderived parameters (pressure, temperature, conductivity, etc.). The rosette cast and bottle numbers were the primary identification for all ODF-analyzed samples taken from the bottle, and were used to merge the analytical results with the CTD data associated with the bottle. At this stage, bottle tripping problems were usually resolved, sometimes resulting in changes to the pressure, temperature and other CTD properties associated with the bottle. All CTD information from each bottle trip (confirmed or not) was retained in a file, so resolving bottle tripping problems consisted of correlating CTD trip data with the rosette bottles.

Diagnostic comments from the sample log, and notes from analysts and/or bottle data processors were entered into a computer file associated with each station (the "quality" file) as part of the quality control procedure. Sample data from bottles suspected of leaking were checked to see if the properties were consistent with the profile for the cast, with adjacent stations, and, where applicable, with the CTD data. Various propertyproperty plots and vertical sections were examined for both consistency within a cast and consistency with adjacent stations by data processors, who advised analysts of possible errors or irregularities. The analysts reviewed and sometimes revised their data as additional calibration or diagnostic results became available.

Quality coding of CTD and water samples was done using a coding scheme developed for the World Ocean Circulation Experiment (WOCE) Hydrographic Programme (WHP) [Joyc94]. Based on the outcome of investigations of the various comments in the quality files, WHP water sample codes were selected to indicate the reliability of the individual parameters affected by the comments. WHP bottle codes were assigned where evidence showed the entire bottle was affected, as in the case of a leak, or a bottle trip at other than the intended depth.

WHP water bottle quality codes were assigned as defined in the WOCE Operations Manual [Joyc94] with the following additional interpretations:

l

2 l No problems noted.

3 l Leaking. An air leak large enough to produce an observable effect on a sample is identified by a code of 3 on the bottle and a code of 4 on the oxygen. (Small air leaks may have no observable effect, or may only affect gas samples.)

4 l Did not trip correctly. Bottles tripped at other than the intended depth were assigned a code of 4. There may l be no problems with the associated water sample data.

5 l Not reported. No water sample data reported. This is a representative level derived from the CTD data for reporting purposes. The sample number should be in the range of 80-99.

9 l The samples were not drawn from this bottle.

WHP water sample quality flags were assigned using the following criteria: l

1 l The sample for this measurement was drawn from the water bottle, but the results of the analysis were not (yet) received.

2 l Acceptable measurement.

3 l Questionable measurement. The data did not fit the station profile or adjacent station comparisons (or possibly CTD data comparisons). No notes from the analyst indicated a problem. The data could be acceptable, but are open to interpretation.

4 l Bad measurement. The data did not fit the station profile, adjacent stations or CTD data. There were analytical notes indicating a problem, but data values were reported. Sampling and analytical errors were also coded as 4.

5 l Not reported. There should always be a reason associated with a code of 5, usually that the sample was lost, contaminated or rendered unusable.

9 l The sample for this measurement was not drawn.

WHP water sample quality flags were assigned to the CTDSAL (CTD salinity) parameter as follows:

2 l Acceptable measurement.

3 l Questionable measurement. The data did not fit the bottle data, or there was a CTD conductivity calibration shift during the up-cast.

4 l Bad measurement. The CTD up-cast data were determined to be unusable for calculating a salinity.

7 l Despiked. The CTD data have been filtered to eliminate a spike or offset.

WHP water sample quality flags were assigned to the CTDOXY (CTD O2) parameter as follows:

1 l Not calibrated. Data are uncalibrated.

2 l Acceptable measurement.

3 l Questionable measurement.

4 l Bad measurement. The CTD data were determined to be unusable for calculating a dissolved oxygen concentration.

5 l Not reported. The CTD data could not be reported, typically when CTD salinity is coded 3 or 4.

7 l Despiked. The CTD data have been filtered to eliminate a spike or offset.

9 l Not sampled. No operational CTD O2 sensor was present on this cast.

Note that CTDOXY values were derived from the down-cast pressure-series CTD data. CTD data were matched to the up-cast bottle data along isopycnal surfaces. If the CTD salinity is footnoted as bad or questionable, the CTD O2 is not reported. CTDOXY quality codes in the bottle files have not been modified from the default "Acceptable/Code 2" for the preliminary data set.

Table 5.0 shows the number of samples drawn and the number of times each WHP sample quality flag was assigned for each basic hydrographic property. Nutrient data are temporarily omitted from this chart until they can be incorporated into the ODF bottle data files.

Rosette Samples Stations 001-126

	Reported Levels	WHP Quality Codes 1	2	3	4	5	7	9
Bottle	3206	0	3162	17	14	0	0	13
CTD Salt	3206	0	3206	0	0	0	0	0
CTD Oxy	3206	0	3206	0	0	0	0	0
Salinity	3038	0	3017	20	1	0	0	168
Oxygen	2928	0	2922	5	1	2	0	276

Table 5.0 Frequency of WHP quality flag assignments for Chukchi Borderland.

5.1. Bottle Pressure and Temperature

All pressures and temperatures for the bottle data tabulations on the rosette casts were obtained by averaging CTD data for a brief interval at the time the bottle was closed on the rosette, then correcting the data based on CTD laboratory calibrations.

The temperatures are reported using the International Temperature Scale of 1990.

5.2. Salinity Analysis

Equipment and Techniques

A single Guildline Autosal Model 8400A salinometer (s/n 57-396), located in the main wet lab, was used for measuring salinity on all stations. The salinometer was modified by ODF to contain an interface for computer-aided measurement. The water bath temperature was set and maintained at a value near the laboratory air temperature. It was set at 24 deg.C for the entire leg.

The salinity analyses were performed when samples had equilibrated to laboratory temperature, usually within 16-36 hours after collection. Equilibration time was sometimes accelerated by blowing warm air on sample boxes with a fan and heater because of the extreme differences between in situ sample temperatures and the lab temperature. The salinometer was standardized for each group of analyses (usually one or two casts, up to ~60 samples) using at least one fresh vial of standard seawater per group. One group included 107 samples and 4 casts between standardizations. A computer (PC) prompted the analyst for control functions such as changing sample, flushing, or switching to "read" mode. The salinometer cell was flushed and results were logged by the computer until two successive measurements met software criteria for consistency. These values were then averaged for a final result.

Sampling and Data Processing

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 collecting each sample, inserts were inspected for proper fit and loose inserts were 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 one run at the end as an unknown was applied linearly to the data to account for any drift. The data were added to the cruise database. 3038 salinity measurements were made and approximately 172 vials of standard water were used. 18 replicate samples were also measured to test the spare salinometer or to compare standard batches. 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 in the salinometer laboratory varied from 22 to 25.3 deg.C, within 2 deg.C of the bath temperature, during the cruise. The air temperature change during a run of samples was less than +/-1.2 deg.C.

Standards

IAPSO Standard Seawater (SSW) Batch P-140 (148 vials) was used to standardize the salinometer for stations 1-97. Batch P-136 (24 vials) was used for stations 98-126, after the P-140 standard was depleted. A few replicate samples from station 76 were run with the P-136 standard 4 days after the original samples were run with P-140. The bottle salinities from the replicate samples were consistently 0.001-0.002 PSU lower than the originals, indicating the P-136 standard could be high compared to its label (or the P-140 low compared to its label).

5.3. 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 (~0.012N) and thiosulfate solution (~65 gm/l). Pre-made liquid potassium iodate standards were run at the beginning of each session of analyses, which typically included from 1 to 3 stations. Reagent/distilled water blanks were determined, to account for presence of oxidizing or reducing materials. The auto-titrator generally performed very well.

Sampling and Data Processing

Samples were collected for dissolved oxygen analyses soon after the rosette sampler was brought on board. Using a Tygon drawing tube, nominal 125ml volume-calibrated iodine flasks were rinsed 2-3 times with minimal agitation, then filled and allowed to overflow for at least 3 flask volumes. The sample draw temperature was measured with a small platinum resistance thermometer embedded in the drawing tube. Reagents were added to fix the oxygen before stoppering. The flasks were shaken twice to assure thorough dispersion of the precipitate, once immediately after drawing, and then again after about 20 minutes.

