Cruise Report

R/V *Thomas G. Thompson* Cruise TN246

DAS-2009-062 and DAS-2009-077

15 January 2010 to 5 March 2010

Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean

DIMES Cruise US2

Survey Cruise

Chief Scientist
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(Photo by K. Newell, U. Washington)

12 December 2011

Acknowledgements

Captain Phillip Smith died after a few days on this cruise. We express our sincere sympathy to his family and to the crew, many of whom had sailed with him for years. The tragedy was handled with both great competence and dignity by the crew. Arrangements for a ceremony of remembrance in Punta Arenas and return of Captain Smith's remains to his home were handled efficiently and sensitively by Daniel Schwartz and Marine Operations at the University of Washington, and by the Chilean authorities. First Mate John Wilson took over expertly as captain when the cruise resumed.

Marine Operations at the University of Washington were helpful and patient in preparing for the cruise. We thank the science party, listed in Appendix A, and the ship's crew, Appendix B, for superb help with a cruise that was severely challenging on many fronts.

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Introduction

This report summarizes the data collected during the cruise. The data sets are on the accompanying DVD, where there is often more detailed explanation of the files. The following summary is organized by data type. Near the end of each section is the name of the directory on the DVD for the data described. The data files on the DVD are also accessible and will be maintained on the DIMES web site at http://dimes.ucsd/edu. Chief Scientist Jim Ledwell of WHOI is responsible for the report (jledwell@whoi.edu). However, another person is often listed at the end of a section as point of contact for a data set or instrument, because that person had primary responsibility for those data and can give advice and assistance with the data.

Objectives

DIMES (the Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean; see http://dimes.ucsd.edu) is a study of mixing in the Antarctic Circumpolar Current (ACC), and the dynamics driving that mixing. The objectives of the present cruise, TN246 on R/V *Thomas G. Thompson*, were to survey tracer that had been released a year earlier in 2009, to survey fine-structure and microstructure using free-falling profilers, to release a number of RAFOS floats to study isopycnal mixing, to deploy two sound sources to augment the array for the RAFOS float program, and to deploy EM-APEX floats and Shearmeters to measure fine-structure over long time periods. The target for most of the floats and for the tracer release was the 27.9 kg/m^3 neutral density surface, located in the deeper region of the Upper Circumpolar Deep Water, one to two hundred meters below the oxygen minimum layer. This surface is at a depth of about 2000 m north of the Subantarctic Front (SAF) of the ACC, about 1500 m deep between the Subantarctic Front and the Polar Front (PF), shoals to less than 1000 m depth south of the Polar Front and blends with the mixed layer near Antarctica in winter. Some of the RAFOS floats were programmed to follow a shallower isopycnal surface at neutral density 27.3 kg/m^3, about midway between the tracer isopycnal and the sea surface.

Cruise Track

Punta Arenas, Chile, was the start and end port of the cruise. The cruise was interrupted after deployment of the first sound source mooring by the tragic death of Captain Philip Smith on 19 January 2010, due to illness. We returned to Punta Arenas with his remains, and headed out again after a ceremony and coroner's report were completed. The activities along the ship track are explained in the caption of Fig. 1.

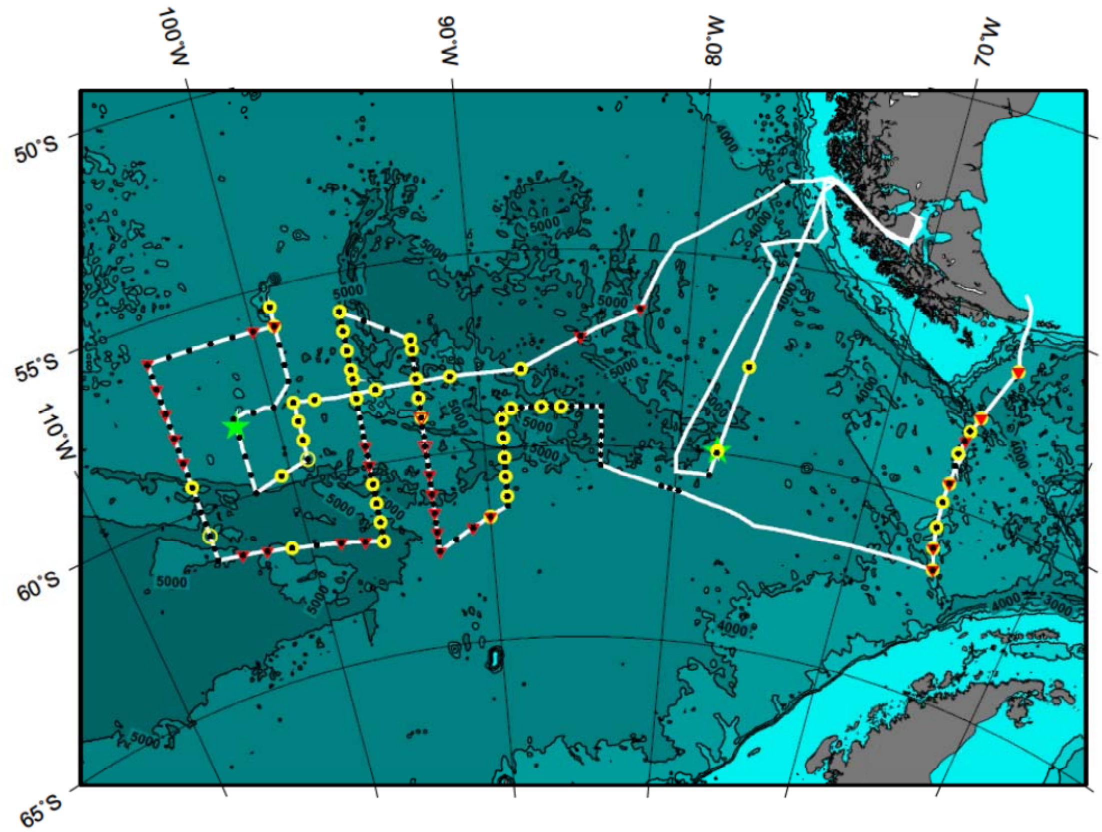

Fig. 1. Cruise track and stations. CTD/LADCP stations (black dots), HRP stations (yellow circles), and DMP stations (red triangles) occupied during Cruise TN246. The green stars mark the positions of two sound source moorings deployed during the cruise. Samples were taken for tracer at all but the Drake Passage CTD/LADCP stations. Floats were launched along the line at 105°W.

Underway Measurements

Meteorological parameters, surface seawater parameters, navigation data, and bottom depth were recorded throughout the cruise. The quality of these data has not been extensively checked, but many of the sensors seemed to produce reasonable values. The air temperature sensor was not functioning for much of the cruise, however. These data and a guide to them are on the DVD in \Underway. Contact Jim Ledwell for further information.

Both a narrow-band and a broad-band 75 khz hull mounted ADCP were running along most of the cruise track. The data from these instruments have been processed by Jules Hummon at the University of Hawaii. The results of her work are on the DVD in \ADCP. Contact Jim Ledwell for further information.

Data return from the 300-kHz Multibeam bathymetry system on board was poor for depths greater than 4000 m and at ship speeds greater than 8 knots or so. The ship was often traveling at speeds of over 11 knots and over depths greater than 4000 meters so that the multibeam bathymetry is only likely to be useful for those times when we were surveying a site for a mooring deployment or a microstructure profile near a seamount or ridge. The quality of the multibeam data has not been checked, but these data are available to the public at http://www.marine-geo.org/tools/search/entry.php?id=TN246. There is also a tool at that site that enables the viewer to zoom into the cruise track and look at the available bathymetry from the archive at high resolution. Contact Jim Ledwell for further information.

CTD/O2/LADCP/Rosette Stations

CTD/O2/LADCP/Rosette stations were occupied all along the ship track to search for tracer, measure the hydrographic and shear structure, and to obtain temperature and conductivity calibration data for the various free-falling profilers (black dots in Fig. 1). The maximum depth of the CTD casts was usually 2000 meters, although several of the early casts went to 3000 meters, and a few casts, spread throughout the cruise, went to within 50 meters of the bottom for calibration of the sensors. Samples were taken for tracer at all of the CTD stations, with the exception of those on the transect across Drake Passage near 65^{o}W toward the end of the cruise. Evidence was strong that no tracer was to be expected in Drake Passage at this time. The method of calibrating the CTD and oxygen sensors is in Appendix C, and the CTD casts are listed in Appendix D. The CTD/O2 data are on the DVD in \CTD. Contact Jim Ledwell for updates and further details on the CTD/O2 data.

