WHP Cruise Summary Information

WOCE section designation	I05P
Expedition designation (EXPOCODE)	74AB29_1
Chief Scientist(s) and their affiliation	John Toole, WHOI
Dates	1987.11.12 - 1987.12.17
Ship	CHARLES DARWIN
Ports of call	Durban, South Africa to Freemantle, Australia
Number of stations	109
Geographic boundaries of the stations	34°10.09''S 30°21.02''E 114°49.06''E 29°00.02''S
Floats and drifters deployed	none
Moorings deployed or recovered	none
Contributing Authors	none listed

A Trans-Indian Ocean Hydrographic Section at Latitude 32°S
Data Report of RRS Charles Darwin Cruise #29

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WHP Cruise and Data Information

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ABSTRACT

A trans-Indian Ocean hydrographic section employing CTD/O_2 profilers was conducted between Africa and Australia during austral spring 1987. The cruise track ranged between 29°S and 34°S; the average latitude of the crossing was 32°S. The purpose of the cruise was to explore various aspects of the South Indian Ocean including the characteristics of the core water masses of this ocean, the strength of the subtropical gyre, the structure and transport of deep western-boundary currents, and the net meridional heat flux. A total of 109 CTD/O_2 profiles with associated rosette water sample measurements and 347 XBT profiles were collected, supplemented by underway upper ocean velocity, bathymetric and sea surface temperature and salinity data. This report details the data collection, calibration, and reduction methods, and summarizes the hydrographic observations.

INTRODUCTION

A trans-Indian ocean hydrographic section along approximate latitude 32°S using Conductivity, Temperature, Depth, Dissolved Oxygen (CTD/O_2) profilers was successfully completed during austral spring 1987. Water samples, collected with a rosette sampler attached to the CTD mounting frame, were analyzed for salinity, oxygen, dissolved nutrients, chlorofluorocarbons (CFC), tritium, and Me content. The expedition, conducted from the RRS Charles Darwin, a NERC (Natural Environment Research Council) /RVS (Research Vessel Services) vessel based out of Great Britain, departed Durban, South Africa on 12 November 1987 and made port at Fremantle, Australia on 17 December 1987. The cruise track covered an area between 29 and 34.11°S; several substantial ridge systems extend across the track, dividing the ocean into distinct basins (Figure 1). The purpose of the cruise was to explore various aspects of the South Indian Ocean circulation including the characteristics of the core water masses of this ocean, the zonal extent of the subtropical gyre including the Agulhas Current and its recirculation zone, and the structure and transport of deep western-boundary currents.

Cruise #29 of the RRS Charles Darwin was a multi-institution oceanographic effort. A U.S. contingent of thirteen joined by four shipboard technicians from NERC/RVS (Table 1) collected a total of 109 CTD/O_2 profiles (including test stations #1, 2, and 11). A summary of station information is given in Table 2. The NERC/RVS technicians operated the CTD winch and the permanent shipboard scientific equipment and computers. The Woods Hole Oceanographic Institution (WHOI) CTD Group staged, prepared and maintained the CTD and rosette equipment during the cruise. The WHOI Hydrography Group coordinated sampling and analysis of rosette salinity and oxygen data. WHOI personnel processed, quality controlled, and archived the collected data. A group from Oregon State University (OSU) analyzed water samples for dissolved nutrient concentrations (dissolved silica, phosphate, nitrite, and nitrate). A team from the University of Miami determined chlorofluorocarbon

(CFC) concentrations (F11, F12) from selected rosette bottles at sea and also collected samples for subsequent processing in the laboratory of 3H and Me. Watchstanders deployed 347 expendable bathythermographs (XBTs) along the transect at nominal spacing of 15-20 km between CTD station positions (Table 3). All hands aided in the deployment and recovery of the instruments. Navigation data as well as continuous sea surface temperature, salinity, and upper ocean velocity were logged digitally throughout the cruise; bathymetry data were logged manually at 20-minute intervals with more frequent sampling over abrupt bottom topography. The data return from the cruise was exceptional, and the major cruise objectives were met due to hard work by both the scientific and shipboard personnel during the trip. Listings of the CTD observations at standard levels and the water sample observations form the bulk of this report, Appendix B.

DATA ACQUISITION SYSTEMS, WATER SAMPLE ANALYSIS, AND INSTRUMENTATION

Two EG&G/Neil Brown Instrument Systems (NBIS) Mark IIIB CTD/O_2 (Conductivity/Temperature/Depth/Oxygen) profilers (WHOI instruments: #8, serial number 01-2252-01, and #9, serial number 01-2405-01) were employed on the cruise. A detailed description of the instrumentation can be found in the report by Brown and Morrison (1978). A 24-position, 10-liter rosette manufactured by Scripps Institution of Oceanography was the primary system for water sample collection; a 24-position 1.2-liter General Oceanics Inc. rosette system was available as a backup. The 10-liter bottle size was dictated by CFC sampling requirements. A 12-kHz pinger was mounted on each CTD underwater package to facilitate sampling close to the ocean bottom.

The CTD data acquisition system employed the NBIS model 1150 deck unit (Figure 2) which passed digital HEXASCII data to a 1/4” Kennedy cartridge tape drive. Data were graphically displayed and listed in real time by an HP-85 computer. Audio tape back-up analog recordings were also collected. Complete back-up sets of acquisition hardware were available on the cruise. Data transcription and processing were performed on Digital Equipment Corporation (DEC) MicroVAX II computer systems (Figure 2). Acquisition data were loaded onto the MicroVAX system via Kennedy cartridge tape drives and displayed graphically using Zeta-8 plotters. Two independent MicroVAX systems were employed: the first devoted to basic processing, the second to data archiving, higher level processing and analysis. Nine-track and DEC TK50 cartridge tapes served as media for data archiving.

Two Guildline Aut Sal Model 8400A salinometers were utilized to determine water sample salinities. These were installed in a portable laboratory capable of maintaining constant environmental temperature within ±1°C. The nominal laboratory temperature was 22°C. A standardization check was performed once per day, using Standard Seawater Batch P-97. No drift of the Autosal was observed during the cruise, thus no standardization adjustments were made. It should be noted that, based upon a comparison of Batch P-97 and PSS78 DCL Standard, Mantyla (1987) has recommended a correction (which has not been made to these data) of +0.0008 for rosette samples analyzed with this batch. The uncertainty in the rosette salinity data is believed to be ±0.003 psu, the manufacturer s stated accuracy of the Aut Sal.

Water sample dissolved oxygen analyses were also performed in the constant temperature laboratory using a modified Winkler titration technique. The measurements were conducted on 50 ml aliquots of the samples. A Metrohm Titroprocessor controlling a Metrohm Dosimat was used to titrate to an amperometric endpoint as described by Knapp et al. (1989). Standardization checks were performed prior to and following the use of each batch of titrant (typically every third day). No observable drift occurred between standardization checks. These data are reproducible to ±0.02 ml/l with accuracy of better than 2%.

The inorganic nutrient determinations were carried out by Dr. Louis I. Gordon's group from Oregon State University. Samples were analyzed for dissolved, reactive nutrients at sea using an Alpkem Corporation RFA-300 continuous, segmented flow analyzer (RFA). Nutrients analyzed included orthophosphate, silicic acid, nitrate plus nitrite, and nitrite. The phosphate method was basically that of Atlas et al. (1971), modified for the RFA. The remaining methods were those furnished by the Alpkem Corporation for use with the RFA (Alpkem, 1986; Patton, 1983). We have established that all other methods are linear to a few tenths of 1% and give results comparable to, or better than, the AutoAnalyzer-II-based methods we employed in the past (Atlas et al., 1971).

The dissolved nutrients were measured at all station locations; in most cases, these analyses were performed immediately after each CTD cast and were completed within two to three hours after the cast. The short term precision (1 standard deviation), estimated from replicate analysis of the same sample and on occasions where two rosette bottles were tripped at the same depth, was approximately 0.2%, 0.5%, and 1.0% of regional deep water values for silicic acid, nitrate plus nitrite, and phosphate, respectively. Nitrite precision is typically 0.02 micromolar. Due to problems with the autosampler (mentioned below), long term precision and accuracy were estimated at 1-2% for silicic acid and nitrate plus nitrite, 3-5% for phosphate, and 0.04 micromolar for nitrite. Data which seemed clearly in error were rejected during the post cruise quality control review of the data.

Chlorofluorocarbon (CFC) samples (F11 and F12) were drawn from rosette bottles at about 70% of the stations. An analytical system similar to that of Bullister and Weiss (1988) was used. CFC concentrations are reported relative to the S1086 calibration scale (Weiss, personal communication). A combination bottle and handling blank was used to correct for contamination from the Niskin bottles, and from the collection and storage of samples. This blank was estimated by rotating Niskin bottles, double tripping them and measuring what was believed to be CFC-free water. For F11 the blanks varied throughout the cruise, generally decreasing with time. They ranged from 0.04 pmol/kg to zero. For F12 the blanks were zero; however, contamination problems preclude the use of some of the F12 data. We estimate our precision based on analysis of 166 duplicate samples from the same syringe. The standard deviation of the series of replicates for F11 was as follows: for concentrations in the range zero to 0.10 pmol/kg precision ±0.004 pmol/kg, in the range 0.1-0.5 pmol/kg precision ±0.007 pmol/kg, in the range 0.5-1.0 pmol/kg precision 0.012 pmol/kg, and greater than 1.0 pmol/kg precision 0.092 pmol/kg. The standard deviation of the series of replicates for F12 was as follows: for concentrations in the range zero to 0.10 pmol/kg precision ±0.009 pmol/kg, in the range 0.1-0.5 pmol/kg precision ±0.011 pmol/kg, in the range 0.5-1.0 pmol/kg precision ±0.035 pmol/kg, and greater than 1.0 pmol/kg precision ±0.04 pmol/kg. Marine airs for F11 were 224±6 ppt. The water sample salinity, oxygen, nutrient, and CFC observations are presented in Appendix B of this report.

Samples from stations 12, 15, 26, 33, 35, 39, 44, 50, 55, 62, 65, 69, 80, 88, 94, 97, 105, and 106 were analyzed for the following quantities: tritium, helium isotope ratio, total helium and neon. Two hundred and forty measurements each are available for helium isotope ratio, total helium and neon; there are 130 measurements for tritium.

For the noble gas analyses, water samples (approximately 40 g) were collected in clamped copper tubes. These samples were also used for tritium analyses in the upper 500 m. For deep tritium samples, water samples (1 liter) were collected in glass bottles. Tritium measurements were made using the mass-spectrometric helium-3 regrowth technique with a precision of 0.01 TU. Helium isotope ratios, as well as absolute helium and neon concentrations, were measured mass-spectrometrically. Isotope ratios, expressed in the del notation (ratio anomaly with respect to the atmosphere), have a precision of 0.2%; absolute concentrations have a precision of 0.25%. These data are presented in listings appearing in Appendix C.