The thermometer used to measure draw temperature began to misbehave around station 96, and was replaced at station 105. The replacement did not work properly, either, so sample draw temperatures were not taken for stations 96 or 106-126.

The samples were analyzed within 1-6 hours of collection, then the data were merged into the cruise database.

Thiosulfate normalities were calculated from each standardization and corrected to 20 deg.C. The 20 deg.C normalities and the blanks were plotted versus time and were reviewed for possible problems. New thiosulfate normalities will be recalculated after the blanks have been smoothed as a function of time, if warranted. These new normalities will then be smoothed, and the oxygen data recalculated.

As samples warmed up to room temperature they would often degas which would cause an occasional noisy endpoint due to gas bubbles in the light path. 2928 oxygen measurements were made, with no major problems with the analyses. In addition, 22 oxygen samples from post-N:Ar sampling and 26 random replicate samples were also analyzed but not reported with the ODF data.

Volumetric Calibration

Oxygen flask volumes were determined gravimetrically with degassed deionized water to determine flask volumes at ODF's chemistry laboratory. This is done once before using flasks for the first time and periodically thereafter when a suspect bottle 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 and bottled in ODF's chemistry laboratory prior to the cruise. The normality of the liquid standard was determined at ODF by calculation from weight. Two different standard batches used during the cruise agreed well. Potassium iodate was obtained from Acros Chemical Co. and was reported by the supplier to be >99.4% pure. All other reagents were "reagent grade" and were tested for levels of oxidizing and reducing impurities prior to use.

5.4. 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 hour after sample collection.

Occasionally samples were refrigerated up to 10 hours at ~4 deg.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 PO4 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 ~55 deg.C to enhance color development, then passed through a 50mm flowcell and the absorbance measured at 820nm.

Sampling and Data Processing

Nutrient samples were drawn into 45 ml polypropylene, screw-capped "oakridge 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 lownutrient seawater matrix. The secondary standards were prepared aboard ship by dilution from primary standard solutions. Dry standards were preweighed at the laboratory at ODF, and transported to the vessel for dilution to the primary standard. Sets of 6-7 different standard concentrations were analyzed periodically to determine any deviation from linearity as a function of concentration for each nutrient analysis. A correction for non-linearity was applied to the final nutrient concentrations when necessary.

After each group of samples was analyzed, the raw data file was processed to produce another file of response factors, baseline values, and absorbances. Computer-produced absorbance 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 an assumed laboratory temperature of 25 deg.C.

2662 nutrient samples were analyzed. The pump tubing was changed 1 time, before analyzing station 65 samples. Silicate molybdate pump tubing was replaced again before analyzing station 95.

Standards

Primary standards for silicate (Na_2SiF_6), nitrate (KNO_3), nitrite ($NaNO_2$) and phosphate (KH_2PO_4) were obtained from Johnson Matthey Chemical Co.; the supplier reported purities of >98%, 99.999%, 97% 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 22 deg.C to 25.5 deg.C, but was relatively constant during any one station (+/-1.5 deg.C).

References

Arms67.

Armstrong, F. A. J., Stearns, C. R., and Strickland, J. D. H., "The measurement of upwelling and subsequent biological processes by means of the Technicon Autoanalyzer and associated equipment," Deep-Sea Research, 14, pp. 381-389 (1967).

Bern67.

Bernhardt, H. and Wilhelms, A., "The continuous determination of low level iron, soluble phosphate and total phosphate with the AutoAnalyzer," Technicon Symposia, I, pp. 385-389 (1967).

Brow78.

Brown, N. L. and Morrison, G. K., "WHOI/Brown conductivity, temperature and depth microprofiler," Technical Report No. 78-23, Woods Hole Oceanographic Institution (1978).

Carp65.

Carpenter, J. H., "The Chesapeake Bay Institute technique for the Winkler dissolved oxygen method," Limnology and Oceanography, 10, pp. 141-143 (1965).

Culb91.

Culberson, C. H., Knapp, G., Stalcup, M., Williams, R. T., and Zemlyak, F., "A comparison of methods for the determination of dissolved oxygen in seawater," Report WHPO 91-2, WOCE Hydrographic Programme Office (Aug 1991).

Gord92.

Gordon, L. I., Jennings, J. C., Jr., Ross, A. A., and Krest, J. M., "A suggested Protocol for Continuous Flow Automated Analysis of Seawater Nutrients in the WOCE Hydrographic Program and the Joint Global Ocean Fluxes Study," Grp. Tech Rpt 92-1, OSU College of Oceanography Descr. Chem Oc. (1992).

Joyc94.

Joyce, T., ed. and Corry, C., ed., "Requirements for WOCE Hydrographic Programme Data Reporting," Report WHPO 90-1, WOCE Report No. 67/91, pp. 52-55, WOCE Hydrographic Programme Office, Woods Hole, MA, USA
(May 1994, Rev. 2). UNPUBLISHED MANUSCRIPT.

Mill82.

Millard, R. C., Jr., "CTD calibration and data processing techniques at WHOI using the practical salinity scale," Proc. Int. STD Conference and Workshop, p. 19, Mar. Tech. Soc., La Jolla, Ca. (1982).

Owen85.

Owens, W. B. and Millard, R. C., Jr., "A new algorithm for CTD oxygen calibration," Journ. of Am. Meteorological Soc., 15, p. 621 (1985).

UNES81.

UNESCO, "Background papers and supporting data on the Practical Salinity Scale, 1978," UNESCO Technical Papers in Marine Science, No. 37, p. 144 (1981).□

End of EXTRACT from ODF Preliminary Cruise Report

4. CFC MEASUREMENTS PROGRAM

(Eugene Gorman, Guy Mathieu, Sarah Zimmermann, Kevin Vranes, Bill Smethie)

Methods

Water samples were collected in 10-l Bullister style rosette bottles. CFC samples - the first samples taken from the bottles - were drawn into 100-cc precision ground glass syringes and stored in a sink filled with clean surface seawater until analysis. Samples were stored for no longer than 8 hours. Air samples were collected by pumping air from the bow directly to the CFC analysis system during periods when the bow was into the wind.

The CFC samples were analyzed using an automated purge and trap system interfaced to a gas chromatograph with an electron capture detector for CFCs 11, 12, and 113. The column arrangement for the gas chromatograph consisted of a 3 foot x 1/8 inch diameter precolumn of Porasil-B, a 5 foot x 1/8 inch diameter main column of Carbograph 1ac and a 4 inch x 1/8 inch diameter post column of molecular sieve 5A. The precolumn and main column were operated at 95°C and the post column at 40°C. The post column separated N_2O from CFC-12 and was valved out of the gas stream before CFC-11 and CFC-113 eluted. The precolumn and main column provided good separation between the CFCs and methyl iodide. Chromatograms were acquired digitally on a PC and the CFC peak areas determined using HP Chemstation software.

Calibration curves were run at the beginning and end of the cruise and every 3-4 days in between. A gas standard with known amounts of CFCs 11, 12 and 113 in nitrogen in seawater ratios was used for calibration. This standard was prepared about 4 months prior to the cruise and since we had no history on its stability, it was calibrated several times during the course of the cruise against a standard kindly provided to us by John Bullister of PMEL/NOAA. From our initial analysis of these results, our standard appeared to be stable and a more careful analysis of these results will be carried out after the cruise. The standards are on the SIO 98 calibration scale.

Two CFC analysis systems were used. Duplicates were collected nearly every station for comparison of the two systems and for determination of the precision for each system. Preliminary calibration curves were fit to the calibration data and preliminary CFC concentrations calculated after the completion of each station. These preliminary data were merged with the preliminary hydrographic data at sea and made available for everyone on the cruise. Approximately 2600 CFC samples (including duplicates) were collected.