The LADCP velocity profiles measured during the R/V *Thompson* Cruise TN246 were obtained using RDI WorkHorse 300 [kHz] ADCPs, one looking upward and the other downward. Bottom tracking was not possible at most stations because the CTD package did not come close enough to the bottom. Details on the LADCP data and the data themselves are on the DVD in \LADCP. Contact Andreas Thurnherr at Lamont-Doherty Earth Observatory (ant@ldeo.columbia.edu) for updates and further details.

XBT/XCTD Profiles

Three types of expendable probes were used on the cruise: Type TF XBTs (Expendable Bathythermographs), which record temperature and depth to 1000 m depth; Type T5 XBTs, which record temperature and depth to 1800 m; and Type C3 XCTDs (Expendable CTDs) which record temperature and conductivity to 1100 m depth. Depths are nominal. Not all probes recorded to their full depth. The drops are listed in Appendix E, and the data are on the DVD in \XBT_XCTD. Contact Sarah Gille at Scripps Institution of Oceanography (sgille@ucsd.edu) for updates and further details for the XCTD data, Jim Ledwell for the XBT data.

Fine- and Microstructure Sampling

Two instruments were used during the cruise to sample fine- and microstructure, the High Resolution Profiler (HRP) built by Woods Hole Oceanographic Institution (WHOI) and the Deep Microstructure Profiler (DMP) built by Rockland Scientific in British Columbia. Also, an Expendable Microstructure Profiler (XMP) from Rockland Scientific was tried out, with promising results. A total of 49 HRP deployments, 30 DMP deployments and 5 XMP drops were made during the cruise TN246 (Fig. 1). Data from these instruments are still being prepared for distribution. A summary of results from the stations in the Pacific, i.e., excluding Drake Passage, is in Ledwell et al, 2011, which is included on the DVD. Contact John Toole and Lou St. Laurent at Woods Hole Oceanographic Institution for updates and further details (jtoole@whoi.edu and lstlaurent@whoi.edu).

RAFOS Program

Two sound sources used for tracking RAFOS floats were deployed early in the cruise to supplement the six that had been deployed in 2009 (Fig. 1). Four SOLO floats deployed along the float line at 105°W were programmed to come to the surface every 10 days and relay data via System Argos. These floats are equipped with RAFOS receivers and were used to evaluate the functioning of the sound sources. They are now part of the global fleet of floats in the ARGO program (see http://www.argo.net).

102 RAFOS floats were deployed along the CTD line at 105°W, starting at 56°S, and every 20 n. miles south to 61°20'S. These floats will come to the surface two years after deployment. Two triplets of floats were deployed at each station. One triplet was programmed to drift on the 27.9 kg/m^3 neutral density surface, on which the tracer was released. The other triplet was programmed to drift on the 27.3 kg/m^3 neutral density surface, which is about 800 m deep between the SAF and PF but which shoals towards the sea surface south of the Polar Front. An additional three floats, with a 300-day mission, were deployed in Drake Passage, at 59°25.11' S, 66°04.55' W. Contact Kevin Speer at Florida State University (kspeer@ocean.fsu.edu) or Breck Owens at WHOI (bowens@whoi.edu) for information about the float program.

EM-APEX Floats

Six EM-APEX (Electro-Magnetic Autonomous Profiling Explorer) Floats were released along the cruise track. These floats are equipped with electromagnetic current meters and CTDs. They cycle between the surface and 2000 dbar every 3 days, obtaining shear profiles. Between profiles they rest at 1500 dbar for 2 days. Their data are transmitted by the Iridium system every time they come to the surface. Some results from EM-APEX floats deployed in 2009 are in Ledwell et al, 2011, which is included on the DVD. Contact James Girton at the Applied Physics Lab, University of Washington, (girton@apl.washington.edu) for further information on the EM-APEX program.

Shearmeter Floats

Four Shearmeters designed by Tim Duda (WHOI) were brought on the cruise. One of these produced data for about 10 days as a test, but could not be recovered due to heavy weather. The other deployments did not return data for various reasons. One Shearmeter was not deployed due to a malfunction and was brought back to WHOI. The other two Shearmeters were deployed but did not return data. Contact Timothy Duda at WHOI (tduda@whoi.edu) for further information on the Shearmeter program.

Tracer Observations

Tracer profiles were obtained from the CTD/Rosette by tripping approximately 20 of the Niskin bottles at intervals of 15 meters in depth, centered near the potential density surface of the tracer release. Figure 2 shows the column integral of tracer at each station west of 75^{o}W. Virtually no tracer was found east of 80^{o}W.

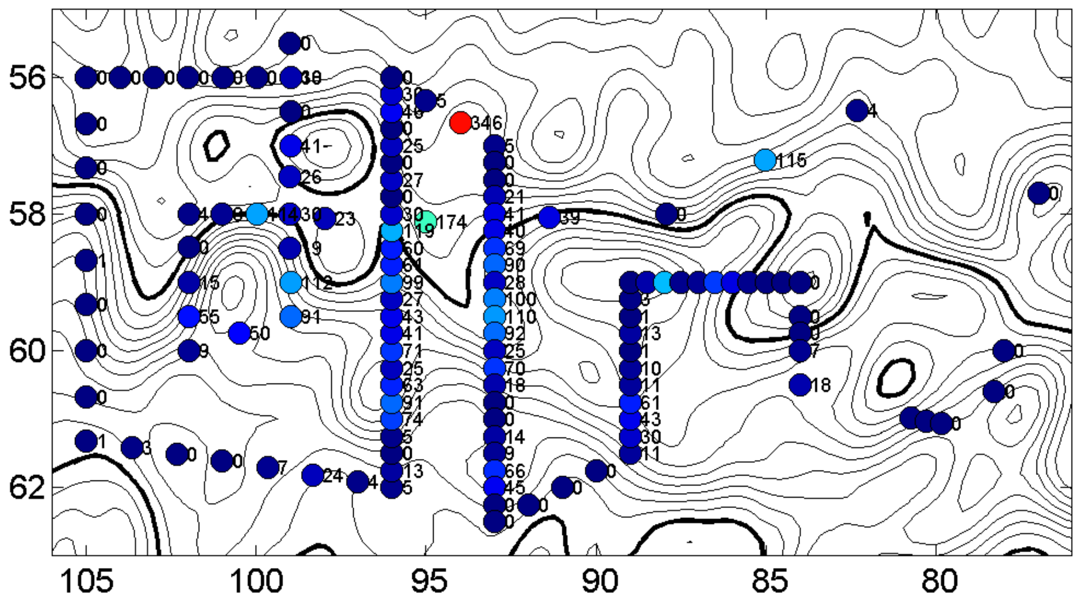

Fig. 2. Tracer survey. The numbers to the right of the stations give the column integral of tracer in units of 10^{-11} mol/m^2. The color indicates qualitatively how much tracer was found. The black contour lines are of sea surface height at intervals of 5 cm.

The distribution of tracer in density space was estimated by interpolating each profile to a uniform potential density grid, and then averaging over all the profiles. At the same time a plot of the average depth as a function of density may be made. Using the relation between density and mean depth the mean tracer profile can be transformed into depth coordinates (Fig. 3).

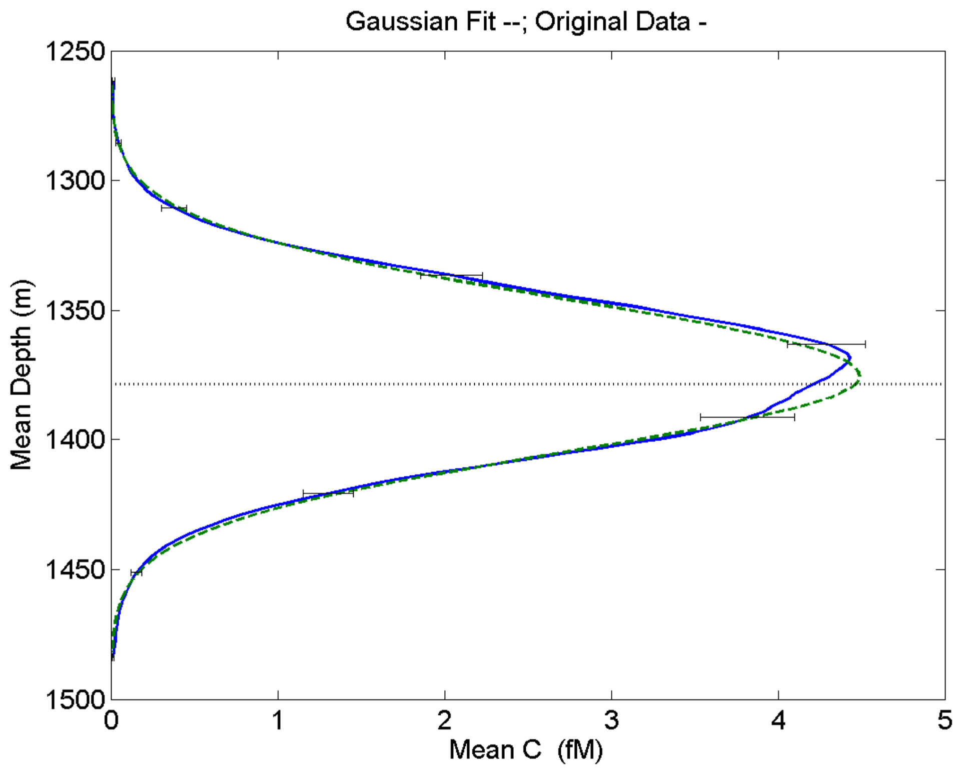

Fig. 3. Distribution of tracer with depth (solid curve), after averaging as a function of density and transforming density to depth using the mean density profile. The error bars envelop the range of shapes of the individual tracer profiles in a 1-standard deviation sense. The dotted line is at the estimated target for the tracer release. The dashed curve is a Gaussian function which best fits the observations, in a least squares sense.