The ship's equipment inventory included an Acoustic Doppler Velocity Profiling (ADCP) system (RD 150-kHz profiler with IBM AT acquisition computer) and a digital expendable bathythermograph (XBT) recorder (Bathysystems, Inc. with HP-85 computer). A thermosalinograph monitored surface temperature and salinity along track; data were logged to the ship's main computer system. This system also recorded navigation information (transit and GPS fixes) from which all CTD station navigation information was updated after the cruise. Wind speed and direction were recorded manually by each watch at the start of each station. All transit fixes were digitally logged in addition to GPS fixes every two minutes when available; all transit fixes were subsequently interpolated to form a one-minute position record using the ship velocity data.

There were relatively few failures of equipment during the cruise. Upon set-up in Durban, CTD #9 was found to have a faulty FSK board, which was quickly identified and replaced before departure. At cruise start, there was a problem with the Scripps-modified General Oceanics rosette unit which was remedied by replacing a faulty pylon unit. The Kennedy Cartridge tape drives employed for acquisition experienced difficulty switching tracks efficiently; stations greater than 3000 db typically lost up to

15 db of data in mid-profile; data were subsequently interpolated across this gap during processing. At the beginning of the cruise, there was a failure of the nutrient RFA's autosampler. This was replaced by an older model autosampler which was only partly compatible with the RFA; this resulted in noisy and erratic phosphate results, particularly during the first third of the cruise. Late in the cruise one MicroVAX II nine-track tape drive failed; the remaining functional unit was shared between computer systems for the rest of the cruise. Several of the rosette bottles suffered breakage, a function of the difficulty handling such a large package. Many of the rosette bottles leaked; the problem was ultimately traced to old O-rings in the bottles. Careful editing has removed all suspect observations from the final data set.

CRUISE NARRATIVE

Staging of the ship was accomplished during a four-day period in Durban, South Africa. Two containers, one a WHOI portable laboratory (a temperature controlled, 20-foot long container equipped with salinity and oxygen analysis equipment), the other a shipping container used to transport the cruise equipment, were secured to the deck. CTD and CFC laboratories were established in the RRS Darwin's large main laboratory; two small adjacent laboratories housed the nutrient and shipboard computer operations.

Departure from Durban was several hours late on November 12 due to a delayed air shipment containing the bulk of the University of Miami chemistry equipment. At 2100 hrs, the ship transited to a test station site roughly 100 km off the African coast in 3000 m of water. On the morning of November 13, CTD #9, mounted with the small 1.2-liter rosette package, was successfully deployed (station 1) to within 10 m of the ocean floor. Station 2 (the test station for CTD #8 mounted in the large rosette package) was aborted at 900 m depth when the CTD signal was lost. The remainder of that day was spent troubleshooting the problem. During this time, the scientific party was notified that the ship was required to return to Durban to put ashore the vessel's electrician because of a home emergency. The replacement electrician was scheduled to arrive Durban on the afternoon of the 15th. Complicating matters, the winds had increased to 40 knots with growing seas. Since the large rosette package was not yet functional, it was decided to work westward from the test station site and occupy the coastal stations of the proposed section using CTD #9 in the small, easily handled rosette package. Stations 3 through 10 make up an east-to-west transect back toward the African coast. A successful CTD #8 test station was subsequently occupied off the coast of Durban with the repaired large rosette system. The balance of the CTD casts were done with this underwater rosette package.

The second departure from Durban occurred at 1700 hrs on 15 November. The ship steamed back to re-occupy the easternmost station position already collected (site of stations 1 and 2) and proceeded to work to the east. The CTD station schedule dictated high-resolution sampling at the western sides of basins and across rough topographic relief with an effort to sample any extraordinarily deep trenches. Larger station spacing intervals were planned over abyssal plains. The section began at the western boundary at 31°S where the Agulhas Current is located near the abrupt African shelf break. Stations were closely spaced down to the abyssal plain of the Natal Valley, spanning the full width of the Agulhas Current. The section then crossed the Mozambique Ridge and Basin, and up over the Madagascar Ridge near Walter's Shoal. High resolution stations were made at the eastern flanks of both ridges so as to observe any western intensification of the baroclinic gradients. Next, the cruise track turned slightly south to cross the Southwest Indian Ridge at approximate right angles, before sampling zonally across the Crozet Basin at latitude 34°S. In the eastern Crozet Basin the section jogged northward at the Southeast Indian Ridge to cross that feature at near right angles before sampling across the southern extremity of the Central Indian Basin along 29°S. The section continued along the crest of Broken Ridge then concluded by sampling across Naturaliste Plateau and up onto the Australian shelf, terminating in 55 m of water midway between Cape Leeuwin and Cape Naturaliste (Figure 1). Upon arrival in Fremantle, gear was packed up into shipping vans within two days and surface freighted via Singapore (RRS Darwin's subsequent port of call) to the United States.

During the cruise, the combination of the large underwater package and the slow winch speed (maximum 60 m/min) led to station times exceeding six hours. The first half of the cruise suffered average lowering/raising rates of 37 m/min. Fortunately, good weather afforded us with more time for CTD stations, and less time devoted to repairs; there were a total of five reterminations of the CTD underwater cable during the entire cruise, several of which occurred in poor weather during the last week.

Selection of the primary CTD instrument for the cruise was based on the consistency with which the CTD sensors matched the analyzed water sample salinity data obtained on test stations and the initial casts. CTD #9 was used to collect the first group of stations (3-10) as noted above, while CTD #8 was employed on stations 11-15. Close scrutiny of these early data revealed that the potential temperature/salinity profiles for the two CTD/O_2 instruments differed slightly; considering both instruments with pre-cruise calibrations applied, CTD #9 better described the hydrographic profile outlined by corresponding rosette water sample data. Thus, at station 16, CTD #9 was placed in the large rosette frame and subsequently employed on stations 16-94, and 96-109. CTD #8 was used once more at station 95 in the Western Australian Basin to confirm its deep-water sensor calibrations.

Estimated accuracies of the final processed and calibrated data are +0.002°C for temperature, ±0.002 for salinity (with respect to the standard sea water used) and ±0.02 ml/l for dissolved oxygen concentration. The following sections detail the procedures used to reduce the CTD data to final form. All stations were collected to within 10 m of the ocean bottom; the deepest station (#91) extends to 5927 db in the Western Australian Basin. The warmest surface waters (T = 23.480°C) were found in the Agulhas Current at station 7; the coldest deep-water temperatures were found at station 50 in the Crozet Basin (T = 0.517°C, Theta = 0.094°C).

CALIBRATION OF CTD/ O_2 PROFILES

Overview:

Laboratory calibrations, performed before and after the cruise, provide the sole correction information for the CTD pressure and temperature sensors. Final CTD data have been pressure averaged at 2 db intervals with the appropriate pressure, temperature and conductivity calibrations. Note that temperature and pressure calibrations are used to scale both the data profiles and the CTD component of the rosette water sample data files. The pre-cruise laboratory calibrations of CTDs #8 and #9 appeared to described the at-sea instrumentation more accurately than post-cruise laboratory calibrations. Extended periods of time elapsed (three months prior, four months post) between CTD calibrations and data acquisition; it is likely that an event during post cruise shipment affected post cruise calibrations for CTD #8. In order to preserve a long-standing history on the stability of these sensors, no electronic adjustments were made to the sensor interface boards during laboratory calibrations. Instead, corrections, determined by polynomial least-square fits to the laboratory calibration data, were applied to the data. Temperature calibrations consisted of quadratic fits to seven temperature points ranging between 0 and 25°C in reference to a platinum thermometer standard (Figure 3). Pressure calibrations were done using a dead-weight tester; data were sampled at 1000 psi intervals with both increasing and decreasing pressure between 0 and 10,000 psi. Data reduction employed a cubic calibration algorithm determined from a least-square fit to these data (Figure 4). Conductivity calibrations were derived using the water sample salinity data which is traceable to the IOS Wormley standard sea water. Additional information on CTD calibration methodology and data processing procedures can be found in the report by Fofonoff, Hayes, and Millard (1974) and Millard (1982).

Pressure:

For both CTD instruments, the pressure bias term applied to each CTD cast was set equal to the pre-lowering deck unit pressure reading (du) The following downcast (0-6000 db range) pressure calibration algorithm was applied to the CTD #8 profiles.

CTD #8: $P = -(du) + (.996485E^{-1})\ P_{raw} + (.204213E^{-7})\ P_{raw}\ \text{-}2 - (.203510E^{-12})P^{3}_{raw}$

where P_{raw} is the raw counts of the pressure channel.

The downcast pressure calibration algorithm for CTD #9 derived from laboratory measurements is listed below:

CTD #9: $P = -(du) + (.997789E^{-1})\ P_{raw} + (.146634E^{-7})\ P^{2}_{raw} -(.199288E^{-12})\ P^{3}_{raw}$

This calibration equation was adjusted with a cubic term which increases the pressure of the CTD trace by 15 db at 6000 db but introduces negligible change for for P < 3000 db. This step was taken to correct a problem with the pressure gauge which resulted in an uncharacteristically salty (.002) CTD trace in the deep water (see Appendix A). The equation for the laboratory pressure calibration plus the adjustment is:

CTD #9: $P = -(du) + (.99934049E^{-1})\,P_{raw} + (.2878124E^{-8})\,P^2_{raw} + (.229295E^{-13})\,P^3_{raw}$

In similar fashion, cubic calibration curves were constructed from the decreasing pressure (upcast) laboratory calibration data. For CTD #8, a weighted combination of the pre-cruise downcast and upcast pressure calibrations was applied to the CTD component of the rosette water sample data (Millard, 1982).

CTD #8: $P_{up} = -.661953E^{1} + (.993626E^{-1})\,P_{raw} + (.358650E^{-7})\,P^2_{raw} - (.370163E^{-12})\,P^3_{raw}$

$P_{dn} = -.408372E^{1} + (.996485E^{-1})\,P_{raw} + (.204213E^{-7})\,P^2_{raw} - (.203510E^{-12})\,P^3_{raw}$

For CTD #9 observations, the upcast pressure calibration algorithm alone (with adjustment described above) was applied to the upcast CTD component of the rosette water sample data. This method of scaling helped minimize discrepancy in the CTD #9 deep-ocean salinity data.

CTD #9: $P_{up} = .296106E^{1} + (.9946015E^{-1})\,P_{raw} + (.2208452E\text{-}7)\,P^2_{raw} - (.1510815E^{-12})\,P^3_{raw}$

Temperature:

The following pre-cruise temperature calibrations were used for the calibration of CTD downcast and water sample rosette data collected with CTD #8. A time lag correction of 0.250 seconds between the C and T sensors (deduced during the cruise) was also made.