Problems

Initially there was a very high F11 blank: this blank decreased over time and was well documented so appropriate corrections could be made. One system was inoperable for the first week of the cruise. Occasional blank problems developed over the course of the cruise but were corrected and presented no problems for data quality

5. MOORING WORK

(Knut Aagaard, Jim Johnson, Rebecca Woodgate)

Three physical oceanographic moorings were deployed and recovered on this cruise.

ID	Latitude & Longitude	Water Depth (m)	Inst.	Inst. Depth (m)	# Days	Record Mean Velocity Mag (cm/s)	Record Mean Velocity Dir (deg)	Speed (cm/s)
CBL-A	76°	626	RCM-7	110	1	2.2	172	4.9
	01.513' N	(corr)	SBE-16	110	24			
	168°		RCM-7	384	24	1.2	254	4.5
	31.751' W		SBE16	385	24			
CBL-B	76°	1090	RCM-7	116	22	0.9	257	4.2
	03.082' N	(corr)	SBE-16	117	22			
	168°		RCM-7	378	22	3.9	263	5.4
	50.984' W		SBE16	379	22			
			RCM-7	848	22	1.4	73	5.2
CBL-C	76°	1617	RCM-7	100	23	1.7	161	5.9
	07.845' N	(corr)	SBE-16	101	23			
	168°		RCM-7	370	23	0.6	86	2.7
	59.155' W		SBE-16	371	23			
			RCM-7	820	23	2.6	73	4.0
			RCM-7	1604	23	5.0	74	5.5
			SBE-37	1605	23			

Deployments were made anchor first off the port stern of the ship, using a feeder-reel, the ship's capstan, a deck-mounted block which fair-led the line to a pulley mounted on the aft J-frame. A stopper chain was also suspended from the aft J-frame.

Mooring deployment and recovery operations were performed with the ship DIW, to prevent mooring equipment being caught in the ship's screws. Thus, in this region of steep topography, setting the mooring at the correct depth required a knowledge of the ship's drift and the bottom bathymetry. Due to the added complication of ice, the moorings were designed such that lengths of mooring line could be removed or added to the original design during the deployment.

Prior to mooring deployments, a CTD cast was taken at the required water depth. Then a bathymetry survey (consisting of a box of side 3 mile, centred on the CTD cast) was performed. A suitable start position for the mooring operation was chosen based on the ship's drift during the CTD cast and this bathymetry survey. Once the ship had repositioned, the current ship's drift was checked for ca.20 min before mooring operations commenced. If necessary, the ship was repositioned again. In practice, the ship's drift was almost unpredictable, being highly variable between different positions. Thus, significant adjustments were made during the mooring deployments to ensure the instruments were placed at the relevant water depths.

Recoveries were also made off the port stern of the ship, using the same deck set up as for deployment. In general, ranging on the moorings was done from the landing craft, which maneuvered in amongst the drifting ice. By this method, the landing craft could wait in an open lead until the lead drifted over the mooring. This worked very well. For the first recovery, ranging was done from the ship. Due to comparatively rapid ice motion, this mooring surfaced under an ice floe. The mooring's position under the ice floe was estimated from ranging from the landing craft, and the Polar Star slowly approached the ice floe, almost stopped, and by gently pushing, split the floe such that part of the mooring bobbed into the open water. The landing craft tied onto this floatation package and, whilst this was being towed back to the Polar Star, the remaining parts of the mooring also came free of the ice.

All the recovered SBE-16s gave good data. The SBE-37 shows excessive drift in its pressure sensor, but pressure information can be calculated from the other sensors on the mooring. One of the RCM-7s leaked seawater through the salinity cell and stopped recording after ca.1 day in the water.

Preliminary results are give in the appendix. Semidiurnal oscillations (presumably tides) are a major feature in the current records. In the mean, however, there is significant velocity shear both between the moorings and in the vertical. The flow in the halocline is frequently perpendicular to the flow below. The velocities in the Atlantic layer show mean westsouthwestward flow for the duration of the deployment at the two shallowest moorings. At the deepest mooring, the flow below the halocline is instead to the eastnortheast and increases with depth. The T-S data show variability in the halocline and semidiurnal oscillations in the Atlantic layer. These records will be combined with the CTD and L-ADCP sections run at the mooring deployments and recoveries.

6. O18 AND BARIUM SAMPLING

(Marlene Jeffries, Kellie Balster, Wendy Ermold, Gail Grimes, Kelly Falkner,)

For the halocline and surface waters, independent information on water mass origin can be obtained from ^{18}O and Ba measurements (Guay and Falkner, 1997; Bauch et al., 1995; Cooper et al., 1997). In particular, oxygen isotopes have been used to distinguish between sea ice melt and river water distributions in the eastern (e.g., Bauch et al., 1995) and western Arctic (e.g., Macdonald et al., 1999), whilst the Ba signature may allow us to distinguish river water influence of North American versus Siberian origin (Guay and Falkner, 1997). Other tracers (e.g. Si, N/P ratios, and the quasi-conservative parameters NO and PO) distinguish Bering summer and winter waters (Coachman and Barnes, 1961; Jones et al., 1998) from Atlantic contributions to the halocline (Jones and Anderson, 1986; Wilson and Wallace, 1990). In combination, this suite of measurements allows us to separate the surface and halocline waters into their component parts (Atlantic-origin halocline, summer and winter Pacific-origin halocline, ice melt, North American and Siberian runoff) and thereby delineate current pathways in the upper layers of the region.

Almost 1000 O18 and Barium samples were taken on the cruise. The focus was on the upper 500m of the water column. A standard cast would take 10 samples, with a strategy aiming at samples from "surface", 20m, 35m, 50m, the Alaskan Coastal water subsurface temperature maximum at about 50-70m, 100m, the 33.1psu salinity in ca 150-180m, the 34.2 psu salinity, the core Atlantic water temperature maximum, and below the temperature maximum. Full water column profile were also taken at the junctions of sections 8 and 9, 9 and 10, 10 and 11, and 11 and 12. These samples will be analyzed on shore by Kelly Falkner at Oregon State University.

Bauch, D., P. Schlosser, and R.G. Fairbanks, Freshwater balance and sources of deep and bottom waters in the Arctic Ocean inferred from the distribution of $H_2{}^{18}O$, *Progr. Oceanogr.*, *35*, 53-80, 1995.
Coachman, L.K., and C.A. Barnes, The contribution of Bering Sea water to the Arctic Ocean, *Arctic*, *14*, 147-161, 1961.
Cooper, L.W., T.E. Whitledge, J.M. Grebmeier, and T. Weingartner, The nutrient, salinity and stable oxygen isotope composition of Bering and Chukchi Seas waters in and near the Bering Strait, *J. Geophys. Res.*, *102*, 12,563-12,573, 1997.
Guay, C.K., and K.K .Falkner, Barium as a tracer of Arctic halocline and river waters, *Deep-Sea Res. Part II*, *44*, 1543-1569, 1997.
Jones, E.P. and L.G. Anderson, On the origin of the chemical properties of the Arctic Ocean halocline, *J. Geophys. Res.*, 91, 10,759-10,767, 1986
Jones, E.P., L.G. Anderson, and J.H. Swift, Distribution of Atlantic and Pacific waters in the upper Arctic Ocean: Implications for circulation, *Geophys. Res. Lett.*, *25*, 765-768, 1998.
Macdonald, R.W., E.C. Carmack, F.A. McLaughlin, K.K. Falkner, and J.H. Swift, Connections among ice, runoff and atmospheric forcing in the Beaufort Gyre, *Geophys. Res. Lett.*, *26*, 2223-2226, 1999.
Wilson, C., and D.W.R. Wallace, Using the nutrient ratio NO/PO as a tracer of continental shelf water in the central Arctic Ocean, *J. Geophys. Res.*, *95*, 22,193-22,203, 1990.