A preliminary estimate can be made of the diapycnal diffusivity of the tracer k_z which brings the initial profile obtained in February 2009 to this mean profile a little over a year later by fitting a Gaussian curve (Fig. 3). The formula is simply:

$$k_z = 1/2\,(\sigma_2^2 - \sigma_1^2)/(t_2 - t_1)$$

where $\sigma_{1,2}$ are the standard deviations of Gaussians fits to the initial and final profiles, and $t_{1,2}$ are the initial and final times of the surveys. We use a tracer-weighted average time for t_1 and t_2. The resulting estimate is:

$$k_z = 1.3 \text{ x } 10^{-5} \text{ m}^2\text{/s}$$

A more elaborate 1-D advection diffusion model has also been run to estimate k_z, with essentially the same result (see Ledwell et al., 2011, included on the DVD).

Tracer data are on the DVD in \Tracer. Contact Jim Ledwell at WHOI (jledwell@whoi.edu) for further information on the tracer program.

Data Use Policy

Please consult with Jim Ledwell or with the originator of a particular data set before working with the data from this cruise with the intention of publication. They will be happy to consult on questions related to the data. Collaboration on research and publication should be discussed with them early in the process of working with the data.

References

M. C. Gregg (1999), Uncertainties and limitations in measuring small ε and χ_T, *J. Atmos. Oceanic Technol.*, *16*, 1483–1490, doi: 10.1175/15200426(1999)016<1483:UALIMA>2.0.CO.

J. R. Ledwell, L. C. St. Laurent, J. B. Girton, and J. M. Toole (2011), Diapycnal mixing in the Antarctic Circumpolar Current, *J. Phys. Oceanogr.*, *41*, 241–246, doi: 10.1175/2010JPO4557.1.

T. R. Osborn (1980), Estimates of the local rate of vertical diffusion from dissipation measurements, *J. Phys. Oceanogr.*, *10*, 83–89, doi: 10.1175/1520-0485(1980)010<0083:EOTLRO>2.0.CO.

Appendices

Appendix A. Cruise Participants

Patrick Neil A'Hearn, UW, Marine Technician
Angel Ruiz Angulo, LDEO, Scientist
David Ciochetto, WHOI, Technician
Gillian Damerell, UEA, Grad Student
Ken Decoteau, WHOI, Technician
Catherine Grendi, Catholic University of the Holy Conception, Chilean Observer
Brian Guest, WHOI, Technician
Robert Hagg, UW, Lead Marine Technician
Jay Hooper, FSU, Grad Student
Leah Houghton, WHOI, Technician
Andrew Kowalczyk, FSU, Technician
Richard Krishfield, WHOI, Technician
Steve Lambert, FSU, Grad Student
Peter Lazarevich, FSU, Scientist
James Ledwell, WHOI, Chief Scientist
Thomas Aaron Morello, UW, Marine Technician
Craig Daniel Rye, UEA, Grad Student
Louis St. Laurent, WHOI, Scientist
Cynthia Sellers, WHOI, Technician
John Toole, WHOI, Scientist
Dave Wellwood, WHOI, Technician

FSU: Florida State University
LDEO: Lamont-Doherty Earth Observatory
UEA: University of East Anglia
UW: University of Washington
WHOI: Woods Hole Oceanographic Institution

Appendix B. Crew List

University of Washington, School of Oceanography

Ship: R/V *Thompson* **Cruise:** 09H/TN-246

Port: Punta Arenas to Punta Arenas **Dates:** 1/15-3/5/10

Full Name	Position
Smith, Philip Alan	Master
Wilson, John Kimball	Ch Mate
Drake, Thomas Glynn	2 Mate
Haugland, Steven Gary	3 Mate
Clampitt, Brian William	AB
Spetla, Frank Leo Jr.	AB
Worrad, Robert Donavin	AB
Hansen, Michael Lauren	AB
Piscitello, Peter Charles	AB
Machado, Ezequiel Eduardo	AB
Anderson, Terrence Sigfred	Ch Engr
Swanton, James Thomas	1 Asst Engr
Aguiar, Christina Maria	2 Asst Engr
Castner, Dominic Raymond	3 Asst Engr
Yordan, Mario Salvan	Oiler
Rowley, Russell Richard	Oiler
McCormick, Richard T.	Oiler
Gardner, Kimberly Marie	Wiper
Wicker, Sarah Lee	Ch Stwd
Balbon, Anthony Tirol	2 C-B
Singerline, Terence	Mess Attd

Appendix C. CTD/O2 Calibration

Two Seabird SBE 9*plus* CTD units were used on the DIMES US2 cruise. One was the Tracer Release Experiment CTD from Woods Hole Oceanographic Institution (WHOI) and the other was supplied by the University of Washington (UW). Both 9*plus* units were used, at different times, on the WHOI rosette frame with a SeaBird SBE 32 Water Sampler rosette pylon and twenty-two 4-liter Niskin bottles at positions 1 through 21 and position 24. The Niskin bottles were used for tracer and salinity samples for most casts and for Oxygen samples on four deep casts. For most casts the CTD was lowered only to 2000 m. A list of the casts and their parameters is in Appendix D.

Both CTD's had dual pumped C/T sensors and a pressure sensor for the primary variables as well as an SBE 43 Oxygen sensor and an Altimeter, both provided by UW. There were some instrument and sensor problems throughout the cruise and sensors and CTD 9*plus* units were changed to diagnose and correct these problems (see Cast Notes, below). Table C.1 lists the serial numbers of the sensors used for groups of casts.

A total of 149 stations were occupied during the cruise. At all but a few of these stations a CTD cast was performed. The station/cast numbers are of the form SSSCC where SSS is the station number and CC is the cast number. At most stations only one CTD cast was performed. At Station 021 only Cast 02 contains good data, and at Station 075 two CTD casts were performed. Table C.2 lists data for those casts that went close to the bottom.

Table C.1. CTD Sensor Serial Numbers and Calibration Dates

Sensor Type	**Serial No.**	**Calibration Date**
Ledwell 9*plus* Casts 00101-02001:		
Pressure	59933	31 Oct 2008
Ship's 9*plus* Casts 02102-14901:		
Pressure	0057	27 June 2008
Casts 00101-08201 & 08401-14901:		
Primary Temperature	1080	11 August 2009
Secondary Temperature	0661	11 August 2009
Casts 00101-08201 & 08501-11201:		
Primary Conductivity	224	11 August 2009
Secondary Conductivity	648	11 August 2009
Casts 11301-14901:		
Primary Conductivity	1084	21 August 2009
Secondary Conductivity	2881	09 December 2009
Cast 08301:		
Primary Temperature	1080	11 August 2009

Secondary Temperature	1085	
Primary Conductivity	224	11 August 2009
Secondary Conductivity	763	11 August 2009
Cast 08401:		
Primary Temperature	0661	11 August 2009
Secondary Temperature	1080	11 August 2009
Primary Conductivity	648	11 August 2009
Secondary Conductivity	224	11 August 2009
Casts 00301-10501 & 10701-14901:		
Oxygen	0542	05 December 2009
Altimeter	1137	Unknown
NOTE: Secondary conductivity on the CTD was often unusable. Many casts had a large difference on the upcast and after Cast 12901 the value is completely unreasonable.		

Table C.2. CTD Casts to Near the Bottom			
Station / Cast #	**Max Depth**	**MAB**	**Water Depth**
02701	4779	15	4794
07501	4912	28	4940
14101	1844	15	1859
14201	3694	15	3709
14301	1243	20	1263
14401	3876	12	3888
14501	3479	18	3497
14601	2665	20	2685
14701	3664	14	3678
14801	2730	17	2747
14901	2512	17	2529

Cast notes:

Cast 00301: The oxygen sensor was first connected for this cast.
Cast 02101: Communication errors appeared on the console and the cast was aborted.
Cast 02102: Ship's 9*plus* unit was installed.
Cast 02901: Switched the port collecting Altimeter and O2 data from 0/1 to 4/5.
Cast 04501: Problems with secondary conductivity differences on the upcast started here.