CTD #8: $T = .481378E^{-2} + (.499839E^{-3})\,T_{raw} + (.183211E^{-11})\,T^2_{raw}$

where T_{raw} is the raw counts of the temperature channel.

A comparison of CTD #9 pre- and post-cruise temperature calibrations indicated that the temperature sensor remained very stable during the cruise and shipping time period; therefore, a combination of the two laboratory calibrations was used to determine the correction formula. The following was applied to the data along with a time lag correction of 0.150 seconds:

CTD #9: $T = .993360E^{-2} + (.499908E^{-3})\,T_{raw} + (.120247E^{-11})\,T^2_{raw}$

Conductivity:

Linear conductivity calibration algorithms, derived from pre-cruise laboratory data (Figure 5), were used to plot and list CTD data during acquisition. The algorithms employed were:

CTD #8: $C = .844399E^{-2} + (.100041E^{-2})C_{raw}\,[1 + a(T - T_O) + b(P - P_O)]$

CTD #9: $C = -.148379E^{-2} + (.100002E^{-2})\,C_{raw}\,[1 + a(T - T_O) + b(P - P_O)]$

where:

C_{raw} is the raw counts of the conductivity channel;
a (alpha) is the temperature correction coefficient (-.65E-5°C^-l);
b (beta) is the coefficient of cell contraction with pressure (1.*5E-8 db"'-l);
T is scaled temperature;
T_O is 2.8°C;
P is scaled pressure;
P_O is 3000 db.

CTD #8 pre-cruise scaling factors resulted in a huge offset (.01 psu) between the CTD and the rosette water sample salinity data. CTD #9 pre-cruise scaling factors described the CTD conductivity cell extraordinarily well, which motivated use of this instrument on the bulk of the stations. It was not until much later in the cruise that a .002 psu inconsistency between CTD #9 and water sample salinity was revealed at very deep stations. Non-standard manipulations of the pressure and conductivity scaling factors were ultimately needed in order to describe the deep ocean accurately (Appendix A).

The final conductivity calibrations applied to the data were determined from multiple regression fits of the CTD data with their respective rosette salinity water samples. CTD #8 stations were calibrated using standard multiple regression fitting methods for conductivity (Millard, 1982). First, a multiple regression fit was done over a homogeneous station group (one in which the differences between water sample and nominally scaled CTD salinities were roughly constant), fitting for conductivity bias and conductivity slope through the entire water column. The resultant bias was next removed from the data, and a second multiple regression fit for conductivity slope was done for the same station group in the deep water. Stations 2 and 11-15 formed a homogeneous calibration group. Station 95 required an independent fit to its corresponding water sample data. The stations which utilized CTD #8 subsequently required a manual adjustment to bring the CTD downcast salinity trace 0.002 psu fresher for consistency with surrounding casts made with CTD #9 and with the upcast water sample data.

Stations 2, 11-15: $C = .16271899E^{-1} + (.99980617E^{-3})\,C_{raw}\,(1 + a(T - T_O) + b(P - P_O)]$

Station 95: $C = .11818043E^{-1} + (.99985533E^{-3})\,C_{raw}\,[1 + a(T - T_O) + b(P - P_O)]$

CTD #9 conductivity scaling coefficients were derived in essentially the same manner as those for CTD #8. As previously mentioned, a deep-water cubic pressure adjustment was made to the CTD #9 data. In addition, the cell contraction coefficient, beta ("b"), was set to zero in order to describe the subtle uncharacteristic properties of the CTD #9 conductivity cell. Three calibration groups were identified in the CTD #9 data set; the resulting algorithms that were applied are:

Stations 1-10: $C = .12371505E^{-1} + (.99949753E^{-3})\, C_{raw}\, [1 + (T - T_O)]$

Stations 16-80:

Stations 81-109: $C = .88715050E^{-2} + (.99949753E^{-3})\, C_{raw}\, [1 + a(T - T_O)]$

$$C = .61719213E^{-2} + (.99968088E^{-3})\, C_{raw}\, [1 + a(T - T_O)]$$

Uncertainty in the final CTD salinity data may be measured by differences between CTD and water sample salinity data. Absolute CTD salinity accuracy of course hinges on the accuracy of the water sample data which in turn is tied to the Wormley standard water. Two measures of CTD/water-sample consistency were prepared (Figures 6, 7). The time series plot of salinity differences as a function of station number shows the final data to be uniformly calibrated. The histogram of the salinity differences for the data below 2000 decibars is essentially Gaussian with a mean of 0.0003; the standard deviation of the population of 645 points is 0.0085 psu.

Oxygen:

Coefficients in the CTD oxygen sensor calibration algorithm were derived from in situ water sample oxygen data according to Owens and Millard (1985). The algorithm is:

Oxm= [a(Oc + b(delta Oc/delta))+C] Oxsat (T,S) e^(D [T + E (To-T)] + F P)

OR LOOK AT THIS AND SEE WHICH WAY YOU WANT IT:

Oxm= (a * (Oc + b * (dOc/dt)) + C] * Oxsat (T,S)e** D*[T+E*(TO-T)I+F*P

where,

Oc	is the oxygen current measurement;
P & T	are CTD pressure (dbar) and temperature (°C);
To	is the oxygen sensor temperature (°C);
S	is salinity computed on the 1978 practical salinity scale;
a (alpha)	is the oxygen current slope adjustment,
b (beta)	is the oxygen sensor lag in seconds; and
C	is the oxygen current bias adjustment.

Parameters D, E, F appearing in the exponential represent adjustments for the permeability of the teflon membrane of the oxygen cell with temperature and pressure. Oxsat (T,S) is the oxygen saturation value as calculated by Weiss (1970).

Stations were first subdivided into groups which appeared to have homogeneous calibration characteristics. A multiple regression technique was then used to define the coefficients. Note that the regression is between downcast CTD oxygen sensor data and water sample observations obtained on the upcast. (This is because erroneous CTD oxygen data are obtained when the underwater package is stopped to close a rosette bottle. As well, the oxygen sensor typically exhibits excessive up-down hysteresis.) Oxygen sensor characteristics changed markedly in time on the trans-Indian cruise. Regression groups were typically small, and frequently consisted of single stations. We have no explanation for the lack of sensor stability. Table 4 details the algorithm coefficients used to generate the final data.

As was the case for the salinity data, a measure of CTD-derived oxygen data uncertainty is given by comparison with the water sample data (Figures 7, 8), but the absolute accuracy depends directly on the water sample accuracy. The population of oxygen difference data below 2000 decibars (678 points) has a standard deviation of 0.037 ml/l with a mean of 0.008 ml/l.

ACOUSTIC DOPPLER CURRENT PROFILER MEASUREMENTS

Upper ocean velocity profile data from the hull mounted ADCP instrument were vector averaged in 10-minute blocks and archived to floppy disk with the standard RDI software package. A default configuration of 8-m ping length and 8-m bin length was specified, with a ping rate of 1 Hz. As noted above, ship navigation data were recorded on a separate computer. Post-cruise processing of the data initially involved merging these data using time as the common denominator. This entailed correction for a linear drift of 24 seconds/day in the ADCP system time data. The other major correction applied to the data involved determination of the ADCP transducer orientation relative to the ship's gyro. Reciprocal runs of 30-45-minute duration were carried out midway through the cruise. A study of the resulting data indicates that a transducer rotation angle of 4.9° is appropriate. Work is continuing to refine this estimate. Representative summary plots of the relative ADCP measurements are given in Figures 9a-d. The top panels in each case denote with bold line the ship position corresponding to each subset of the data shown. The 10-minute average east and north relative velocity profiles are displayed in "waterfall" format in the middle panels. The bottom panels present the time series of depth-averaged relative velocity (east is the bold curve). As is apparent from the figures, the ADCP velocity profiles are characterized by structures with short vertical scales, having small horizontal scale. Table 5 presents estimates of the ADCP-derived absolute across-track velocity averaged horizontally between CTD stations, and in the vertical between 100 and 200 m. For comparison, the table also shows the differences between the ADCP data and the geostrophic velocity relative to 1500 db averaged over the same vertical interval. There is qualitative agreement between ADCP and geostrophic velocities; mean and standard deviation of the difference between them are 1.729 E^{-2} m/s and 8.035 E^{-2} m/s, respectively. Understanding the sources of these differences is an ongoing research topic.

SUMMARY PRESENTATIONS OF THE FINAL DATA SET

As noted in the INTRODUCTION, the bathymetry of the South Indian Ocean is quite complex. To a large degree, the water property characteristics on the RRS Darwin trans-Indian section reflect the underlying bathymetry; significant property differences are seen from basin to basin. As a means of summarizing the observations, potential temperature--property diagrams were constructed from selected stations in each of the major basins sampled on the cruise (Figures 10-21).

Six property vs. depth sections (Figures 22-27) of the trans-Indian Ocean section were prepared. Vertical distortion of the full-depth profiles is 500:1, while the expanded shallow sections have a vertical distortion of 1250:1. The continuous bottom topography shown on these profiles is based on depth recordings made approximately every 20 minutes when the ship was underway. Depths have been corrected for variations in the speed of sound in seawater (Carter, 1980). Profiles of potential temperature, salinity, and dissolved oxygen are based on the calibrated CTD data. The black dots on the SiO_2, PO_4 and NO_3 profiles represent bottle positions. All isopleths are interpolated linearly between observations, and contoured by hand.

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DESCRIPTION OF TABLES

Table 1: RRS Charles Darwin Cruise #29 Shipboard Personnel.
Table 2: RRS Charles Darwin Cruise #29 CTD Station Summary Information.
Table 3: RRS Charles Darwin Cruise #29 XBT Station Summary Information.
Table 4: Parameters of the CTD Oxygen Algorithm Used to Calibrate RRS Darwin Cruise #29 CTD Oxygen Data.
Table 5: RRS Charles Darwin Cruise #29 Average Along- and Across-Track ADCP Velocity Estimates. [Velocities are between 96 and 208 db as computed between

consecutive station positions. The last column shows the difference between the actual (ADCP) and computed (geostrophic) velocities between station pairs.]

Oxm= [a(Oc + b(delta Oc/delta))+C] Oxsat(T,S) e^(D [T + E (To-T)] + F P)

where, Oc is the oxygen current measurement; P & T are CTD pressure (dbar) and temperature (°C); To is the oxygen sensor temperature (°C); S is salinity computed on the 1978 practical salinity scale; a (alpha) is the oxygen current slope adjustment, b (beta) is the oxygen sensor lag in seconds; and C is the oxygen current bias adjustment.