7. RADIOACTIVE ISOTOPE SAMPLING

Analysis of other isotopes (tritium, helium, iodine and cesium) also gives information about the history of a water mass. The waste outflow from nuclear reprocessing plants in Europe contains trace quantities of I-129 and Cs-137, so these tracers can be used to identify Atlantic influence. The atomic bomb tests of the 1960s were a source of radioactive enrichment of the surface waters. Combined with knowledge of background isotopic levels, water sampling of these isotopes can give information on the age of a water mass.

On this cruise, samples were taken for Helium, Iodine and Cesium isotopes.

Helium Sampling

(Wendy Ermold, Marlene Jeffries, Kellie Balster, Gail Grimes, Peter Schlosser)
A total of 108 copper tube samples for Helium were taken on the cruise, concentrated on four of the sections, viz, section 2, section 6, the eastern end of section 11, and the penultimate CTD section, that run from the southern Northwind Abyssal Plain up onto the Chukchi shelf. On these sections, the CTD casts at ca.600m, 1000m and 1700m were sampled, with one sample taken in the "surface" layer, one in the Being inflow, one in the upper halocline water, one in the lower halocline water, three taken around the temperature maximum of the Atlantic layer (the Fram Strait branch), and five taken below the temperature maximum in the Barents Sea branch. These samples will be analyzed on shore by Peter Schlosser at the Lamont-Doherty Earth Observatory.

Iodine-129 and Cesium-137 Sampling

(Kellie Balster, Marlene Jeffries, Wendy Ermold, Gail Grimes John Smith)
A total of 96 one-liter samples were taken for I-129. A total of 27 samples (each 20 or 30 liters) were taken for Cs-137. These samples were taken (at reduced coverage) from the same casts and depth as sampled for Helium. At any cast, only three water depths, corresponding to the lower halocline waters, the core of the Fram Strait Branch and the core of the Barents Sea Branch, were taken. The shallowest cast on section 2 was also omitted. These samples will be analyzed on shore by John Smith at Bedford Institute, Canada.

8. DENITRIFICATION NITROGEN:ARGON SAMPLING

(Kellie Balster, Al Devol)

The process of denitrification in the ocean removes nutrients from the water column, impacting the ocean's ability to take up carbon dioxide from the atmosphere through photosynthesis. In sediments and in the water column where dissolved oxygen values are low, microbes will also scavenge oxygen from nitrate and nitrite, releasing nitrogen gas into the water. Thus elevated levels of nitrogen gas are an indicator of denitrification having occurred.

As part of her Master's thesis work at University of Washington, Kellie Balster took 21 "egg" samples for analysis of Nitrogen:Argon ratios and Nitrogen isotopes from 5 shelf stations on the cruise. These samples have been analyzed on shore at UW. Roughly half suggest evidence of denitrification. This topic will be pursued with reference also to the nutrient data.

9. LOWERED ACOUSTIC DOPPLER CURRENT PROFILER MEASUREMENTS

(Wendy Ermold, Sarah Zimmermann, Marlene Jeffries, Kellie Balster, Rebecca Woodgate)

Two RDI workhorse (300kHz) ADCPs kindly loaned to the project from Bob Pickart and Dan Torres (WHOI), were mounted on the CTD rosette. The upward-looking instrument is slaved to the downward-looking instrument. (Although the ping sequence sounded synchronized, a ping synchronization error flag appeared during data processing.) The instruments are internally recording. Power during the cast comes from a rechargeable lead-acid battery pack also mounted on the CTD rosette. This battery was charged between casts using a standard battery charger. Due to out-gassing during charging, a vent plug must always be open during charging. (A few m of plastic tube were inserted in this plug hole to allow venting whilst preventing entry of water into the battery. This long hose acted as an extra reminder to replace the vent plug before deployment.) Care must be taken not to over charge this battery!!

A few minutes prior to every cast, the ADCPs were started using Dos command routines written by Dan Torres. From cast #32 and subsequently, this start procedure included checking the ADCP clocks against GMT and resetting the ADCP clocks when they differed by more than a few seconds from GMT. The upward ADCP was started first, then the computer connection swapped to the downward ADCP (the master) by a toggle switch in the lab. Once both ADCPs were started, both communications cables were removed and dummy plugs installed. The battery dummy plug was also replaced. For a successful deployment, both ADCPs would be pinging both before deployment and after recovery. On recovery, the connectors were rinsed with fresh water, the communications cables reconnected, the battery vent plug removed and the tube inserted, the battery charger turned on, and the data downloaded. The battery charger was switched off once the charging current fell below 0.3A.

Upward- and downward-looking profiles of velocity shear were collected at almost every CTD cast. For a handful of casts, only one ADCP was started due to operator error. For two further casts, problems in the communication cables between the lab and the instruments resulted in data being lost. On occasions the battery would not charge initially after recovery. Waiting for the battery to warm up and/or unplugging and replugging the battery cables fixed this problem.

Initial on-board processing was done using the Sep2002 Version 7a release of the LDEO LADCP software. (Casts 1-19 used the older version of the software, but will be reprocessed on land.)

To correct for ship drift during the cast, it is essential that the start and end positions of the ADCP going in the water are accurately recorded. An error of 20m in these positions results in a barotropic velocity error of ca 1cm/s for a 1 hour long cast. (The expected currents are of order a few cm/s.) The positions recorded by hand by the operator were subject to error (both human error and system error when the data display would freeze for several seconds or even minutes) and thus were checked/corrected with reference to the GPS position recorded by the ship's data network. Initial processing did not account for the offset in physical location between the ship's GPS antenna and the launch site of the CTD rosette.
The software allows use of the pressure time series from the CTD for comparison with the integrated vertical velocity from the ADCP. This requires a synchronization of the ADCP and the CTD clocks, all of which have distinct clock drifts. For this initial processing, no correction was made for the disparate clocks, although records exist to do this correction. The CTD clock was generally not more than 1 minute off the ADCP clocks, which themselves differed by a maximum of 7 seconds.

Preliminary results are inconclusive. The target strength, though weakening midwater column in deep water, is reasonably strong. The final error in the measurement is generally between 2 and 10 cm/s depending on cast. The final velocities are of this order. It remains to be seen if these errors, combined with the error in extracting the tidal signal from the data, remain smaller than the measured velocities.

10. XBT WORK

(MSTs)
A total of 53 Sippican Deep Blue XBTs were kindly made available to the project by the ship. These resulted in 47 successful casts at 41 locations. The six failures were caused by ice or by instrument problems. Six further casts were repeated where the earlier cast was bad, or terminated too shallow to reach the Atlantic temperature maximum. Both XBT systems on the Polar Star were used. That in the aft wet lab was more convenient, being a 1-person job and also having the GPS position automatically routed to the file. (The system in the met lab requires the position to be handtyped before the probe is launched. In regions of medium ice cover, this could occur 10 minutes or more before enough open water was available to launch the probe.)

The XBTs were thrown on sections 2, 6, 7, 10, 11 and the 2 final CTD sections from the southern end of the Northwind Abysal plain up into the Chukchi shelf to the west, and back down from the Chukchi shelf towards the Chukchi abyssal plain, as fill-in between the CTD casts to better define frontal structures. A final section of 8 XBTs were thrown on the final steam to Barrow, to help define the pathways of the Chukchi waters over the shelf.

11. BATHYMETRY AND UNDERWAY MEASUREMENTS

The USCG kindly installed a Knudsen echosounder on the Polar Star before the Arctic West 2002 mission. This data proved vital to the success of the Borderland cruise, since the best available bathymetric charts were far from accurate. This data, along with underway data, are stored with latitude, longitude and ship information, every 10 seconds or more frequently. Of the underway data, the wind data is considered reliable, whilst the barometric pressure and relative humidity are likely inaccurate. Temperature data is also recorded, but is substantially erroneous.

12. EDUCATIONAL OUTREACH

(Gail Grimes, Rebecca Woodgate)

As part of the outreach activities of the project, Gail Grimes, a science teacher from Lake Stevens High School (just north of Seattle) took part both in the cruise and in school visits before and after the trip.