Cast 05501: An outflow tube was attached to the secondary pump, with the outflow of tube at same level as inflow to the temperature sensor.
Cast 05601: Secondary pump was replaced prior to this cast.
Cast 05701: Changed target density surface from 27.6745 to 27.678.
Cast 06101: Reterminated CTD wire after two-blocking during deployment; detached altimeter for this cast only.
Cast 08301: Swapped secondary sensors with alternates for this cast.
Cast 08401: Returned original sensors for this cast but swapped primary and secondary cables at the sensors for this cast only.
Cast 10501: Changed target density surface from 27.680 to 27.6765.
Cast 10601: Removed Y cable to O2 sensor and altimeter at the bottle; took O2 out of the primary pump loop.
Cast 10801: Replaced Y cable to O2 sensor and altimeter at the bottle; put O2 back into the primary pump loop.
Cast 11301: Replaced primary and secondary conductivity sensors with ship's sensors.
Cast 12701: Added Altimeter data to 1m and 1dbar .mat files (first deep cast).
Cast 12901: Secondary conductivity failed at 850 m on upcast; sensor not replaced.

CTD Processing

CTD data were processed using the Seabird Data Processing software. The following steps were performed for 24 hz data (.hf):

Datcnv
Wildedit
Filter
CellTM

CTD data were further processed into 1-meter, 1-second, and 1-dbar files. The additional steps performed on the .hf files were:

LoopEdit
Binavg
Derive (to compute potential temperature and potential density)

The values suggested by SeaBird were used in Filter, and CellTM. In LoopEdit all pressure reversals were excluded. The parameters actually used are always listed in the header of each file, along with the history of the processing steps applied to the file. Consult SeaBird Data Processing documentation for details.

Conductivity and Salinity Calibration

Six Niskin bottles were usually sampled for salinity analysis on each cast. For deep casts (02701 and 07502) all bottles were sampled for salinity. Salinity samples were taken directly from the Niskin bottles into 250-ml glass bottles (pre-rinsed three times prior to sampling). Samples were then allowed to equilibrate to ambient temperature (22–24^{o}C) for a minimum of 24 hrs. They were run on a Guildline Autosal 8400B salinometer with the bath temperature set at 24°C. The most recent performance evaluation check (OSIL, attached) yielded a +0.002 PSU difference. A new, sealed vial of standard seawater (Ocean Scientific International, IAPSO Std SW batch #P151 expiry date 20 May 2012) was used for each run of samples. Samples were run every 2-3 days. A check seawater sample was run at the beginning and end of each run to monitor potential drift. Sensor calculated salinities vs. measured sample bottle salinities averaged roughly 0.001–0.004 PSU difference.

The conductivity at the *in situ* temperature and pressure for each sample was calculated from the Autosal measurement of salinity. This back-calculated conductivity was compared with the original *in situ* conductivity to obtain a conductivity offset.

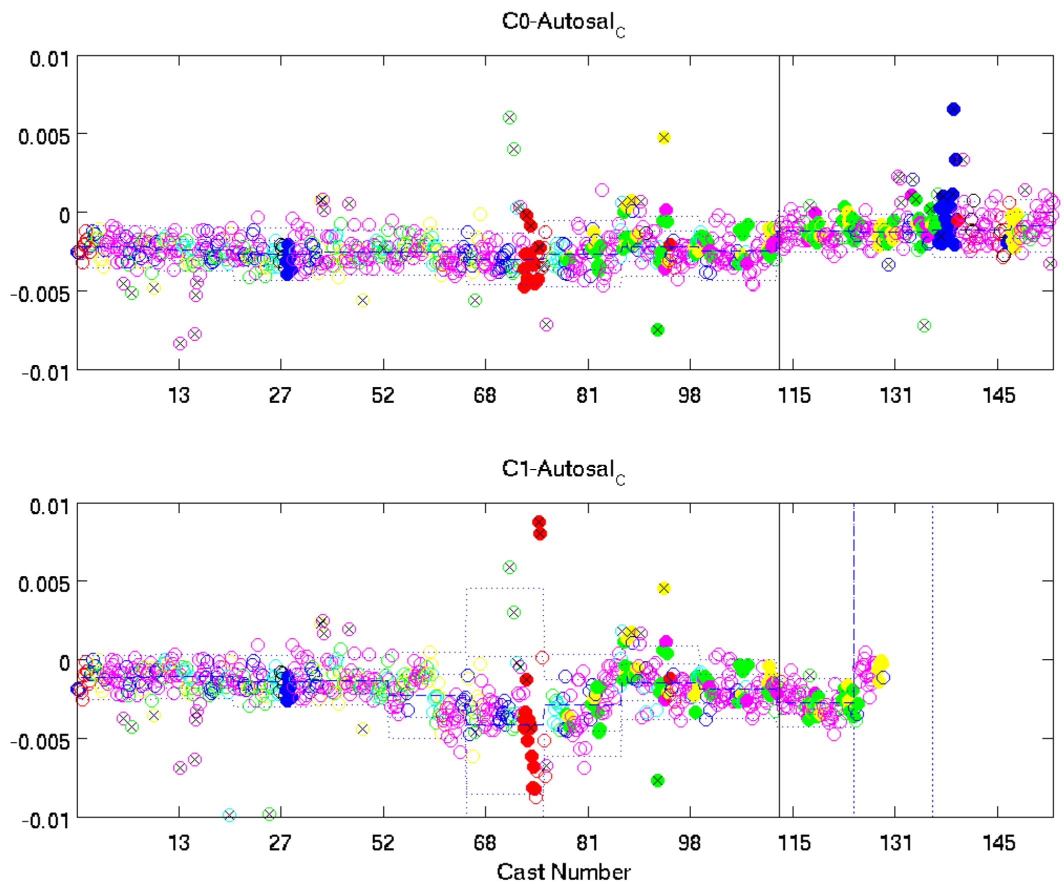

Fig.C.1. Differences (mS/cm) between the original reading from the primary (C0, upper panel) and secondary (C1, lower panel) conductivity and the conductivity back-corrected from the Autosal calibration (Autosal_C). The points marked with an 'x' were not used for the mean correction.

Figure C.1 shows the differences C0-Autosal and C1-Autosal. The vertical line indicates where the sensors were changed for Cast 11301. The horizontal lines represent the mean and ± one and two standard deviations from 76-sample averages. An ‘x’ is placed over symbols for data not considered in these averages.

The average difference for the primary conductivity (from sensor 224) prior to cast 113 (excluding cast 84 where the sensors were swapped) is Autosal – C0 = 0.00251 mS/cm.

The average difference for the secondary conductivity (from sensor 648) prior to cast 113 (excluding casts 08301 and 08401 where a different sensor was used) is Autosal – C1 = 0.00193 mS/cm.

The average difference for the primary conductivity (from sensor 1084) for casts 113 and beyond is Autosal – C0 = 0.00115 mS/cm.

The secondary conductivity sensor (2881) was not working properly for cast 113 and beyond.

Table C.3 lists the corrections to be applied to the conductivities from the primary and secondary sensors for all of the casts. The corrections should be added to the raw conductivities. This correction has been made for high level files on the DVD, i.e. for files in \CTD\1dbar_asc and \CTD\netCDF, but not for the lower level files in the other directories generated directly by the SeaBird Data Processing Software.

Table C.3. Corrections to be Applied to Conductivities

Station	Primary Conductivity		Secondary Conductivity	
	Sensor	**Correction (mS/cm)**	**Sensor**	**Correction (mS/cm)**
1 to 82	224	+0.00251	648	+0.00193
83	224	+0.00251	763	Unknown
84	648	+0.00193	224	+0.00251
85 to 112	224	+0.00251	648	+0.00193
113 to 149	648	+0.00193	2881	Dysfunctional

Oxygen Calibration

Accurate oxygen concentrations were not a high priority on this cruise. However, there was usually an oxygen sensor in the CTD/Rosette system and samples were taken at four stations for calibration of this sensor. These samples were analyzed using Carpenter’s modification of the Winkler titration method (Carpenter 1965a; 1965b). The differences between the Winkler analysis and the readings from the CTD sensor are shown in Fig. C.2, with the points distinguished by station. One can see a systematic variation with both pressure and station.