Table 1: RRS Charles Darwin Cruise #29 Shipboard Personnel

Woods Hole Oceanographic Institution:	
Dr. J. Toole	Co-Principal Investigator
Dr. B. Warren	Co-Principal Investigator
A. Morton	WHOI CTD Group Manager
J. Kinder	WHOI CTD Group Hardware Technician
M. Francis	Software Technician - Data Processor
R. Stanley	Rosette Oxygen Analyst
G. Knapp	Rosette Salt Analyst
J. Zemba	Watchstander
Oregon State University:	
J. Jennings	Rosette Nutrient Analyst
J. Johnson	Rosette Nutrient Analyst
University of Miami:	
Dr. R. Fine	Co-Principal Investigator
K. Sullivan	Rosette CFC Analyst
L. Pope	Rosette CFC Analyst
NERC/RVS:	
G. Miller	Instrumentation Technician
G. Knight	Computer System Manager
R. Griffiths	Mechanical Technician
K. Smith	Mechanical Technician

Officers and Engineers:	Crew:	
S. Mayl (Master)	C. Woods	J. Coleman
G. Harries	A. Olds	I. Gibb
S. Sykes	D. Buffery	G. Pook
G. Procter	M. Metcalfe	P. Hough
J. Baker	K. Peters	
D. Anderson	P. Bishop	
A. Greenhorn	J. McKeown	
W. Groody	A. Philp	

Table 2: RRS Charles Darwin Cruise #29 CTD Station Summary Information

Stn	Cast	Day/Mo/Yr	St GMT	End GMT	Latitude	Longitude	P Max	Depth	CTD
1-test	0	13/11/87	0625	0746	-31 35.07	31 10.56	3127	3107	9
2-test	0	13/11/87	1000	1100	-31 34.86	31 09.55	889	3071	8
2-test	1	13/11/87	1350	1420	-31 34.86	31 09.55	911	3071	8
2-test	2	13/11/87	1652	1723	-31 35.13	31 08.09	1505	3071	9
3	0	13/11/87	2035	2140	-31 22.54	30 50.10	2951	2931	9
4	0	14/11/87	0125	0230	-31 15.59	30 39.30	2935	2926	9
5	0	14/11/87	0546	0658	-31 12.09	30 35.84	2655	2675	9
6	0	14/11/87	0929	1025	-31 09.14	30 32.08	2247	2306	9
7	0	14/11/87	1219	1300	-31 06.12	30 27.82	1783	1739	9
8	0	14/11/87	1440	1508	-31 02.91	30 24.17	893	905	9
9	0	14/11/87	1637	1649	-31 02.95	30 22.07	247	290	9
10	0	14/11/87	1720	1729	-31 02.31	30 21.21	65	90	9
11-test	0	15/11/87	0332	0415	-30 18.46	31 19.84	1175	1178	8
12	0	16/11/87	0148	0303	-31 34.73	31 09.67	3107	3091	8
13	0	16/11/87	1138	1249	-31 56.62	31 36.31	3567	3535	8
14	0	16/11/87	1947	2122	-32 11.67	32 30.13	3581	3551	8
15	0	17/11/87	0442	0610	-32 32.75	33 24.74	3501	3491	8
16	0	17/11/87	1214	1310	-32 41.54	34 10.30	2461	2481	9
17	0	17/11/87	1849	1930	-32 53.96	35 00.12	1615	1593	9
18	0	17/11/87	2330	0008	-33 00.14	35 35.04	1469	1474	9
19	0	18/11/87	0340	0421	-32 59.37	36 04.75	2011	2006	9
20	0	18/11/87	0656	0750	-33 00.87	36 20.65	2603	2591	9
21	0	18/11/87	1029	1130	-33 00.69	36 30.87	3315	3304	9
22	0	18/11/87	1416	1551	-33 00.32	36 40.49	4755	4744	9
23	0	18/11/87	2033	2213	-32 59.65	37 04.82	5165	5108	9
24	0	19/11/87	0608	0742	-33 00.39	37 59.97	5127	5062	9
25	0	19/11/87	1802	1935	-32 59.42	39 29.43	5145	5092	9
26	0	20/11/87	0540	0714	-33 00.32	41 00.34	5097	5010	9
27	0	20/11/87	1752	1915	-32 59.71	42 44.81	4417	4352	9
28	0	20/11/87	2304	2350	-32 59.87	43 02.46	2337	2331	9
29	0	21/11/87	0420	0443	-32 59.95	43 40.13	909	906	9
30	0	21/11/87	0911	0933	-32 59.64	44 29.41	959	964	9
31	0	21/11/87	1815	1853	-33 12.41	46 04.79	2201	2196	9
32	0	21/11/87	2227	2321	-33 18.70	46 30.25	2673	2660	9
33	0	22/11/87	0302	0401	-33 22.78	46 54.98	3187	3147	9
34	0	22/11/87	0832	0940	-33 29.94	47 26.84	3629	3591	9
35	0	22/11/87	1538	1653	-33 33.66	48 14.68	4033	3976	9
36	0	23/11/87	0123	0245	-33 45.01	49 30.39	4397	4323	9
37	0	23/11/87	1135	1257	-33 59.75	50 55.55	4393	4336	9
38	0	23/11/87	2039	2206	-33 59.54	52 10.57	4587	4484	9
39	0	24/11/87	0249	0415	-33 59.91	52 44.66	4555	4444	9

Stn	Cast	Day/Mo/Yr	St GMT	End GMT	Latitude	Longitude	P Max	Depth	CTD
40	0	24/11/87	0904	1032	-34 00.42	53 10.22	4687	4607	9
41	0	24/11/87	1522	1649	-34 00.45	53 36.86	4613	4586	9
42	0	24/11/87	2148	2309	-34 00.73	54 07.11	4455	4393	9
43	0	25/11/87	0919	1052	-33 59.46	55 46.98	4387	4291	9
44	0	25/11/87	1945	2117	-33 58.35	57 02.08	5207	5129	9
45	0	26/11/87	0221	0401	-33 59.68	57 29.09	5433	5299	9
46	0	26/11/87	0953	1124	-33 59.93	58 10.05	5201	5093	9
47	0	26/11/87	1725	1842	-33 59.73	58 53.63	4011	3905	9
48	0	27/11/87	0218	0357	-33 59.61	59 56.99	5207	5150	9
49	0	27/11/87	0940	1124	-33 59.67	60 34.15	5447	5346	9
50	0	27/11/87	2102	2248	-33 59.37	61 59.67	5195	5125	9
51	0	28/11/87	1024	1146	-33 59.53	63 59.93	4755	4649	9
52	0	28/11/87	2340	0100	-33 59.81	66 00.21	4587	4582	9
53	0	29/11/87	1200	1321	-34 00.14	67 59.86	4619	4547	9
54	0	30/11/87	0120	0242	-33 59.95	70 00.33	4397	4302	9
55	0	30/11/87	1435	1606	-34 00.10	71 59.84	5063	4987	9
56	0	01/12/87	0133	0250	-33 19.52	73 20.15	4133	4109	9
57	0	01/12/87	1224	1330	-32 40.09	74 39.66	3789	3678	9
58	0	01/12/87	2354	0055	-31 59.89	76 00.09	3419	3380	9
59	0	02/12/87	0826	0923	-31 30.03	76 59.91	3033	2962	9
60	0	02/12/87	1510	1609	-31 07.67	77 44.36	3073	3003	9
61	0	02/12/87	2212	2313	-30 45.01	78 29.81	3557	3471	9
62	0	03/12/87	0522	0631	-30 22.43	79 15.32	3795	3739	9
63	0	03/12/87	1241	1345	-30 00.44	80 00.14	3565	3476	9
64	0	03/12/87	2125	2242	-29 30.23	80 59.51	4219	4129	9
65	0	04/12/87	0633	0739	-29 00.23	82 00.09	4173	4124	9
66	0	04/12/87	1816	1932	-29 09.41	83 29.55	4447	4368	9
67	0	05/12/87	0500	0613	-29 19.23	84 59.44	3993	3885	9
68	0	05/12/87	1315	1437	-29 27.94	85 58.69	4527	4470	9
69	0	05/12/87	2205	2311	-29 32.16	86 55.20	3587	3562	9
70	0	06/12/87	0540	0609	-29 39.75	87 50.08	1355	1228	9
71	0	06/12/87	1030	1107	-29 49.81	88 34.84	1843	1844	9
72	0	06/12/87	1649	1731	-30 04.66	89 29.86	2283	2282	9
73	0	07/12/87	0011	0046	-30 20.00	90 30.30	1663	1670	9
74	0	07/12/87	0825	0902	-30 40.05	91 49.63	1935	1928	9
75	0	07/12/87	1720	1746	-30 50.29	93 24.64	1237	1248	9
76	0	08/12/87	0101	0131	-31 10.82	94 26.11	1559	1571	9
77	0	08/12/87	0731	0755	-31 33.96	95 27.31	1213	1223	9
78	0	08/12/87	1401	1429	-31 59.70	96 29.67	1293	1305	9
79	0	08/12/87	2136	2210	-32 00.06	97 44.79	1619	1617	9
80	0	09/12/87	0451	0535	-31 59.88	99 00.12	2105	2089	9
81	0	09/12/87	1102	1147	-31 59.61	99 58.56	2423	2407	9
82	0	09/12/87	1822	1906	-31 59.94	100 59.48	2235	2228	9

Stn	Cast	Day/Mo/Yr	St GMT	End GMT	Latitude	Longitude	P Max	Depth	CTD
83	0	10/12/87	0036	0128	-32 14.54	101 49.73	2873	2842	9
84	0	10/12/87	0429	0538	-32 20.11	102 00.03	3785	3740	9
85	0	10/12/87	0953	1105	-32 24.90	102 29.69	4069	4014	9
86	0	10/12/87	1356	1520	-32 29.73	102 39.41	4633	4544	9
87	0	10/12/87	1917	2045	-32 35.90	102 59.45	4855	4779	9
88	0	11/12/87	0109	0248	-32 44.88	103 24.00	5341	5261	9
89	0	11/12/87	0824	1003	-32 54.91	103 59.00	5559	5467	9
90	0	11/12/87	1519	1658	-33 05.54	104 30.27	5535	5508	9
91	0	11/12/87	2207	2353	-33 14.90	105 00.14	6053	5927	9
92	0	12/12/87	0646	0826	-33 26.35	105 44.89	5417	5415	9
93	0	12/12/87	1524	1717	-33 39.61	106 29.47	5607	5514	9
94	0	13/12/87	0013	0204	-33 53.66	107 13.45	5385	5302	9
95	0	13/12/87	0846	0958	-34 09.78	107 59.77	5065	4984	8
96	0	13/12/87	1514	1701	-34 09.85	108 34.38	5545	5452	9
97	0	13/12/87	2226	0014	-34 10.00	109 09.05	5145	5014	9
98	0	14/12/87	0514	0620	-34 09.89	109 42.30	3303	3260	9
99	0	14/12/87	0920	1018	-34 09.92	110 00.08	2589	2572	9
100	0	14/12/87	1647	1736	-34 09.80	110 59.81	2123	2123	9
101	0	15/12/87	0012	0109	-34 09.66	112 09.72	2635	2627	9
102	0	15/12/87	1201	1259	-34 09.26	113 29.39	3041	3023	9
103	0	15/12/87	1613	1709	-34 10.10	113 43.81	2223	2208	9
104	0	15/12/87	1945	2023	-34 10.06	113 59.84	1503	1508	9
105	0	15/12/87	2240	2307	-34 10.93	114 14.53	1069	1078	9
106	0	16/12/87	0049	0111	-34 10.22	114 24.64	685	700	9
107	0	16/12/87	0220	0226	-34 09.71	114 30.26	141	160	9
108	0	16/12/87	0353	0358	-34 10.27	114 44.85	111	130	9
109	0	16/12/87	0438	0440	-34 09.52	114 49.64	41	55	9