As well as being part of the hydrography team, Grimes sent daily updates from the ship to a public website, to be read by her class and by other schools and individuals across the country and around the world. This site is available at http:\\psc.apl.washington.edu\CBLteacher.html. It features articles about the science projects on the cruise, life aboard ship, what it takes to be an oceanographer or a member of the Coast Guard, as well as lighter articles concerning "Cindy, the shrinking head" and just how many layers of parkas and waterproofs one needs to water sample.

The website attracted over 3000 individual visitors over the 2-month period of the cruise. Fourteen schools or organizations registered, and 31 questions were sent to the website from the general public.

Prior to sailing from Barrow, Grimes and Woodgate visited the three schools (Elementary, Middle and High) in Barrow to explain the oceanographic research in general and the purpose of this cruise in particular. They taught the classes about the ocean currents carrying Pacific waters from low latitudes up to Barrow and the Arctic, illustrating the journey by introducing the animals that might be encountered on the way by 2 water parcels (named Brian and Sid) starting in the Pacific. (On reaching the Chukchi Sea, Brian turns east and goes to Barrow, whilst Sid heads north into the high Arctic and meets the Ship.) The High school class also learnt about salinity and the circulation of the Atlantic waters in the Arctic. To illustrate the differences in water properties, the class learned how to use their own "human salinometer", i.e. their tongues, to distinguish between fresh water, Pacific waters, and Atlantic waters. To illustrate the effects of ocean pressure, Grimes also provided a styrofoam model head and the Barrow Arctic Science Consortium (BASC) kindly provided a collection of styrofoam cups for the Elementary and Middle school classes to decorate. The cups and the head were sent down with the CTD during the cruise and returned, shrunk by ocean pressure, to the classes in visits post-cruise. We are grateful to BASC for arranging these classroom visits for us.

Grimes also enrolled for and passed course OCEAN 499B Undergraduate Research at the College of Ocean and Fisheries Science, University of Washington.

13. APPENDICES

Table of CTD and XBT casts

Preliminary Hydrographic Sections

The following sections are contour plots of preliminary hydrographic data contoured using the Java Ocean Atlas program. The y-axis is CTD pressure in dbar. The x-axis is along-track distance. Major topographic features are indicated beneath the figures by the following abbreviations:

CS = Chukchi Shelf
MR = Mendeleev Ridge
CC = Chukchi Cap
NW = Northwind Ridge.

For orientation, please refer to the track map at the beginning of the report. Tick marks on the top of the sections indicate the individual CTD casts. Data is interpolated between stations even where the station spacing is large (e.g. between the penultimate CS and final NW markers). Color scales may vary between plots. The color bar is standard rainbow (red, yellow, green, cyan, blue, purple). The values corresponding to red, green and blue are marked with each contour plot. Temperature sections are insitu temperature.

The following plots are included:

Temperature	0-300db	250-600db	500-4000db	0-4000db
Salinity	0-300db	250-600db	500-4000db	0-4000db
Sigma-0	0-300db	250-600db	500-4000db	0-4000db
CTD Oxygen	0-300db	250-600db	500-4000db	0-4000db
SiO3	0-500db	0-4000db		
PO4	0-500db	0-4000db		
NO3	0-500db	0-4000db		
NO2	0-500db	0-4000db		
F11	0-4000db			
F12	0-4000db			
F113	0-4000db			

Preliminary Mooring Results

Current meters and seacats (temperature, conductivity sensors) were set to record hourly. The following plots are included:

Stickplots for current meters on moorings CBL-A, CBL-B, CBL-C

Progressive vector diagrams for current meters on moorings CBL-A, CBL-B, CBL-C

Time series and T-S plots for all seacat instruments.

The data for these plots has been calibrated using pre-deployment calibrations. The progressive vector diagram and stickplots have been corrected for magnetic declination (ca.16 deg.). The salinities are calculated from conductivity using the insitu pressure at the SBE. The pressure sensor on the microcat at ca.1600m on CBL-C is obviously faulty. A constant pressure equivalent to 1628m depth has been assumed for the salinity calculation. Final pressures will be determined with reference to the post-calibrations, depth sounding and mooring length, other instruments on the mooring and nearby CTD casts. In all plots, the data is unfiltered.

Ice Charts

The climatological ice cover in the region is 7-10/10ths. During the cruise, however, much lighter ice conditions were encountered, especially in the north western limits of the cruise track, where substantial leads and ice free areas made progress extremely fast. These regions are not reflected in the Ice Analysis charts of NOAA (the following pictures).

Throughout the cruise, when weather permitted, the helicopters would fly on ice reconnaissance missions along the proposed cruise track. The ship received RADARSAT imagery from the National Ice Center approximately every day, and this information proved extremely helpful for planning purposes, the high resolution showing clearly the significant areas of open water between large floes. The heaviest ice was encountered on the initial approach to section 2, on the return up into the Chukchi Plateau (junction of sections 9-10) and the southwestward run after the junctions sections 11-12. The CBL-A mooring was in ca 10/10th new ice when we returned to recover it. The final two sections of the cruise (westward up the Northwind Ridge and into the southen Northwind Abysal Plain, and up onto and back off the Chukchi shelf) were in open water save for the last few stations.

Cruise Diary

OCTOBER 2001

Wednesday 31st Woodgate, Johnson, and Aagaard visit Polar Star in Seattle.

MAY 2002

Wednesday/Thursday 1st/2nd CBL planning meeting on Polar Star - UW, SIO, USCG.

JUNE 2002

Week 10th-14th Loading of Polar Star in Seattle.

JULY 2002

Tuesday 9th Polar Star sails from Seattle for SBI mooring cruise.

AUGUST 2002

Thursday 15th M.Johnson, Mathieu, Zimmermann join ship in Dutch Harbor for instrument set up during transit to Barrow. Woodgate and Grimes arrive in Barrow for educational outreach.

Friday 16th Woodgate and Grimes visit 3 schools in Barrow. Polar bear sighted on ice off Barrow.

Saturday 17th SIO science party arrives in Barrow. Polar bear (mother plus cub) in Barrow rubbish dump.

Sunday 18th Remainder of science party arrives in Barrow.

Monday 19th Science party transferred from Barrow to Polar Star by ship's helicopters. Science equipment set up. First ice around 9pm local time (GMT-8).

Tuesday 20th Science set-up continues. Test CTD cast (998) run successfully.

Wednesday 21st Science set-up continues. Around 11am local turn ship for Barrow for Medivac accomplished by land based helicopter ca 7pm local.

Thursday 22nd *CTDs 1-2* Arrive at first cast ca 2pm local time. Proceed down line 2, the mooring line, running CTDs and XBTs through the night. Some 10/10th ice cover.

Friday 23rd *CTDs 3-5* Run bathymetry surveys and deploy moorings CBL-A and CBL-B. Run CTDs and XBTs along line 2.

Saturday 24th *CTDs 6-8* Run bathymetry survey and deploy mooring CBL-C. Complete line 2 of CTDs and XBTs. Skip sections 3 and 4 and head for section 5.

Sunday 25th *CTDs 9-11* Run CTDs along line 5. Skip the repeat of the slope stations and the shallowest cast in anticipation of heavy ice conditions in the north. Problems with the winch controller (pauses in paying out or heaving line). Work around these issues by using manual joystick control instead.

Monday 26th *CTDs 12-13* Steam most of the day to reach the start point of line 6. Change gears on manual control of winch to allow lowering at 60 m/min. Recommence CTD on line 6 around midnight.

Tuesday 27th *CTDs 14-17* Continue CTD and XBTs up line 6. Still sufficient open water and leads for CTD casts.

Wednesday 28th *CTDs 18-19* Continue CTD and XBTs up line 7.