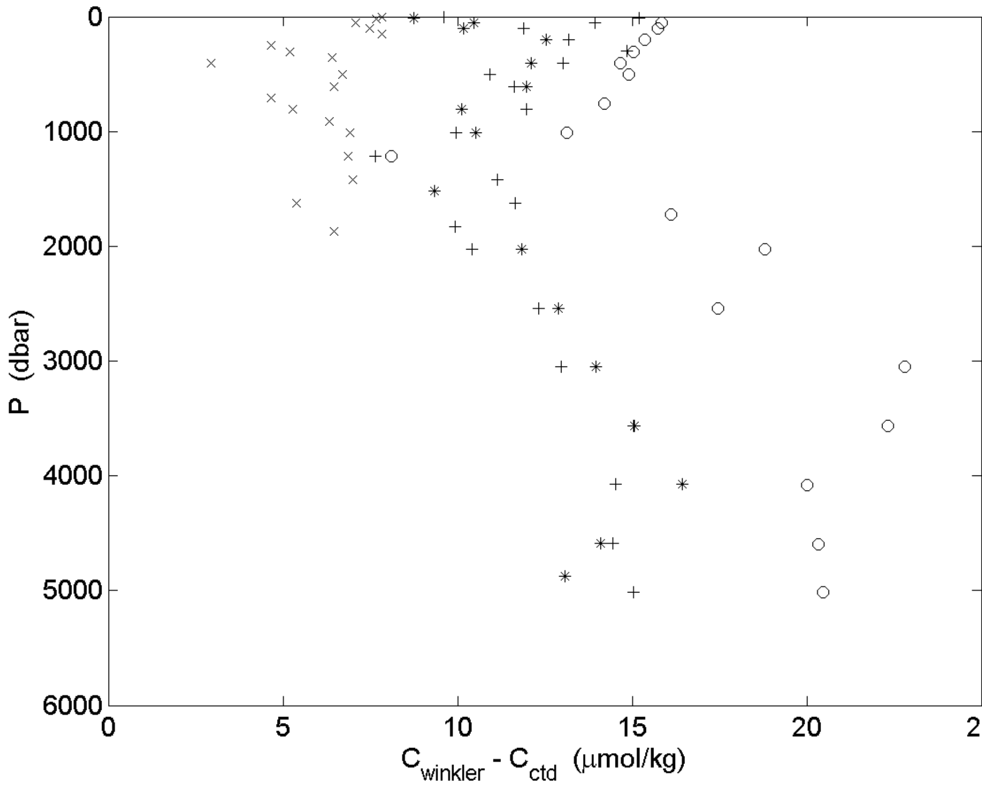

Fig. C.2. Scatter plot of the difference between Winkler analysis and CTD sensor reading versus pressure. The different symbols denote the stations as listed in Table C.4.

Table C.4. Symbols Used for Stations in Fig. C.2 and Station Locations

Symbol	Station	Latitude (°S)	Longitude (°W)
o	3	60.0003	77.9995
*	27	56.0002	98.9993
+	75	57.7510	95.9985
x	141	61.6638	65.4317

The mean difference for each station is plotted versus station number in Fig. C.3. A linear fit between mean difference and station number is drawn. It is obvious that this linear fit is poor. It is possible that the mean difference at each station, if samples were taken, would have been constant for most of the cruise, while the differences for the early and late stations were exceptionally large and small, respectively. However, we will use the linear fit to make a reasonable correction, and accept the uncertainty as relatively large.

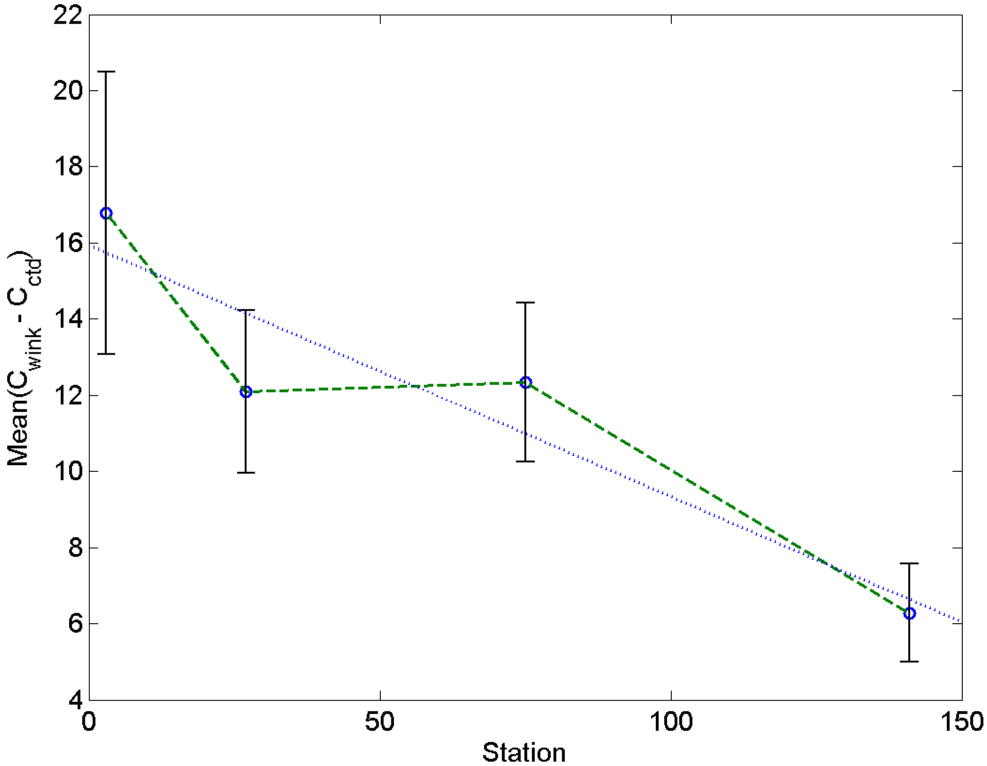

Fig. C.3. Mean difference, in μmol/kg between Winkler and CTD oxygen concentration for each station. The error bars show one standard deviation of the differences for each station. The dotted line is a linear fit to the data used for correcting by station number.

After subtracting the mean difference from the individual differences for each station, the residual differences were plotted as a function of pressure (Fig. C.4).

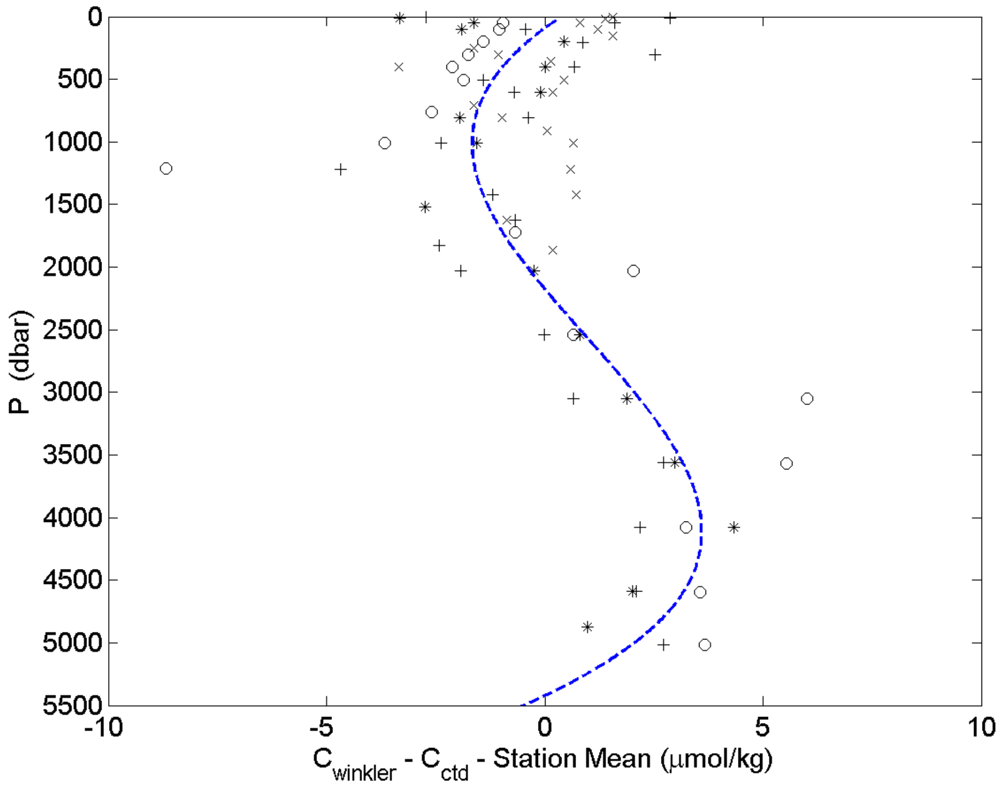

Fig. C.4. Residual differences between the Winkler and CTD oxygen concentrations as a function of pressure. The mean difference for each station has been subtracted to obtain the residuals. The symbols identify the casts as listed in Table C.1. The dashed curve is a cubic fit to the differences as a function of pressure. This curve is used to correct the CTD Oxygen concentrations.