Table 3: RRS Charles Darwin Cruise #29 XBT Station Summary Information

XBT #	JDAY (1987)	Time (GMT)	Latitude (S)	Longitude (E)	Surftemp (C)	Surfsalt (psu)	Comment
7-2A	320	0753	31 46.89	31 07.69	20.9	- - -	
7-3A	320	0855	31 48.76	31 11.58	21.0	- - -	
7-4A	320	0953	31 51.14	31 20.71	21.0	- - -	
7-5A	320	1052	31 53.46	31 29.22	20.9	- - -	
7-6A	320	1546	32 59.00	31 41.80	20.8	- - -	
7-7A	320	1655	32 03.98	31 53.61	20.7	- - -	
7-8A	320	1749	32 07.13	32 05.98	20.7	- - -	
7-9A	320	1846	32 09.50	32 17.70	20.7	- - -	
7-10A	320	2351	32 13.71	32 36.47	20.5	- - -	
7-11A	321	0045	32 17.81	32 46.22	20.3	- - -	
7-12A	321	0146	32 23.32	32 55.55	20.1	- - -	no good

XBT #	JDAY (1987)	Time (GMT)	Latitude (S)	Longitude (E)	Surftemp (C)	Surfsalt (psu)	Comment
7-13A	321	0215	32 24.45	33 00.00	20.0	- - -	redo
7-14A	321	0316	32 28.42	33 10.30	20.0	- - -	no good
7-15A	321	0336	32 30.18	33 13.54	20.1	- - -	redo
7-16A	321	0909	32 36.43	33 36.19	19.9	- - -	
7-17A	321	1004	32 39.01	33 45.57	19.9	- - -	no good
7-18A	321	1005	32 39.01	33 45.57	19.9	- - -	redo
7-19A	321	1108	32 40.96	33 57.75	20.1	- - -	
7-20A	321	1510	32 43.61	34 17.76	20.2	- - -	
7-21A	321	1530	32 45.18	34 21.30	20.3	- - -	
7-22A	321	1629	32 49.36	34 32.30	20.2	- - -	
7-23A	321	1727	32 52.30	34 43.24	20.1	- - -	
7-24A	321	1815	32 54.57	34 54.04	20.1	- - -	
7-25A	321	2133	32 56.37	35 14.16	20.1	- - -	
7-26A	321	2230	32 58.48	35 25.60	19.3	- - -	
7-27A	322	0204	33 00.00	35 48.48	19.7	- - -	no good
7-28A	322	0216	33 00.00	35 51.00	19.7	- - -	redo
7-29A	322	1132	33 00.87	36 32.91	19.9	- - -	
7-30A	322	1930	32 59.42	36 52.96	19.2	- - -	
7-31A	323	0138	33 00.06	37 12.24	19.0	- - -	
7-32A	323	0244	33 01.18	37 24.12	18.9	- - -	
7-33A	323	0343	33 00.48	37 34.18	19.0	- - -	
7-34A	323	0442	33 00.42	37 45.36	19.0	- - -	
7-35A	323	1122	32 59.83	38 07.79	19.1	35.76	
7-36A	323	1227	33 02.98	38 20.91	19.8	35.62	
7-37A	323	1330	33 02.42	38 33.48	19.3	35.72	
7-38A	323	1429	33 03.00	38 47.48	18.9	35.74	
7-39A	323	1529	33 02.54	39 00.48	18.9	35.62	
7-39B	323	1630	33 01.60	39 12.90	19.1	- - -	
7-40A	323	2330	32 59.56	39 45.02	19.1	35.71	
7-41A	324	0024	33 00.89	39 56.27	19.0	35.71	
7-42A	324	0129	33 00.54	40 10.30	18.8	35.74	
7-43A	324	0140	33 00.48	40 12.54	18.7	35.74	
7-44A	324	0244	33 00.24	40 27.12	18.8	35.74	
7-45A	324	0344	32 59.54	40 40.12	18.8	35.74	
7-46A	324	0445	33 00.06	40 53.12	18.7	35.74	
7-47A	324	1026	33 00.11	41 10.10	19.3	35.70	
7-48A	324	1128	33 00.08	41 22.70	18.9	35.70	
7-48B	324	1128	33 00.08	41 22.70	18.9	35.70	
7-49A	324	1337	33 02.40	41 52.30	20.7	- - -	
7-50A	324	1429	33 02.70	42 03.20	19.6	- - -	
7-51A	324	1606	33 01.54	42 24.06	20.7	- - -	
7-52A	324	1619	33 01.48	42 27.06	20.9	- - -	

XBT #	JDAY (1987)	Time (GMT)	Latitude (S)	Longitude (E)	Surftemp (C)	Surfsalt (psu)	Comment
7-53A	324	1720	33 00.28	42 39.49	19.9	- - -	
7-54A	324	2200	33 00.16	42 51.67	20.7	35.59	
7-55A	325	0214	32 59.85	43 17.27	19.2	35.65	
7-56A	325	0319	32 59.48	43 30.36	19.2	35.62	
7-57A	325	0614	33 00.38	43 50.29	19.1	35.62	
7-58A	325	0715	32 59.04	44 06.50	19.9	- - -	
7-59A	325	0815	32 59.30	44 20.39	19.7	- - -	
7-60A	325	1131	33 00.73	44 45.69	19.7	35.66	
7-60B	325	On data tape, but not listed in station log with all information					
7-61A	325	1306	33 04.73	45 04.00	18.9	35.63	
7-62A	325	1410	33 08.37	45 16.34	18.8	35.62	
7-63A	325	1526	33 11.00	45 30.54	18.7	35.64	
7-64A	325	1546	33 11.28	45 34.48	19.2	35.63	
7-65A	325	1648	33 12.70	45 48.50	18.8	- - -	
7-66A	325	2100	33 14.88	46 14.98	19.3	35.57	
7-66B	325	2100	33 14.88	46 14.98	19.3	35.57	
7-67B	326	0721	33 25.36	47 13.12	19.4	- - -	no good
7-68A	326	0751	33 26.36	47 18.36	19.3	- - -	
7-69A	326	1220	33 30.30	47 36.70	19.2	- - -	
7-70A	326	1258	33 30.54	47 44.18	20.0	- - -	
7-71A	326	1328	33 33.55	47 51.15	20.0	- - -	
7-72A	326	1349	33 33.54	47 54.30	- - -	- - -	
7-73A	326	1448	33 33.60	47 06.20	- - -	- - -	
7-74A	326	1952	33 37.66	48 26.11	- - -	- - -	
7-75A	326	2056	33 38.67	48 37.86	19.3	35.55	
7-76A	326	2202	33 40.33	48 51.08	19.3	35.56	
7-77A	326	2303	33 41.58	49 04.10	19.3	35.57	
7-78A	327	0003	33 43.00	49 16.06	19.6	35.62	
7-79A	327	0558	33 47.50	49 43.16	20.3	- - -	
7-80A	327	0700	33 49.64	50 56.18	20.2	- - -	
7-81A	327	0857	33 56.62	50 22.41	20.6	35.75	
7-82A	327	1002	33 57.04	50 37.36	20.1	35.76	
7-83A	327	1055	33 58.18	50 48.64	20.7	35.77	
7-84A	327	1600	33 59.19	51 09.09	21.5	- - -	
7-85A	327	1700	34 00.48	51 29.91	21.1	- - -	
7-86A	327	1800	34 01.30	51 37.19	20.8	- - -	
7-87A	327	1900	34 01.01	51 50.85	20.0	- - -	
7-88A	328	0058	33 59.12	52 21.54	20.1	35.78	
7-89A	328	0204	34 00.06	52 35.54	20.0	35.76	
7-90A	328	0701	33 59.32	52 51.57	20.2	- - -	
7-91A	328	1340	33 59.44	53 21.54	20.1	35.75	
7-92A	328	2003	34 00.69	53 52.09	19.5	35.74	

XBT #	JDAY (1987)	Time (GMT)	Latitude (S)	Longitude (E)	Surftemp (C)	Surfsalt (psu)	Comment
7-93A	328	2100	34 01.27	54 03.69	20.0	35.74	
7-94A	329	0223	34 01.30	54 18.54	20.2	35.75	
7-95A	329	0322	34 00.54	54 29.24	19.7	35.74	
7-96A	329	0430	34 00.95	54 46.50	19.5	35.77	
7-97A	329	0530	34 01.00	54 59.00	19.1	35.72	
7-80B	329	0631	34 01.35	55 11.58	18.9	35.73	
7-81B	329	0802	34 01.32	55 31.76	20.0	35.77	
7-98A	329	1517	3359.59	55 59.77	- - -	- - -	
7-99A	329	1615	3359.95	5611.91	19.2	35.73	
7-100A	329	1715	33 59.65	56 26.34	19.1	35.77	
7-101A	329	1815	34 00.62	56 35.49	19.5	35.71	
7-102A	329	1915	34 01.02	56 52.50	18.7	35.70	
7-103A	330	0029	34 00.24	57 07.12	18.7	35.69	
7-104A	330	0128	34 00.24	57 19.18	18.3	35.69	
7-105A	330	0730	34 00.68	57 40.17	19.0	35.72	
7-106A	330	0830	34 00.07	57 53.21	19.0	35.72	
7-107A	330	1439	33 59.42	58 19.54	18.8	35.65	no good
7-109A	330	1506	33 59.10	58 25.20	18.7	- - -	redo
7-115A	331	1015	34 00.00	60 34.00	- - -	- - -	no good
7-118A	331	1653	33 59.60	61 11.00	18.9	35.64	
7-120A	331	1943	34 00.83	61 45.37	19.1	35.62	
7-121A	331	2000	34 00.87	61 48.50	19.2	35.64	
7-122A	332	0158	33 59.54	62 11.00	18.9	35.60	
7-124A	332	0428	34 00.12	62 40.42	19.1	35.65	
7-127A	332	0656	34 01.06	63 14.34	19.3	35.67	
7-128A	332	0754	34 01.09	63 28.02	19.3	35.68	
7-129A	332	0856	34 00.36	63 41.97	19.4	35.65	
7-130A	332	1500	33 58.72	64 13.82	19.5	35.77	
7-131A	332	1600	34 00.29	64 27.39	19.2	35.66	
7-132A	332	1700	34 00.74	64 39.37	19.1	35.68	
7-133A	332	1800	34 02.09	64 52.44	19.2	35.67	
7-134A	332	1922	34 02.39	65 08.87	18.8	35.64	
7-135A	332	2013	34 01.18	65 19.55	18.9	35.62	
7-136A	332	2111	34 00.07	65 30.89	19.3	35.72	
7-137A	332	2200	33 59.96	65 41.03	19.6	35.83	
7-138A	333	0358	34 00.90	66 10.33	19.0	35.75	
7-139A	333	0500	34 00.75	66 22.29	18.9	35.75	
7-140A	333	0600	34 01.01	66 36.47	18.9	35.75	
7-141A	333	0704	34 00.64	66 51.21	19.1	35.75	
7-142A	333	0800	34 00.96	67 05.38	19.3	35.78	
7-143A	333	0858	34 00.61	67 18.82	19.4	35.80	
7-144A	333	0959	34 00.24	67 32.82	19.8	35.84	