Thursday 29th *CTDs 20-22* Continue CTD and XBTs up line 7, into deeper water. Cut from line 7 north to line 8 and head back east, CTDing. Evening lecture "A Street Guide to the Arctic".
Friday 30th *CTDs 23-29* Continue CTDing along line 8. Large areas of open water. (several CTDs done with hardly any ice in sight. Start to worry about sea state!) Move south from original trackline to capitalize on large leads. Zigzags in ship's track show attempts to move back north. Note bottom topography complex here, may influence interpretation of CTD data. Very steep drop-offs in places.
Saturday 31st *CTDs 30-33* Continue CTDing along line 8. Again large areas of open water and leads tending south of original trackline. Pizza Night (made by science party).

SEPTEMBER 2002
Sunday 1st *CTDs 34-36* Turn the corner at line 8 after a deep cast and head back up onto the Chukchi Plateau, line 9. To accommodate high station density, subsample the nutrient profiles. Note evidence of ship's outflows in top few meters of CTD casts. End of the balmy weather we have been having. Water now starting to freeze, and progress much slower.

Monday 2nd *CTDs 37-40* Labour day (i.e. Sunday routine). Water still freezing, ice much heavier. Speed made good nearer 4 knots, and hard to find suitable lead in the ice for the CTD. Skip 2000m station as ice too heavy. Bottom also steep up into plateau, 0.5nm drift during CTD cast changes depth by 100m.
Tuesday 3rd *CTDs 41-47* Beautiful sunny day. Ice heavier again. Finish line 9 and head back out on line 10 with CTDs and XBTs.
Wednesday 4th *CTDs 48-52* CTDing out line 10. Grimes (our teacher) ill. Topography very steep off Chukchi Cap, and hard to find a hole in the ice at the right depths, so station depths variable.
Thursday 5th *CTDs 53-57* CTDing out line 10 into deeper water. Another gloriously sunny day. Ice melting again.
Friday 6th *CTDs 58-62* CTDs and XBTs back south along line 11. Station spacing very close as topography steep again. Sun and sudden fog (canceling flight ops). Two seals sighted.
Saturday 7th *CTDs 63-65* Continue CTDs and XBTs along line 11, again at close station spacing. Pinewood Derby held in heli hanger in the evening.
Sunday 8th *CTDs 66-71* More CTDs up the slope. Track again south of original plan following leads in the ice. Appear to follow a gully through the ridge (7nm all the same depth), so turn back N to regain original track.

Monday 9th *CTDs 72-76* More CTDs, now down off the ridge into the deep basin. Styrofoam head passes CFC airsample test and so is put down on the deepest cast. Unusual upper water column structure at the deepest cast (76). Head back up slope (start of line 12), but do not repeat deep stations on the Northwind Ridge.
Tuesday 10th *CTDs 77-79* Leak in cooler for port shaft. DIW from ca.2am-noon. Fog and heavy ice makes progress very slow. First Polar Bears in weeks (mother plus 2 cubs) approached ship during CTD cast in early morning.
Wednesday 11th *CTDs 80-85* Patriot Day. More CTDs, along line 12 into Northwind Abyssal Plain. Sign of bottom boundary layer in stations on the Plain, possibly related to waters entering the region through gaps in topography from the north.

Thursday 12th *CTDs 86-91* As have made good progress, divert from line 12 WNW at the north end of the Northwind Abyssal Plain and head back up onto the Chukchi Cap. Topography again VERY steep.
Friday 13th *CTDs 92-96* Polar Bears sighted in the early morning. Trouble shooting blown fuse in engine controller means DIW for ca 3 hours (some of that CTD cast). Proceed on 2-2-1 engine configuration as ice sufficiently light. Large areas of open water, and ice avoidance takes us 6nm off original trackline. CTDs and XBTs across plateau and back down the western side.
Saturday 14th *CTDs 97-100* Finish CTD line. Start engine work during last deep cast (pre breakfast). Underway again around 1pm, headed for moorings. Ice VERY light (max speed 17 knots), so rerun deep CTD stations on the mooring line.
Sunday 15th *CTDs 101-102* Rerun deep CTD stations on the mooring line. Drive past CBL-C as ice quite heavy. Start mooring recovery at CBL-B at first light. Mooring up under ice, but recovered by skillful ship maneuvering and towing the mooring from the small boat. Proceed to CBL-A but ice coverage ca.10/10th (if thin). Return to CBL-C, and recover, after ranging from small boat. Polar bear footprints at CBL-B and CBL-A mooring sites.

Monday 16th *CTDs 103-106* CTD through the night. At CBL-A at first light. Recover after many hours of waiting for ice drift. (More Polar Bear footprints and a walrus.) Two CTDs to complete rerun of mooring line. Head to Barrow.
Tuesday 17th Aagaard and Johnson flown off to Barrow by ship's helicopter. Head north in open water to do CTD line up Northwind Ridge.
Wednesday 18th *CTDs 107-111* Recommence CTDs west up Northwind Ridge. Problems with L-ADCP. Open water, significant ship drift during stations.
Thursday 19th *CTDS 112-119* Continue CTD line into southern end of Northwind Abyssal Plain. Station 114 is intercalibration cast with Canadian cruise. Turn WSW after station 116 to run CTD and XBT section back up onto the slope.
Friday 20th *CTDs 120-126* From shallowest station, run CTD and XBT line down slope towards WNW. Since Barrow, all but the last few casts have been in open water. End of science at 2100 local. (Last CTD on deck at 2055.)
Saturday 21st Head back for Barrow, science party packing up. Run final XBT section across slope on this last leg. Evening skits.
Sunday 22nd Packing up.

Monday 23rd Science party transfered to Barrow by helicopter, Polar Star standing some miles off to the south west. Some of science party depart on evening flight. (During our absence, many polar bears have been sighted in Barrow.)
Tuesday 24th Grimes and Woodgate revisit Middle and Elementary schools. Remainder of science party deparst Barrow on both morning and evening flights.

OCTOBER 2002
Monday 7th Polar Star arrives back in Seattle.
Week 21st-25th Polar Star offload in Seattle.

In transit Reports from the Polar Star

Report from Chief Scientist, Rebecca Woodgate, August 27, 2002

Greetings from the Chukchi Sea, sitting in ice and sun. We've been out 48 hours and already it seems like a lot longer (though not in the bad sense!) We've been busily at it, setting up instruments and did the test casts on the CTD last night. There was a little preening still to do, but now we are "good to go" and just need to finish the transit through the ice to the first station.

The Polar Star arrived Monday as planned, but stood 15 miles off the coast due to ice. The helicopter transfer over to the ship on Monday, August 19 was as fun as ever, and we've not really stopped since. It's good to be out, after kicking our heels in Barrow for the last few days. Gail and I did the rounds of the school classes. GREAT schools, very modern and bright, and keen teachers and kids. Small classes, and a great interest in science. Oceanography for 7 year olds - will we be forgiven for likening the complex CTD-Rosette to a complicated bucket? Or the mix of waters in the Arctic (the Atlantic and Pacific) as being the equivalent of American (i.e. all now Arctic, but with their origins somewhere else). Or the fact that we can trace the waters from either ocean just like how they could tell that I "wasn't from around here"? Fun stuff, waving around globes and maps, though unlike at a conference, the school bell is the ultimate deadline.

The coast in Barrow was solid with old broken-up floes that had just blown in a few days before. The locals were out fishing, standing on the ice just a few feet from the shore, with lines on short rods. They'd stand for hours, but I never saw a catch. We DID see polar bears though, one out a few hundred yards on the ice, and obviously with a mission of his own. Also, a mother and cub, this time on land, and prompting the police to close the road so the bear and her cub could be encouraged back out on the ice. A science talk took us out for a walk on the tundra, which isn't as barren as one might expect. Browns now, but evidence of flowers from the summer, reminded me of Scotland, though a LOT flatter, and you get less caribou in Scotland. Rebecca

Report from Chief Scientist, Rebecca Woodgate, August 22, 2002

Gail's been having email problems, but that should be solved soon. Gotthe second CTD cast in today, and progressing to the 3rd. We're tight on people till the moorings are all in. Should start that tomorrow am. Fingers crossed. The ice is a variable feast, but so far so good. Jim was right about the ship shaking though! Lots of sweet corn, peas, pasta, meatloaf, pork tonight, anything you can think of for breakfast and a line of cakes that gets better every day. All is well. Rebecca

Report from Chief Scientist, Rebecca Woodgate, August 27, 2002

Greetings from the Arctic ice - supposedly 9-10/10ths ice cover. Despite that forecast, we have frequently been lucky enough to find large leads of open water through the ice, and can make a heady 7 knots (equivalent to a reasonable jogging pace) or more. Here's hoping that continues. When we really hit the 9-10/10ths, we'll be making more like 2 knots (a country stroll pace) or less. Barrow is now just over a week and 500 miles behind us, the latter as the crow flies (well, ok, Arctic tern perhaps, though we've not seen many), not according to our track which is nearer 1000 miles, and our experiences. We are in the southwestern most region of our CTD box, with the three moorings behind us in the water, recording stoically (I assume) until our return.