The CTD oxygen concentrations should be corrected with the cubic fit to pressure shown in Fig. C.4, as well as with the linear fit to station number shown in Fig. C.2. The equation for the overall correction is:

$$\Delta C = a_1 + a_2 n + b_1 + b_2 P + b_3 P^2 + b_4 P^3$$

Where the constants a_1 and a_2 are for the linear fit with station number, *n*, shown in Fig. C.3, and the constants b_i (i = 1 to 4) represent the cubic fit with P shown in Fig. C.4. The values of the constants are listed in Table C.5. The units of P should be dbar. The correction ΔC is to be added to the CTD oxygen concentration originally produced by the calibration set prior to the cruise in the SBE Data Processing software. This correction has been applied to the highest level CTD files on the DVD (in \CTD\1dbr and \CTD\netCDF) but not to the raw and intermediate files, nor in the bottle files.

Table C.5. Constants for Correction of CTD Oxygen Readings

Constant	Value
a_1	15.9280
a_2	–0.06597
b_1	0.37672
b_2	–4.4058 E-03
b_3	2.7137 E-06
b_4	–3.5316 E-10

Fig. C.5 shows the residuals if this correction is made. The range of the residuals is about 10 µmol/kg, the mean residual is 0.11 µmol/kg and the square root of the variance is 2.2 µmol/kg. The square root of the variance of the original differences shown in Fig. C.2 is 4.4 µmol/kg, so the corrections have reduced the variance, relative to a constant mean offset of about 10 µmol/kg, by a factor of 4. Either a formal application of statistics or an inspection of the various figures suggest that an uncertainty of 5 µmol/kg be assigned to the oxygen concentrations from the CTD sensor after calibration is applied, in the sense of 95% confidence limits.

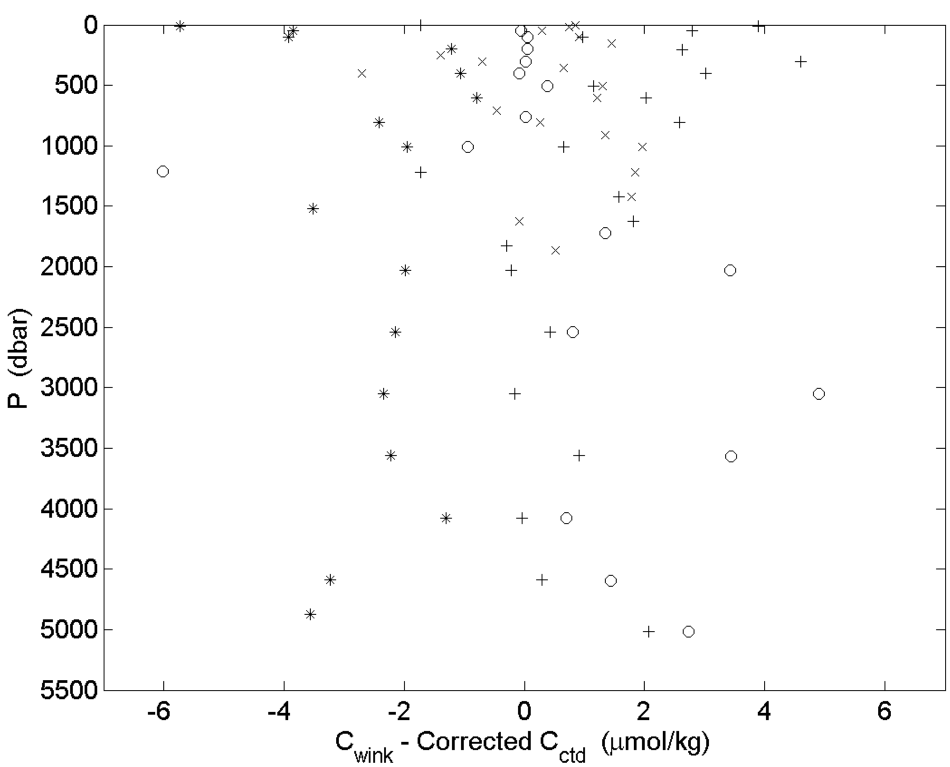

Fig. C.5. Scatter plot of the differences between the Winkler concentrations and the CTD concentrations after the latter have been corrected for both the linear dependence on station number shown in Fig. C.3 and the cubic fit shown in Fig. C.4. The symbols identify the stations as listed in Table C.1.

CTD Data Files

CTD-related files are on the DVD in \CTD, and are described in more detail there. Contact Jim Ledwell or Cynthia Sellers at Woods Hole Oceanographic Institution (csellers@whoi.edu) for updates and further information.

References for Appendix C

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Appendix D. CTD Cast List

R/V *Thompson TN246*			DIMES Cruise US2			15 Jan–5 Mar 2010			
Station/	**Date**	**Time**	**Lat**	**Lon**	**Max**	**Target**	**Target**	**PDR**	**EM300**
Cast		**GMT**	**Deg(S)**	**Deg(W)**	**Depth**	**Sigma**	**Surface**	**Depth**	**Depth**
					(m)	**(m)**	**(m)**	**(m)**	**(m)**
101	01/16/10	18:42	54.6948	75.5967	3503	27.6745	1911	4099	NaN
201	01/17/10	12:49	57.7005	76.9613	4951	27.6745	1721	4910	4992
301	01/18/10	6:07	60.0003	77.9995	4911	27.6745	1524	4945	4908
401	01/18/10	23:08	60.5903	78.2582	2010	27.6745	1448	NaN	4961
501	01/25/10	16:29	52.9432	76.4943	2506	27.6745	2022	4703	NaN
601	01/27/10	7:15	56.4800	82.2998	3001	27.6745	1852	4780	4765
701	01/27/10	19:37	57.2098	85.0298	3003	27.6745	1766	NaN	5466
801	01/28/10	9:14	58.0000	87.9300	3002	27.6745	1627	5201	5200
901	01/28/10	22:11	58.0497	91.3703	2001	27.6745	1533	4264	4259
1001	01/29/10	10:53	58.1192	95.0143	2001	27.6745	1634	4600	NaN
1101	01/29/10	22:31	58.0687	97.9883	2002	27.6745	1603	4825	NaN
1201	01/30/10	4:12	58.0018	99.0030	2002	27.6745	1561	4160	NaN
1301	01/30/10	9:14	58.5000	98.9998	2002	27.6745	1553	NaN	NaN
1401	01/30/10	14:49	59.0008	98.9985	2002	27.6745	1354	4840	NaN
1501	01/30/10	20:19	59.5003	98.9987	2002	27.6745	1205	4654	NaN
1601	01/31/10	2:57	59.7480	100.4945	2003	27.6745	1194	NaN	NaN
1701	01/31/10	10:05	59.9965	101.9990	2004	27.6745	1171	NaN	NaN
1801	01/31/10	17:10	59.4988	101.9942	2004	27.6745	1196	5109	NaN
1901	01/31/10	22:03	59.0027	101.9992	2001	27.6745	1275	4504	NaN
2001	02/01/10	2:19	58.4918	101.9850	2004	27.6745	1537	4467	NaN
2102	02/01/10	23:29	57.9990	101.9975	2003	27.6745	1660	4505	4457
2201	02/02/10	6:09	57.9920	101.0030	2003	27.6745	1575	4188	4147
2301	02/02/10	11:49	57.9965	99.9950	2001	27.6745	1532	4479	4464
2401	02/02/10	18:02	57.4980	99.0032	2001	27.6745	1511	4580	4587
2501	02/02/10	22:32	57.0028	98.9940	2000	27.6745	1450	4929	4958
2601	02/03/10	2:52	56.5028	98.9942	2001	27.6745	1657	4551	4527
2701	02/03/10	7:19	56.0002	98.9993	4779	27.6745	1803	4750	4790
2801	02/03/10	14:20	55.5012	99.0048	2004	27.6745	1777	NaN	NaN
2901	02/03/10	20:31	55.9968	98.9993	2001	27.6745	1814	4761	NaN
3001	02/04/10	2:09	56.0002	99.9985	2002	27.6745	1802	4562	NaN
3101	02/04/10	8:11	56.0017	100.9818	2001	27.6745	1760	4512	NaN
3201	02/04/10	14:08	56.0002	101.9948	2002	27.6745	1696	NaN	NaN
3301	02/04/10	20:15	55.9995	102.9953	2005	27.6745	1700	4454	3368
3401	02/05/10	3:30	55.9973	103.9980	2002	27.6745	1754	4500	NaN
3501	02/05/10	9:04	55.9988	104.9973	2004	27.6745	1732	4190	4028
3701	02/05/10	16:34	56.6690	105.0000	2004	27.6745	1688	4524	NaN
3901	02/05/10	23:36	57.3318	105.0000	2002	27.6745	1536	4285	NaN
4101	02/06/10	6:18	58.0005	105.0043	2003	27.6745	1404	NaN	NaN