XBT #	JDAY (1987)	Time (GMT)	Latitude (S)	Longitude (E)	Surftemp (C)	Surfsalt (psu)	Comment
7-145A	333	1101	33 59.36	67 47.18	19.8	35.84	
7-146A	333	1631	33 58.64	68 11.92	19.1	35.73	
7-147A	333	1730	33 59.94	68 24.50	19.1	35.73	
7-148A	333	1828	34 00.23	68 36.71	18.3	35.66	
7-149B	333	1925	34 00.27	68 48.91	18.3	35.65	redo
7-150A	333	2028	34 00.00	69 02.41	18.2	35.61	
7-151A	333	2126	33 59.99	69 14.48	18.1	35.59	
7-152A	333	2226	33 59.77	69 25.87	18.1	35.60	
7-153A	333	2322	33 59.24	69 37.42	18.6	35.68	
7-154A	334	0027	34 00.06	69 51.00	19.0	35.78	
7-155A	334	0529	34 00.65	70 11.15	18.9	35.78	
7-156A	334	0630	34 00.06	70 22.55	18.8	35.78	
7-157A	334	0727	34 00.42	70 34.67	18.4	35.73	
7-158A	334	0828	34 00.43	70 46.91	17.9	35.54	
7-159A	334	0923	34 00.42	70 58.29	17.7	35.55	
7-160A	334	1021	34 00.07	71 08.94	17.9	35.58	
7-161A	334	1130	34 00.06	71 22.42	17.7	35.54	
7-163A	334	1243	34 00.50	71 37.20	17.9	34.44	
7-164A	334	1331	34 00.18	71 47.24	17.8	35.48	
7-165A	334	1923	33 55.03	72 11.04	17.9	35.51	
7-166A	334	2022	33 49.53	72 21.30	18.0	35.55	
7-167A	334	2121	33 46.80	72 36.55	18.5	35.85	
7-168A	334	2222	33 40.65	72 47.42	18.5	35.89	
7-169A	334	2330	33 33.20	72 58.10	18.3	35.88	
7-170A	335	0031	33 25.48	73 09.18	18.4	35.86	
7-171A	335	0530	33 15.71	73 28.18	18.6	35.92	
7-172A	335	0630	33 10.29	73 38.14	18.6	35.92	
7-173A	335	0721	33 05.50	73 50.79	18.4	35.70	
7-174A	335	0823	32 59.38	74 02.73	18.8	35.74	
7-175A	335	0921	32 54.10	74 12.72	19.1	35.83	
7-176A	335	1022	32 48.21	74 23.69	19.3	35.96	
7-177A	335	1121	32 45.24	74 31.30	19.2	35.97	
7-178A	335	1630	32 36.08	74 51.11	19.1	35.99	
7-179A	335	1730	32 31.21	75 00.12	19.3	35.98	
7-180A	335	1831	32 26.07	75 09.35	19.3	35.98	
7-181A	335	1922	32 22.03	75 16.53	19.3	35.97	
7-182A	335	2021	32 16.93	75 24.87	19.2	35.95	
7-183A	335	2123	32 11.89	75 37.87	18.9	35.94	
7-184A	335	2223	32 06.92	75 47.38	19.3	35.98	
7-185A	336	0330	31 55.73	76 07.76	18.8	35.95	
7-186A	336	0430	31 51.78	76 20.56	18.9	35.97	
7-187A	336	0530	31 46.43	76 31.79	19.0	35.97	

XBT #	JDAY (1987)	Time (GMT)	Latitude (S)	Longitude (E)	Surftemp (C)	Surfsalt (psu)	Comment
7-188A	336	0630	31 40.80	76 41.72	19.8	35.96	
7-189A	336	0722	31 35.80	76 51.29	18.7	35.82	
7-190A	336	1147	31 25.48	77 07.18	19.3	35.99	
7-191A	336	1243	31 21.42	77 19.48	19.6	36.04	
7-192A	336	1358	31 14.54	77 31.18	19.0	36.03	
7-193A	336	1455	31 08.29	77 42.30	19.7	35.99	
7-194A	336	1825	31 03.82	77 53.01	20.1	36.00	no record
7-194B	336	1922	30 59.36	78 03.71	20.0	36.00	
7-195A	336	2028	30 53.63	78 14.04	19.4	36.02	
7-196A	336	2122	30 48.36	78 23.27	19.3	36.03	
7-197A	337	0144	30 40.42	78 37.06	19.4	36.01	
7-198A	337	0245	30 35.83	78 48.51	19.1	36.01	
7-199A	337	0345	30 30.41	78 58.89	19.2	36.01	
7-200A	337	0446	30 24.89	79 10.84	18.9	35.82	
7-201A	337	0825	30 21.59	79 16.78	19.7	35.93	
7-202A	337	0926	30 17.15	79 27.45	20.3	35.99	
7-203A	337	1030	30 12.06	79 37.24	20.2	35.99	
7-207A	337	1130	30 06.50	79 49.20	20.1	35.72	
7-208A	337	1231	30 00.24	79 59.18	20.1	35.99	
7-209A	337	1600	29 57.78	80 04.74	20.0	36.00	
7-210A	337	1700	29 52.86	80 16.06	19.9	36.00	
7-211A	337	1759	29 48.38	80 25.06	19.8	36.02	
7-212A	337	1856	29 43.67	80 36.08	19.7	36.02	
7-213A	337	1958	29 38.42	80 45.89	19.6	36.07	
7-214A	337	2059	29 30.84	80 56.30	19.8	36.01	
7-215A	338	0144	29 25.06	81 07.30	19.0	35.94	
7-216A	338	0245	29 20.39	81 19.49	18.9	35.84	
7-217A	338	0347	29 15.34	81 29.71	19.5	35.93	
7-218A	338	0445	29 09.12	81 42.93	19.6	35.97	
7-219A	338	0545	29 03.74	81 54.20	19.8	35.89	
7-220A	338	0930	28 59.10	82 02.13	21.0	35.97	
7-221A	338	1049	29 01.48	82 18.48	21.2	35.89	
7-222A	338	1147	29 05.00	82 29.36	21.0	35.92	
7-223A	338	1245	29 07.00	82 40.42	21.2	35.89	
7-224A	338	1349	29 08.56	82 53.77	21.6	35.81	
7-225A	338	1445	29 09.32	83 05.14	21.8	35.83	
7-226A	338	1545	29 10.25	83 18.76	22.0	35.78	
7-227A	338	2220	29 10.94	83 38.46	21.2	35.85	
7-228A	338	2322	29 13.06	83 51.06	21.2	35.82	
7-229A	339	0022	29 14.42	84 03.30	21.6	35.82	
7-230A	339	0122	29 16.00	84 15.00	21.6	35.79	
7-231A	339	0230	29 17.62	84 30.41	21.4	35.81	

XBT #	JDAY (1987)	Time (GMT)	Latitude (S)	Longitude (E)	Surftemp (C)	Surfsalt (psu)	Comment
7-232A	339	0330	29 19.18	84 42.66	21.4	35.95	
7-233A	339	0900	29 20.95	85 08.73	22.0	36.01	
7-234A	339	1101	29 26.24	85 33.42	22.4	36.07	
7-235A	339	1217	29 27.48	85 49.12	22.5	35.97	
7-236A	339	1731	29 27.94	86 07.15	21.5	36.03	
7-237A	339	1827	29 28.70	86 17.57	21.4	36.03	
7-238A	339	1928	29 29.60	86 28.83	21.5	36.04	
7-239A	339	2022	29 33.29	86 39.60	21.7	36.03	
7-240A	339	2128	29 33.57	86 50.11	21.5	36.01	
7-241A	340	0205	29 35.34	87 07.03	21.3	36.00	
7-242A	340	0300	29 36.79	87 17.98	21.3	35.94	
7-243A	340	0400	29 38.99	87 31.13	21.6	35.95	
7-244A	340	0500	29 39.87	87 43.53	21.6	36.00	
7-245A	340	0721	29 42.75	87 55.26	21.7	36.99	
7-246A	340	0825	29 45.45	88 10.15	21.5	36.00	
7-247A	340	0926	29 47.96	88 22.93	22.0	36.00	
7-248A	340	1316	29 52.90	88 50.60	21.3	36.00	
7-249A	340	1415	29 56.30	89 01.80	21.3	37.02	
7-250A	340	1515	29 59.63	89 12.80	21.1	36.02	
7-251A	340	1615	30 03.44	89 24.32	21.1	36.01	
7-252A	340	1922	30 07.13	89 38.07	21.0	35.99	
7-253A	340	2030	30 10.98	89 50.92	20.5	35.96	
7-254A	340	2130	30 14.00	90 00.68	20.8	35.94	
7-255A	340	2231	30 16.12	90 12.24	20.6	36.01	
7-256A	340	2330	30 18.00	90 23.18	21.3	36.01	
7-257A	341	0230	30 22.16	90 40.81	21.1	36.04	
7-258A	341	0330	30 25.00	90 53.39	21.2	36.05	
7-259A	341	0430	30 28.81	91 04.98	21.4	36.03	
7-260A	341	0530	30 31.66	91 16.84	21.0	36.05	
7-261A	341	0622	30 34.55	91 27.08	20.5	35.94	
7-262A	341	0724	30 36.73	91 40.28	20.8	35.93	
7-263A	341	1110	30 42.30	92 02.20	20.8	- - -	
7-264A	341	1230	30 45.20	92 19.10	20.4	35.95	
7-265A	341	1332	30 46.12	92 30.48	20.3	35.98	
7-267A	341	1432	30 46.92	92 41.91	19.5	35.85	
7-268A	341	1530	30 48.21	92 53.40	19.5	35.85	
7-269A	341	1630	30 49.12	92 05.56	19.5	35.85	
7-270A	341	1930	30 54.09	93 26.84	19.6	35.95	
7-271A	341	2024	30 56.73	93 37.21	19.6	35.91	
7-272A	341	2126	30 59.51	93 48.22	19.3	35.92	
7-273A	341	2231	31 03.00	93 59.12	20.0	36.02	
7-274A	341	2331	31 06.10	94 10.60	20.0	36.03	