From Barrow we headed straight to the mooring and CTD line - an ambitious start with both mooring and CTD teams working long hours to get both operations up and running quickly. The ice was kind to us on the mooring deployments, though finding open water to deploy was still a reasonable challenge. We deploy the moorings with the ship nuzzled against the ice, and drifting with the wind, so, since we are aiming for certain water depths in a region of moderately steep (and poorly known) topography, determining the drift is important, but tricky. Anticipating the latter, we had designed the moorings to be adjustable for water depth, and when a steady 0.3 knot across-isobath drift turned into dead calm, we were glad

we had the flexibility! So, now all three moorings are out, sampling the temperature, salinity and velocity structure of the Arctic Ocean boundary current hourly. Already thoughts turn to the recovery at the end of the cruise. Much of the ice near the mooring site was "rotten" (1st year ice, melting away under solar insolation), so we can hope for at least equally open water on our return in a month.
Since the moorings, we have swung into a CTD routine. Two 12-hour watches cover us through day and night, though with the midnight sun (or midnight fog) the distinction is really one of meal timings. We are now approaching our 17th cast. Winch issues temporarily slowed the CTD casts, but we now have a work-around and are back up to the maximum drop speed (60 m/min) the CTD likes, and we are set to CTD and sample from now till we get back to the moorings. I'll write more next time on the water sample programs. I wouldn't like to get ahead of the reports from our teacher! I hope you've looked at the website, especially the "getting dressed for being sampling cop" section. And there was me thinking Gail was just liking the food (which is, as I know you'll be wondering, very good, especially the cakes!). All's well out here. With the willing help of the ship's crew, who are marvelous, we are well on our way! Look after the mainland for us.
Best regards, Rebecca

Report from Chief Scientist Rebecca Woodgate, August 31, 2002
A quick update for the weekend. CTDing away here merrily. The ice suddenly opened up. They did casts last night where there was no ice to be seen and ship's roll started to be noticeable! We topped 14 knots at times today, but now are back to the more usual 5 or 6. She's a BIG powerful ship. While other icebreakers will fall into a crack they make in the ice, changing their heading to go with the crack, the Polar Star just carries straight on. Must run. CTD just on deck.
Take care all, Rebecca

Report from Chief Scientist Rebecca Woodgate , September 1, 2002
Greetings from the Arctic! All well and things are going smoothly. There's been a substantial amount of open water and wide leads, and we've been making good time. Our cruise track would look a little odd without knowing about the leads, which take us significant distances from our direct route. Still, it makes more sense to move faster in a circuitous manner than force our way along a dead heading. The CTD casts progress at a fine pace. The chemical analyses run around the clock, and we are taking advantage of our promising progress to catch a few more CTD profiles in key spots.
The data are "lovely"- very clean, no ship roll and almost zero interference, a surprising amount of fine structure temperature/salinity steps, and other intriguing things. I'm not going to hypothesis on unfinished sections, but it's turning out very nicely so far. I sit now in the "science library", a computer lab one deck below the working (our CTD) deck. A TV screen in the corner acts as a repeater for the outside cameras (pointed forward, aft, down on the CTD) and the bridge navigation screen. A feed from the ship's science data system gives me real time depth and course information, so I can work at the computer whilst still monitoring exactly how we are getting on!
You really have to remind yourself to go outside (other than to launch the CTD). Weather is definitely getting colder. During the cast, a thin layer of ice starts to form on the water and recently we've had dustings of snow. That helps to remind you where you are, especially when we've done casts in leads so big you can hardly see any ice! SO - all well here. Hope things are well back on dry land! Rebecca

Report from Chief Scientist Rebecca Woodgate, September 10, 2002
Greetings from a foggy/sunny Northwind Ridge! Tuesday and the 77th cast. We have been making very good progress, and are bringing in water samples just as fast as we can analyze them. The light ice has upped the work pace considerably, and the science team and the crew are answering the challenge marvelously. We've completed our deepest cast, some 3800m down to the foot of the Northwind Ridge and the Canadian Basin, and are now CTDing our way south back to the mooring site, with a little time in hand for some extra casts if things continue well.
This early morning brought our first serious mechanical problem - a leak in part of a cooler for the port shaft, but a long night/morning from the engineers has us back in operation having lost only half a day. (We have 3 shafts, each of which turns one propeller, so don't worry, we'll get home ok.)
The data continue beautiful! We have cut forward and back across the boundary current core in the coastal and ridge sections, over the Mendeleev and up and down the Chukchi Plateau. The variety of structure is unexpected and the nutrient and CFC data will prove an important part of solving the puzzle. The Pacific waters are also showing intriguing variations, which in idle moments (had we any) one could link to the wildlife. In the wee hours of the morning a polar bear with 2 cubs approached the ship - the first sighting in weeks.
With the Scripps team's onboard chemistry analysis and data quality control, it's like being a kid in a candy shop, as every new day brings newly processed and calibrated CTD and bottle data. The CFC team has two analysis instruments up and running, and is always hungry for water. They also tested the Styrofoam head brought aboard by our teacher to illustrate the effects of deep-sea pressure. Since it was given a clean bill of health, the head went down on the deepest station, along with Styrofoam cups colored by the school kids in Barrow and people aboard. I'll leave you to speculate on the results till the photos make the website!
Our "teach" is back on form after a couple of days of sickness, which gave others the chance to be "reporter". It seems there is nothing to which our students won't turn their hand to. They are proving an indispensable and enthusiastic part of the team. Hump day has come and gone and with it, the Pine Wood Derby (a model car race, in which each competitor is given a block of wood and some wheels and has to build the fastest car they can). The science party made a very respectable showing, with three entries. Though we didn't win for speed, the CFC team won for style, with their model of the Polar Star, complete with helicopter.
So all well in the high Arctic. I hope this finds you all as well as it leaves us, Best regards, Rebecca

Report from Chief Scientist Rebecca Woodgate, Sunday 22nd September, En route to Barrow
A quick closing email to wrap up the cruise. We are in the final throes of packing and tomorrow morning the Polar Star's helicopters should sweep the science party back to dry land. We've had an extremely busy and a productive 35 days.
The moorings are safely recovered, and the data looks good. Our hopes for light ice were unfounded, but a combination of waiting and extremely skillful ship driving proved successful.
We brought our 126th CTD cast onto deck late Friday night, 25% more than we had originally hoped for. The lightness of the ice allowed us to substantially increase our spatial coverage of the Chukchi Borderland region, with extra sections over the Northwind Ridge

and the Chukchi Plateau. A first look at the data shows a rich variety of features, pathways of Pacific waters, variability in Atlantic water structure, and much more. It's a gem of a dataset!
It's hard to resist statistics on something like this. We brought up around 30 tons of water for samples. We've analyzed over 2500 CFC samples, 2662 nutrient tubes, 2999 oxygen flasks, 3066 salts, taken almost 1000 samples each for Barium and Oxygen-18 isotopes, around 100 for Iodine and Helium, and ca 30 for Cs. In total, the Rosette traversed almost 250 miles vertically, the equivalent of driving from Seattle to Vancouver and back. I could continue, but I won't! Instead, back to the packing and then to dry land!
With best wishes from the Arctic, Rebecca

UNOLS Report

****

13) MEETING OF PLANNED OBJECTIVES 100% or more
Objectives - 5 week physical oceanographic research cruise, including
- CTD casts (target 100)
- 3 mooring deployments
- 3 mooring recoveries

in a region with a climatological ice cover of 7-10/10ths.
Completion - 126 CTD casts
- all moorings successfully deployed and recovered. The cruise expectations were significantly exceeded, due to the dedication, enthusiasm and tireless efforts of the Polar Star crew and the science team and the exceptionally light ice cover in the region. The team work and combined skills of the ship and science crews allowed us to overcome the few technical hitches experienced at sea, such that their impact on the science was minimal/zero. These hitches were:
- issues with the winch controller
- issues with interference on the CTD cable

These, and other suggestions, are discussed below. This list should not detract from the extremely positive and successful experience we have had working with the Coast Guard and the Polar Star.