4301	02/06/10	13:06	58.6658	104.9967	2003	27.6745	1356	NaN	NaN
4501	02/06/10	19:49	59.3360	104.9935	2001	27.6745	1291	4890	4847
4701	02/07/10	3:26	60.0022	104.9927	2002	27.6745	1198	NaN	NaN
4901	02/07/10	9:32	60.6667	104.9998	2004	27.6745	1075	5210	NaN
5101	02/07/10	16:36	61.3330	105.0002	2002	27.6745	970	4960	4222
5201	02/07/10	22:16	61.4168	103.6695	2003	27.6745	1076	5148	NaN
5301	02/08/10	4:24	61.5162	102.3347	2004	27.6745	1141	~5000	NaN
5401	02/08/10	10:19	61.6177	101.0000	2001	27.6745	1035	5000	NaN
5501	02/08/10	16:31	61.7163	99.6672	2002	27.6745	1082	5252	NaN
5601	02/08/10	21:37	61.8172	98.3313	2002	27.6745	1060	5168	NaN
5701	02/09/10	3:39	61.9160	97.0005	2002	27.6780	1162	5180	NaN
5801	02/09/10	9:19	62.0000	95.9998	2004	27.6780	1144	5000	NaN
5901	02/09/10	13:36	61.7485	96.0002	2002	27.6780	1148	5130	NaN
6001	02/09/10	16:56	61.5007	96.0000	2002	27.6780	1163	4482	NaN
6101	02/10/10	1:01	61.2495	95.9947	2003	27.6780	1201	4739	NaN
6201	02/10/10	4:27	60.9990	95.9995	2004	27.6780	1287	4971	NaN
6301	02/10/10	8:45	60.7497	96.0002	2003	27.6780	1334	4620	NaN
6401	02/10/10	12:00	60.4963	96.0065	2002	27.6780	1410	4894	NaN
6501	02/10/10	16:21	60.2475	96.0017	2004	27.6780	1433	5075	NaN
6601	02/10/10	19:41	59.9982	96.0017	2002	27.6780	1394	4218	NaN
6701	02/10/10	23:40	59.7528	96.0003	2003	27.6780	1360	4811	NaN
6801	02/11/10	3:13	59.4893	95.9955	2001	27.6780	1368	4400	NaN
6901	02/11/10	7:00	59.2512	95.9987	2003	27.6780	1397	4475	NaN
7001	02/11/10	10:22	58.9995	95.9998	2003	27.6780	1472	4610	NaN
7101	02/11/10	13:57	58.7477	95.9998	2002	27.6780	1542	4840	NaN
7201	02/11/10	18:34	58.4975	96.0057	2002	27.6780	1523	3962	3940
7301	02/11/10	21:56	58.2503	96.0008	2003	27.6780	1495	4656	4670
7401	02/12/10	2:18	58.0007	95.9993	2004	27.6780	1550	4947	NaN
7501	02/12/10	5:27	57.7510	95.9985	4912	27.6780	1603	4930	NaN
7502	02/12/10	10:01	57.7548	95.9835	2002	27.6780	1607	5040	NaN
7601	02/12/10	14:50	57.5032	95.9965	2001	27.6780	1630	4790	NaN
7701	02/12/10	19:13	57.2500	96.0003	2003	27.6780	1605	~4450	NaN
7801	02/12/10	22:37	56.9998	95.9998	2000	27.6780	1605	5127	5135
7901	02/13/10	3:03	56.7495	96.0033	2002	27.6780	1614	4670	4860
8001	02/13/10	6:24	56.5007	95.9983	2002	27.6780	1644	5770	NaN
8101	02/13/10	11:31	56.2505	95.9990	2001	27.6780	1692	4100	4260
8201	02/13/10	14:51	56.0015	95.9982	2001	27.6780	1722	4590	NaN
8301	02/13/10	20:59	56.3332	94.9995	2002	27.6780	1773	5087	NaN
8401	02/14/10	2:00	56.6660	93.9998	2002	27.6780	1607	5319	NaN
8501	02/14/10	7:21	56.9985	93.0000	2002	27.6780	1672	5090	NaN
8601	02/14/10	11:16	57.2510	92.9995	2002	27.6780	1680	4890	NaN
8701	02/14/10	18:26	57.5032	92.9970	2001	27.6780	1680	4888	NaN
8801	02/14/10	21:37	57.7498	92.9987	2001	27.6780	1628	5603	5630
8901	02/15/10	0:53	58.0008	93.0005	2002	27.6780	1570	NaN	5635?

9001	02/15/10	5:12	58.2497	92.9978	2002	27.6780	1550	4995	NaN
9101	02/15/10	8:34	58.5000	92.9998	2001	27.6780	1464	4400	NaN
9201	02/15/10	12:51	58.7502	93.0002	2004	27.6780	1438	NaN	NaN
9301	02/15/10	16:11	59.0028	93.0028	2002	27.6780	1486	4172	4261
9401	02/15/10	21:22	59.2493	93.0002	2002	27.6780	1523	5015	NaN
9501	02/16/10	0:48	59.4997	92.9997	2000	27.6780	1526	5004	NaN
9601	02/16/10	4:06	59.7497	93.0002	2002	27.6780	1483	4710	NaN
9701	02/16/10	8:09	60.0010	92.9970	2002	27.6780	1415	4990	NaN
9801	02/16/10	11:19	60.2492	92.9995	2001	27.6780	1298	4830	NaN
9901	02/16/10	14:39	60.4995	92.9988	2003	27.6780	1215	5000	5000
10001	02/16/10	18:26	60.7500	92.9993	2003	27.6780	1140	4991	4992
10101	02/16/10	21:48	60.9998	92.9998	2001	27.6780	1124	4990	NaN
10201	02/17/10	1:44	61.2498	93.0010	2002	27.6780	1140	4966	NaN
10301	02/17/10	5:02	61.4990	93.0027	2001	27.6780	1172	NaN	4898
10401	02/17/10	8:58	61.7498	92.9998	2002	27.6780	1243	4930	4930
10501	02/17/10	12:08	62.0002	92.9995	2002	27.6765	1160	4930	4930
10601	02/17/10	16:42	62.2512	92.9967	2002	27.6765	1072	4900	NaN
10701	02/17/10	19:55	62.5000	92.9998	2002	27.6765	1027	4917	NaN
10801	02/18/10	1:50	62.2490	91.9985	2001	27.6765	1038	4869	NaN
10901	02/18/10	6:19	62.0000	90.9993	2002	27.6765	986	4890	4890
11001	02/18/10	12:12	61.7495	89.9978	2002	27.6765	997	4500	4500
11101	02/18/10	18:24	61.5002	88.9995	2001	27.6765	1171	4583	NaN
11201	02/18/10	21:33	61.2500	88.9998	2001	27.6765	1273	4882	NaN
11301	02/19/10	1:56	61.0000	88.9993	2001	27.6765	1324	4831	NaN
11401	02/19/10	5:10	60.7500	89.0010	2001	27.6765	1363	4535	NaN
11501	02/19/10	9:27	60.4998	88.9998	2002	27.6765	1363	4770	4840
11601	02/19/10	12:30	60.2498	89.0013	2001	27.6765	1341	NaN	5040
11701	02/19/10	16:42	60.0002	89.0002	2001	27.6765	1291	5025	NaN
11801	02/19/10	19:47	59.7500	89.0000	2002	27.6765	1330	4558	NaN
11901	02/20/10	0:02	59.5003	88.9995	2002	27.6765	1381	4987	4887
12001	02/20/10	3:27	59.2522	88.9995	2001	27.6765	1347	NaN	5070
12101	02/20/10	7:49	59.0000	88.9997	2001	27.6765	1315	NaN	5060
12201	02/20/10	11:00	58.9987	88.4965	2001	27.6765	1301	4750	NaN
12301	02/20/10	16:01	59.0000	88.0002	2001	27.6765	1260	5041	NaN
12401	02/20/10	19:02	59.0002	87.4992	2002	27.6765	1214	4960	NaN
12501	02/20/10	22:14	58.9998	87.0012	2003	27.6765	1348	5218	NaN
12601	02/21/10	2:49	59.0017	86.5013	2003	27.6765	1476	5201	NaN
12701	02/21/10	5:58	59.0005	86.0022	2001	27.6765	1528	4850	NaN
12801	02/21/10	10:41	59.0002	85.5002	2003	27.6765	1577	5000	5430
12901	02/21/10	14:08	58.9997	84.9990	2002	27.6765	1671	5100	4910
13001	02/21/10	17:21	58.9997	84.5018	2002	27.6765	1711	5103	NaN
13101	02/21/10	21:51	58.9993	83.9993	2003	27.6765	1718	NaN	5108
13301	02/22/10	5:20	59.4945	84.0007	2001	27.6765	1683	5090	5090
13401	02/22/10	12:42	59.7532	83.9975	2003	27.6765	1604	5080	5080