XBT #	JDAY (1987)	Time (GMT)	Latitude (S)	Longitude (E)	Surftemp (C)	Surfsalt (psu)	Comment
7-275A	342	0030	31 08.70	94 21.10	20.0	36.05	
7-276A	342	0330	31 18.48	94 41.29	19.4	35.89	
7-277A	342	0430	31 21.28	94 51.93	19.7	35.95	
7-278A	342	0523	31 25.53	95 02.59	19.7	35.95	
7-279A	342	0627	31 31.54	95 15.51	19.7	35.95	
7-280A	342	0930	31 38.48	95 39.48	19.5	35.99	
7-281A	342	1030	31 43.30	95 52.20	19.5	35.99	
7-282A	342	1129	31 47.36	96 02.54	18.9	35.66	
7-283A	342	1226	31 52.24	96 12.30	19.2	35.81	
7-284A	342	1330	31 58.11	96 24.68	19.1	35.82	
7-285A	342	1527	32 00.52	96 33.29	18.7	35.89	
7-286A	342	1629	32 00.27	96 45.81	19.1	35.65	
7-287A	342	1732	32 00.46	96 57.93	18.2	35.59	
7-288A	342	1824	32 00.19	97 08.04	18.3	35.61	
7-289A	342	1925	31 59.98	97 19.80	18.7	35.58	
7-290A	342	2025	32 01.03	97 32.11	19.3	35.82	
7-291A	343	0002	32 00.60	97 55.80	19.0	36.02	
7-292A	343	0115	32 00.45	98 10.61	19.2	36.05	
7-293A	343	0212	32 00.79	98 24.35	18.8	36.04	
7-294A	343	0330	32 00.51	98 42.29	19.2	36.05	
7-295A	343	0430	31 59.90	98 56.01	19.3	36.05	
7-296A	343	0730	32 00.10	99 12.96	19.1	36.07	
7-297A	343	0826	32 59.72	99 25.55	19.2	36.02	
7-298A	343	0929	32 00.00	99 40.06	19.4	36.02	
7-299A	343	1031	31 59.30	99 53.60	18.3	35.68	
7-300A	343	1330	31 59.77	100 06.34	17.9	35.65	
7-301A	343	1430	32 00.00	100 18.21	18.1	35.63	
7-302A	343	1530	32 01.19	100 28.54	18.5	35.84	
7-303A	343	1630	32 00.71	100 40.19	17.5	35.64	
7-304A	343	1726	32 00.89	100 50.66	17.8	35.50	
7-305A	343	2027	32 01.65	101 02.73	18.3	35.84	
7-306A	343	2132	32 05.00	101 16.12	18.2	35.90	
7-307A	343	2229	32 09.06	101 25.48	18.4	35.88	
7-308A	343	2330	32 12.30	101 37.60	18.0	35.74	no good
7-309A	344	0828	32 22.34	102 14.04	18.0	35.74	
7-310A	344	2400	32 39.66	103 12.05	17.6	35.75	
7-311A	345	0601	32 47.66	103 34.13	18.1	35.92	
7-312A	345	0655	32 50.67	103 43.92	17.9	35.91	
7-313A	345	1344	32 59.95	104 13.47	17.9	35.98	
7-314A	345	2013	33 09.12	104 41.65	18.3	35.93	
7-315A	345	2115	33 16.50	104 52.00	17.9	35.94	
7-316A	346	0330	33 18.00	105 10.70	18.0	35.91	

XBT #	JDAY (1987)	Time (GMT)	Latitude (S)	Longitude (E)	Surftemp (C)	Surfsalt (psu)	Comment
7-317A	346	0430	33 21.94	105 22.08	18.1	35.93	
7-318A	346	1210	33 28.84	105 57.11	19.3	36.01	
7-319A	346	1310	33 32.52	106 07.10	19.3	36.02	
7-320A	346	1410	33 36.49	106 16.45	19.1	36.01	
7-321B	346	2057	33 44.24	106 40.18	18.7	36.00	no good
7-322A	346	2129	33 46.30	106 45.30	18.7	36.00	due to bad
7-322B	346	2144	33 47.18	106 47.54	18.6	36.00	launcher
7-777A	346	- - -	- - - - - - -	- - - - - - -	- - -	- - -	test/cal stn 94
7-323A	347	0530	33 58.42	107 26.95	17.4	35.84	
7-324A	347	0628	34 02.38	107 36.86	17.4	35.84	
7-325A	347	0724	34 05.87	107 47.10	17.3	35.85	
7-326A	347	1310	34 10.00	108 11.26	17.1	35.83	
7-327A	347	1413	34 10.15	108 23.05	17.1	35.83	
7-328A	347	2023	34 10.18	108 47.06	17.2	35.79	
7-329A	347	2120	34 10.42	108 58.06	17.3	35.79	
7-330A	348	0340	34 10.50	109 24.07	17.3	35.80	
7-331A	348	0430	34 10.82	109 35.23	17.3	35.80	
7-332A	348	0845	34 09.48	109 54.36	17.4	35.79	
7-332B	348	1159	34 09.92	110 05.43	17.3	35.77	
7-333A	348	1258	34 10.58	110 17.81	17.2	35.77	
7-334A	348	1400	34 19.93	110 27.84	16.9	35.67	
7-335A	348	1500	34 11.00	110 40.88	16.8	35.70	
7-336A	348	1600	34 10.69	110 51.98	17.2	35.72	
7-337A	348	1923	34 09.80	111 09.00	18.0	35.89	
7-338A	348	2029	34 10.30	111 23.42	18.0	35.89	
7-339A	348	2129	34 10.30	111 36.06	18.0	35.89	
7-340A	348	2229	34 10.18	111 48.42	18.0	35.90	
7-341A	348	2330	34 10.00	111 58.60	18.0	35.89	
7-342A	349	0300	34 10.32	112 19.33	17.9	35.77	
7-343A	349	0405	34 10.79	112 33.99	17.9	35.85	
7-344A	349	0828	34 09.54	112 47.48	17.8	36.65	
7-345A	349	0930	34 09.80	113 00.70	- - -	- - -	
7-346A	349	1027	34 10.24	113 12.54	18.9	35.93	
7-347A	349	1129	34 10.10	113 24.30	18.9	35.93	

Table 4: Parameters of the CTD Oxygen Algorithm Used to Calibrate RRS Charles Darwin Cruise #29 CTD Oxygen Data

Stations	C	alpha a	D	E	F	beta b
1	0.163	0.532	0.1456E-03	-0.1107E-01	0.3594E+00	0.8115E+01
3-5	0.061	0.666	0.1581E-03	-0.2037E-01	0.1019E+01	0.8000E+01
6-7	0.007	0.767	0.1557E-03	-0.2738E-01	0.9145E+00	0.6274E+01

Stations	C	alpha a	D	E	F	beta b
11-12	-0.020	0.798	0.1954E-03	-0.2367E-01	0.1943E+00	0.1780E+02
13-15	-0.003	0.795	0.1701E-03	-0.2317E-01	0.8059E+00	0.8016E+01
16-19	0.040	0.660	0.1887E-03	-0.2089E-01	0.5664E+00	0.3696E+01
20-22	0.024	0.744	0.1509E-03	-0.2653E-01	0.8161E+00	0.4182E+01
23-24	0.026	0.748	0.1455E-03	-0.2537E-01	0.1252E+01	0.8000E+01
25	0.009	0.801	0.1478E-03	-0.3024E-01	0.7307E+00	0.8000E+01
26	0.023	0.794	0.1390E-03	-0.2896E-01	0.8505E+00	0.7994E+01
27	0.049	0.725	0.1434E-03	-0.2417E-01	0.8776E+00	0.8000E+01
28-36	0.028	0.755	0.1462E-03	-0.2562E-01	0.9920E+00	0.4370E+01
37	0.108	0.648	0.1215E-03	-0.2436E-01	0.4646E+00	0.7990E+01
38	0.113	0.651	0.1227E-03	-0.2101E-01	0.5163E+00	0.7973E+01
39-42	0.038	0.747	0.1413E-03	-0.2674E-01	0.8302E+00	0.2819E+01
43-47	0.050	0.720	0.1400E-03	-0.2352E-01	0.1068E+01	0.4720E+00
48-55	0.036	0.748	0.1428E-03	-0.2513E-01	0.8710E+00	0.7999E+01
56	0.038	0.746	0.1427E-03	-0.2753E-01	0.7105E+00	0.7994E+01
57-58	0.053	0.719	0.1402E-03	-0.2225E-01	0.8985E+00	0.6000E+01
59-60	0.026	0.758	0.1525E-03	-0.2478E-01	0.9031E+00	0.8000E+01
61-64	0.037	0.739	0.1472E-03	-0.2357E-01	0.9310E+00	0.8005E+01
65-67	0.043	0.729	0.1457E-03	-0.2326E-01	0.7681E+00	0.8000E+01
68-69	0.046	0.725	0.1421E-03	-0.2223E-01	0.8972E+00	0.8000E+01
70-81	0.028	0.706	0.1784E-03	-0.2004E-01	0.7328E+00	0.8000E+01
82-83	0.036	0.711	0.1665E-03	-0.2107E-01	0.5484E+00	0.8000E+01
84-88	0.009	0.807	0.1471E-03	-0.2730E-01	0.8875E+00	0.8000E+01
89-91	0.029	0.777	0.1409E-03	-0.2612E-01	0.7450E+00	0.8001E+01
92-93	0.037	0.763	0.1394E-03	-0.2631E-01	0.7288E+00	0.7996E+01
95	-0.017	1.445	0.1000E-03	-0.2231E-01	0.7375E+00	0.8000E+01
96	0.049	0.757	0.1348E-03	-0.2692E-01	0.5672E+00	0.8000E+01
97-102	0.037	0.763	0.1394E-03	-0.2631E-01	0.7288E+00	0.7996E+01

Table 5: RRS Charles Darwin Cruise #29 Average Along- and Across-Track ADCP Velocity Estimates

Station Number		Along-Track Average ADCP Velocity m/s	Across-Track Average ADCP Velocity m/s	Across-Track ADCP-GEOST Velocity m/s
3	12	-0.220	-0.390	-0.096
4	3	-0.223	-0.649	0.031
5	4	-0.153	-0.731	-0.117
6	5	0.048	-0.890	0.327
7	6	-0.203	-1.040	0.315
8	7	-0.027	-0.917	0.398
9	8	-0.359	-0.289	0.086
12	13	0.031	-0.353	-0.087