****

14) SCIENCE PARTY
N/A

****

15) SHIP OPERATOR PRE-CRUISE ACTIVITIES/SHORE SUPPORT Excellent
The support we received from both the Science Liaison team and the crew of the Polar Star were excellent. Few points:
1) The planning meetings were exceedingly useful and productive.
2) We are particularly grateful for the speedy acquisition of the Knudsen echosounder so close to the sailing date of the Polar Star.
3) Some email queries to/from the ship got lost stressing the importance of a dependable email system (see below).
4) It would be helpful for planning purposes (including at the proposal writing stage) for yet more information on the ship to be generally available, for example on the website. Even experienced sea-going PIs could be unfamiliar with the ship and the practices necessary to the Polar Class (e.g. hub purification). The "Welcome Aboard" document is an excellent example of pre-cruise information. The access to dimensioned drawings of labs is also very useful, and could be extended to include photos of the laboratory spaces.

****

16) SHIP OPERATOR EQUIPMENT AND MSTS Excellent

With the exception of

- the winch controller system, with which we experienced significant difficulties during the cruise, particularly intermittent winch payout. The problem was suspected to be a full computer hard disc, but rather than experiment we opted to use the manual controls on the winch. This worked well when combined with some extra wiring to allow readout of 'wire out' and rezeroing of 'wire out'. We understand the winch control system is to be replaced during the current yard work.
- significant electrical noise induced on the CTD signal wires that transit from the winch slip rings down to the CTD deck unit (Forward Wet Lab). The CTD telemetry line could be rerouted and separated from potentially noisy EMF areas. (This fix was installed temporarily during the CBL cruise.)
- lack of reliability of the email system (both Inmarsat and Iridium). Both worked at times. However, even within range of the Inmarsat footprint, there were several incidences of incoming and outgoing emails not being delivered. The Iridium worked spasmodically. Also, the combination of different operating systems in the science library led repeatedly to serious faults in email accounts.
- during the CBL cruise, science email/internet access was set at 2 hours a day out of the Coast Guard's 24hr access, since shipside or the scienceside could not be connected simultaneously. Whilst this worked reasonably enough for the CBL mission, the issue of increased science internet access could be very important for other cruises.
- poor readability of the bridge waypoint video display on monitors elsewhere on the ship. To overcome this, the science party set up a Nobeltec navigation program on a separate computer in the wetlab, linked to a separate GPS system mounted near the CTD cast deck. This independent system was an excellent tool for cruise planning and it might be worth the Polar Star considering such a system as a tool for science.

Things that were particularly useful

== the Knudsen echosounder

== the science data system - this worked well and could usefully be extended (e.g. to include winch parameters), and made more real-time (an issue for some of the navigation parameters), more reliable (e.g. the data stream when accessed from remote locations would frequently crash) and more user-friendly (e.g. so that changing one variable does not require taking the whole system down).

== the TV screens repeating the camera views (could this be extended to include winch parameters e.g. wire out?)

== fume hood in wetlab (which appears to vent back into the wetlab)

Other suggestions for improving the science set up

== junction boxes could be installed at the winch and in the lab for user access to the CTD telemetry line (e.g. readouts of wire out, ways of zeroing winch, etc.)

== Forward Wet Lab

- some manner of accessing DI water directly in the wetlab (DI water is currently only available in the engine room)
- more electrical outlets (120VAC)
- more network hubs
- better access to science data (GPS, MET and Winch readings)
- better access through exterior bulkheads for temporary cruise wiring.
  (i.e.. for cables run from the lab to the rosette room or out to a weather deck)
- dedicated winch operator/lab communications, instead of VHF radios.

- dedicated science storage space in lab (e.g. drawers/shelves/cupboards) Currently available space is mostly full with ship's equipment.

== Science Library - this is a nice science space, which would benefit from more (intercompatible) computers (see comments above on email)

****

17) SCHEDULING Above average

The final scheduling arrangements worked very well. Whilst none of us, I suspect, wish a repeat of the months of uncertainty in the spring when it was unclear what ship would be available for the mission, we realize that this situation arose from complex circumstances, and was (hopefully) unique.

****

18) SAFETY ON BOARD Excellent

We were fortunate in having calm seas for the launching and recovering of the CTD rosette. Given the confined cast deck, it is easy to see how the current operation gets shut down in bad weather despite the routine use of tag lines and poles.

Some suggestions for the CTD operations:

- use of a rigid docking mechanism or arm to stop the rosette from swinging during recovery/deployment in rolling seas. (There are reputedly some CTD launching systems used on NAVO ships which might be suitable.)
- a more substantial line/barrier to stop people from going into the ocean during launch and recovery. (This would probably require lifting the rosette higher during these operations, which might require substantial modifications to the system.)
- positioning of a life ring nearer to the rosette launch pad

****

19) OFFICERS and CREW Excellent

.or higher. The enthusiasm and "can-do" attitude of the crew, especially the MSTs, Captain and Ops made the cruise the great success it was. Any concerns from the science team were solved promptly and courteously. In every circumstance, the ship went the extra mile to help us out.

****

19) VESSEL AND EQUIPMENT/CONDITION/LIVING SPACES Above Average/Excellent

Given the original design of the ship was not for research, the facilities aboard the Polar Star are exceedingly good. Naturally, more science space would be desirable, (lab space, deck space), but obviously that is not easily realizable. For the CBL cruise, a separate laboratory container was mounted on the port deck, and connected for power, phone, etc. This worked exceedingly well.

To focus on improvements that would be achievable without structural work:

- winch controller system (see above)
- suggestions for wetlab (see above)

Living Spaces

- The "Welcome Aboard" document is wonderfully helpful. Could it also include some maps to help with orientation?
- the preliminary introduction to the ship is very good, and conveys a lot of information. The cribsheet handed out is a good memory jogger and could usefully be extended. Signs in staterooms (e.g. reminding of what is/is not allowed down the toilets; location of cleaning supplies; expectations of cleaning) might be valuable.
- mixing scientists and crew in staterooms did not always work out smoothly.
- more substantial mattresses would be appreciated, as would more hooks and towel racks in staterooms.

These points are raised only for future reference. I would emphasis that the Polar Star responded fully and promptly to our concerns here, as in all other instances.
General Points
- the health requirements for the cruise were far less stringent than those frequently required for participation in polar field work. For operations this remote, these requirement should be revised, perhaps to include a medical examination within the last ca.12 months.
Number of days lost to:
Weather - none
Ship's mechanical systems - 1-2
Ship's scientific equipment - none
User scientific equipment - none
Medical issues - 2

14. ACKNOWLEDGEMENTS

The funding for this cruise was provided by NSF-Arctic Natural Sciences (OPP-0117480). We are indebted to the Captain and crew of the Polar Star, for their enthusiastic, energetic and professional support of this cruise, which made it both extremely successful and enjoyable. Our thanks go also the USCG Science Liaison LCDR April Brown and Dave Forcucci for answering all our needs pre-cruise and to the Barrow Arctic Science Consortium (BASC) for their support of pre- and post-cruise logistics in Barrow.