13501	02/22/10	16:49	59.9950	84.0025	2003	27.6765	1536	5075	5064
13701	02/22/10	23:03	60.4930	84.0022	2002	27.6765	1392	4489	NaN
13801	02/23/10	15:27	60.9848	80.7053	2002	27.6765	1440	4938	NaN
13901	02/23/10	19:06	61.0265	80.2592	2003	27.6765	1377	4933	NaN
14001	02/23/10	22:28	61.0632	79.8147	2001	27.6765	1333	4935	4932
14101	02/26/10	7:40	61.6638	65.4317	1844	27.6765	568	1850	1851
14201	02/26/10	15:52	61.1235	65.7922	3694	27.6765	910	3708	3706
14301	02/27/10	0:39	60.5837	65.9743	1243	27.6765	924	1251	1286
14401	02/27/10	8:35	59.9195	66.0887	3876	27.6765	977	3910	3900
14501	02/27/10	16:00	59.4165	66.0865	3479	27.6765	1059	NaN	3506
14601	03/01/10	1:30	58.9323	66.0620	2665	27.6765	1104	3657	NaN
14701	03/01/10	09:08	58.6082	66.1355	3664	27.6765	1224	3650	NaN
14801	03/01/10	15:54	58.2587	66.0045	2730	27.6765	1382	2738	2740
14901	03/01/10	21:42	57.9767	65.9333	2512	27.6765	1608	2572	2500

Cast notes (repeated from Appendix C):

Cast 00301: The oxygen sensor was connected.
Cast 02101: Communication errors appeared on the console and the cast was aborted.
Cast 02102: Ship's 9*plus* unit was installed.
Cast 02901: The port collecting Altimeter and O2 data was switched from 0/1 to 4/5.
Cast 04501: Problems with secondary conductivity differences on the upcast started here.
Cast 05501: An outflow tube was attached to the secondary pump. Outflow of tube at same level as inflow to temperature sensor.
Cast 05601: Secondary pump was replaced prior to this cast.
Cast 05701: Changed target density surface from 27.6745 to 27.678.
Cast 06101: Reterminated CTD wire after tube blocking during deployment; detached altimeter for this cast only.
Cast 08301: Swapped secondary sensors with alternates for this cast.
Cast 08401: Returned original sensors for this cast but swapped primary and secondary cables at the sensors for this cast only.
Cast 10501: Changed target density surface from 27.680 to 27.6765.
Cast 10601: Removed Y cable to O2 sensor and altimeter at the bottle; took O2 out of the primary pump loop.
Cast 10801: Replaced Y cable to O2 sensor and altimeter at the bottle; put O2 back into the primary pump loop.
Cast 11301: Replaced primary and secondary conductivity sensors with ship's sensors.
Cast 12701: Added Altimeter data to 1m and 1dbar .mat files (first deep cast).
Cast 12901: Secondary conductivity failed at 850m on upcast; sensor not replaced.

Appendix E. XBT/XCTD Cast List

Station No.	Date	Time (GMT)	Latitude (deg S)	Longitude deg W)	Depth (m)	Type	Serial no.	Filename
1	01/16/2010	22:06	54.8996	75.6654	1000	Fast-Deep XBT	not recorded	TF_00001.edf
12-13	01/30/2010	07:40	58.2505	98.9979	1000	Fast-Deep XBT	00010617	TF_00007.edf
13-14	01/30/2010	13:08	58.7527	98.9748	1830	T5 XBT	00348325	T5_00008.edf
14-15	01/30/2010	18:35	59.2522	98.9850	1830	T5 XBT	00348326	T5_00009.edf
27	02/03/2010	11:14	56.0017	98.9944	1100	XCTD	08112116	C3_00013a.edf
35	02/05/2010	08:28	55.9971	104.9598	218	XCTD	08112113	C3_00014a.edf
36	02/05/2010	13:55	56.3320	104.9991	1342	T5 XBT	00348327	T5_00015.edf
37	02/05/2010	16:20	56.6690	105.0002	1100	XCTD	08112119	C3_00016a.edf
38	02/05/2010	20:58	56.9999	105.0004	1830	T5 XBT	00348328	T5_00017.edf
39	02/05/2010	23:24	57.3319	105.0002	500	XCTD	08112112	C3_00018a.edf
40	02/06/2010	03:52	57.6699	105.0057	370	T5 XBT	00348332	T5_00019.edf
41	02/06/2010	05:55	57.9919	105.0048	1100	XCTD	08112115	C3_00020a.edf
42	02/06/2010	10:31	58.3332	104.9965	1830	T5 XBT	00348331	T5_00021.edf
44	02/06/2010	17:29	59.0032	104.9998	1830	T5 XBT	00348330	T5_00022.edf
45	02/06/2010	19:26	59.3306	104.9996	1100	XCTD	08112114	C3_00023a.edf
45	02/06/2010	23:14	59.3488	104.9932	692	XCTD	08112111	C3_00025a.edf
45	02/06/2010	23:26	59.3492	104.9921	855	T5 XBT	00000000	T5_00026.edf
46	02/07/2010	01:17	59.6675	104.9989	1200	T5 XBT	00348335	T5_00029.edf
48	02/07/2010	06:55	60.3194	104.9981	1830	T5 XBT	00348334	T5_00030.edf
49	02/07/2010	09:04	60.6502	104.9891	40	XCTD	08112122	C3_00031.edf
50	02/07/2010	14:20	60.9920	104.9987	1830	T5 XBT	00348329	T5_00032.edf
66	02/10/2010	19:22	60.0102	96.0026	1100	XCTD	08112118	C3_00035.edf
68	02/11/2010	02:47	59.4998	95.9947	1100	XCTD	08112117	C3_00036.edf
70	02/11/2010	09:54	59.0079	95.9908	1100	XCTD	08112121	C3_00037.edf
72	02/11/2010	17:20	58.5063	96.0015	1100	XCTD	08112120	C3_00038.edf
73	02/11/2010	21:35	58.2566	96.0002	522	XCTD	08112110	C3_00039.edf
76	02/12/2010	14:31	57.5091	95.9959	1100	XCTD	08112109	C3_00040.edf
78	02/12/2010	22:17	57.0059	95.9925	1100	XCTD	08112108	C3_00041.edf
80	02/13/2010	06:01	56.5155	96.0003	1100	XCTD	08112105	C3_00042.edf
82	02/13/2010	14:30	56.0168	95.9976	1100	XCTD	08112106	C3_00043.edf

89	02/15/2010	00:36	57.9907	92.9959	1100	XCTD	08112107	C3_00044.edf
91	02/15/2010	08:10	58.4863	92.9950	1100	XCTD	08112104	C3_00045.edf
93	02/15/2010	15:49	58.9880	93.0030	1100	XCTD	08112103	C3_00046.edf
99	02/16/2010	14:20	60.4849	92.9955	1100	XCTD	08112102	C3_00047.edf
101	02/16/2010	21:21	60.9837	93.0053	1100	XCTD	08112101	C3_00048.edf
103	02/17/2010	04:36	61.4845	92.9990	1100	XCTD	08112100	C3_00049.edf
105	02/17/2010	11:45	61.9844	92.9931	1100	XCTD	08112099	C3_00050.edf
142	02/26/2010	15:18	61.1236	65.7805	1100	XCTD	08080673	C3_00052.edf
143	02/27/2010	00:09	60.5854	65.9727	1100	XCTD	08080677	C3_00053.edf
144	02/27/2010	08:19	59.9196	66.0887	1100	XCTD	08080682	C3_00054.edf
145	02/27/2010	15:41	59.4294	66.0856	1100	XCTD	08080680	C3_00055.edf
146	03/01/2010	05:11	58.9577	66.0792	1100	XCTD	08080681	C3_00056.edf
147	03/01/2010	08:39	58.6000	66.1046	1100	XCTD	08080679	C3_00057.edf
148	03/01/2010	15:39	58.2584	65.9917	1100	XCTD	08080676	C3_00058.edf
149	03/01/2010	21:27	57.9769	65.9229	1100	XCTD	08080678	C3_00059.edf
150	03/02/2010	03:51	57.5500	65.6451	1100	XCTD	08080672	C3_00060.edf
150	03/02/2010	07:04	57.5470	65.6298	1100	XCTD	08080675	C3_00061.edf
151	03/02/2010	17:48	56.1608	64.7580	T failed	XCTD	08080674	C3_00062.edf
152	03/03/2010	01:09	55.7015	64.9737	1100	XCTD	08080671	C3_00063.edf