Station Number		Along-Track Average ADCP Velocity m/s	Across-Track Average ADCP Velocity m/s	Across-Track ADCP-GEOST Velocity m/s
13	14	0.067	-0.026	0.026
14	15	0.040	-0.072	-0.060
15	16	-0.112	-0.050	0.013
16	17	-0.030	0.092	0.048
17	18	0.054	0.128	0.046
18	19	0.111	0.026	-0.026
19	20	0.013	-0.035	0.001
20	21	-0.035	-0.032	0.083
21	22	-0.143	-0.088	0.124
22	23	-0.086	-0.040	0.136
23	24	-0.271	0.048	0.003
24	25	-0.167	-0.025	-0.046
25	26	-0.007	0.086	-0.039
26	27	0.106	-0.023	0.032
27	28	0.000	-0.058	0.262
28	29	0.039	-0.045	-0.096
29	30	0.112	0.112	0.063
30	31	-0.186	0.171	0.132
31	32	-0.089	0.040	0.006
32	33	-0.033	-0.030	-0.081
33	34	-0.062	0.074	0.051
34	35	-0.093	-0.023	-0.022
35	36	-0.065	-0.070	-0.008
36	37	0.067	-0.032	0.023
37	38	0.237	-0.008	0.010
38	39	0.204	-0.027	-0.074
39	40	0.345	0.047	0.036
40	41	0.181	-0.012	-0.057
41	42	0.224	0.015	0.031
42	43	0.055	0.023	0.016
43	44	-0.313	0.094	0.083
44	45	-0.059	-0.021	0.017
45	46	-0.003	-0.126	-0.033
46	47	-0.236	-0.114	-0.101
47	48	-0.342	0.003	-0.053
48	49	-0.152	0.105	-0.014
49	50	-0.041	-0.028	-0.052
50	51	0.031	-0.041	-0.038
51	52	-0.078	-0.108	-0.088
52	53	0.032	-0.014	-0.008
53	54	0.140	-0.003	-0.025

Station Number		Along-Track Average ADCP Velocity m/s	Across-Track Average ADCP Velocity m/s	Across-Track ADCP-GEOST Velocity m/s
54	55	0.067	0.051	-0.024
55	56	0.027	0.055	0.048
56	57	0.038	-0.038	0.060
57	58	-0.059	0.000	0.003
58	59	0.019	0.095	0.059
59	60	0.013	0.081	0.013
60	61	0.071	0.017	0.034
61	62	0.083	0.030	-0.036
62	63	0.094	0.000	0.030
63	64	0.115	0.062	-0.001
64	65	0.067	0.042	0.030
65	66	0.040	-0.051	0.001
66	67	0.091	0.004	-0.017
67	68	0.015	0.123	-0.006
68	69	0.013	-0.082	0.066
69	70	0.108	-0.099	-0.097
70	71	0.305	0.029	-0.014
71	72	0.188	0.044	-0.057
72	73	0.218	-0.089	-0.033
73	74	0.103	0.023	-0.022
74	75	-0.065	-0.016	-0.003
75	76	0.017	-0.078	-0.040
76	77	0.071	-0.106	-0.010
77	78	-0.035	0.132	0.021
78	79	0.007	-0.074	-0.037
79	80	0.213	-0.074	0.026
80	81	0.360	0.175	-0.001
81	82	0.092	0.043	0.034
82	83	0.153	0.019	-0.019
83	84	-0.002	-0.044	0.048
84	85	0.020	-0.046	0.029
85	86	0.194	-0.023	-0.053
86	87	0.071	0.087	-0.017
87	88	0.067	0.075	0.034
88	89	0.057	0.031	0.028
89	90	0.022	0.037	0.005
90	91	0.018	-0.041	0.039
91	92	-0.097	0.101	0.037
92	93	-0.354	0.069	0.021
93	94	-0.129	-0.033	0.017
94	95	-0.179	-0.026	0.038

Station Number		Along-Track Average ADCP Velocity m/s	Across-Track Average ADCP Velocity m/s	Across-Track ADCP-GEOST Velocity m/s
95	96	-0.076	0.079	0.038
96	97	0.106	0.020	0.057
97	98	0.245	0.069	0.011
98	99	0.121	0.068	0.055
99	100	0.102	0.147	0.062
100	101	0.328	0.078	-0.019
101	102	0.221	-0.015	0.024
102	103	-0.025	0.077	0.044
103	104	0.021	0.024	0.036
104	105	0.041	-0.094	0.026
105	106	0.055	-0.157	0.000

FIGURES

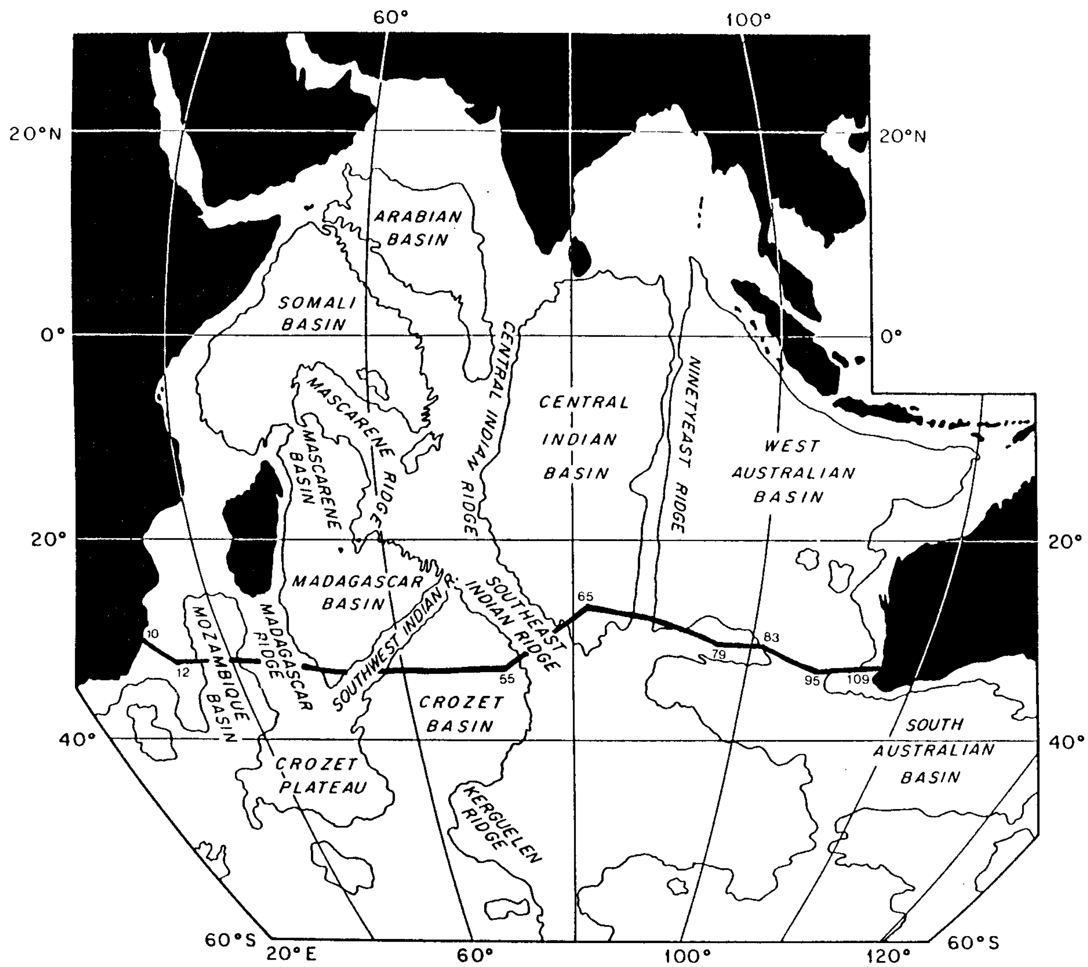
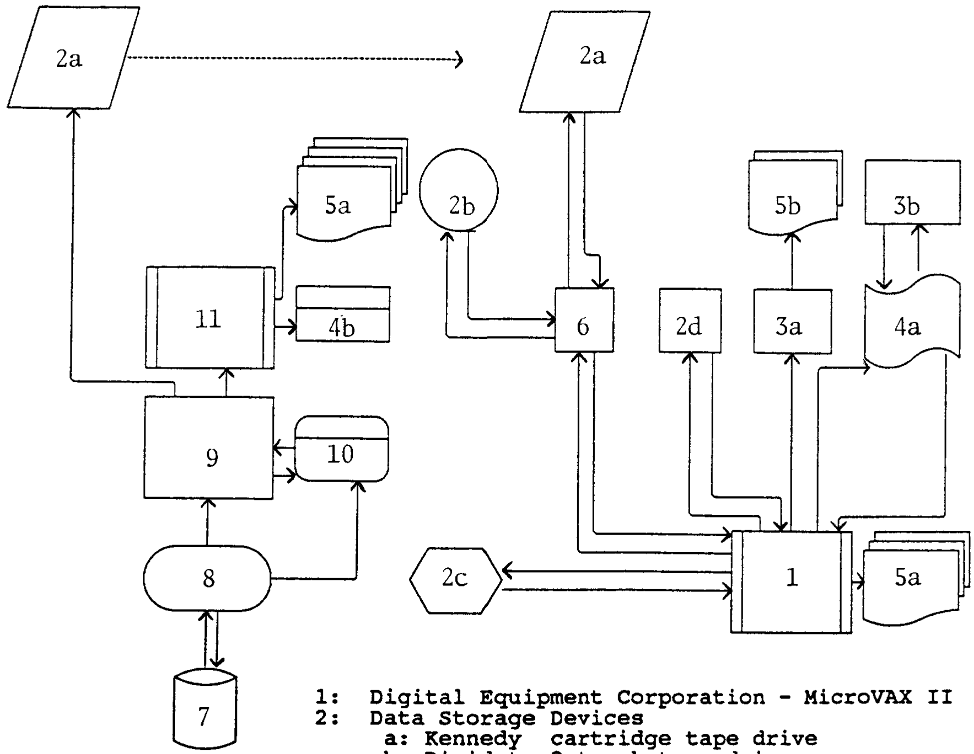


Fig. 1 The trans-Indian ocean cruise track and CTD station locations of RRS Charles Darwin cruise #29 from Africa to Australia. Note the many ridges and basins traversed by the cruise track.

CTD DATA ACQUISITION ... AND ... PROCESSING SYSTEMS



1: Digital Equipment Corporation - MicroVAX II
2: Data Storage Devices
a: Kennedy cartridge tape drive
b: Digidata 9 track tape drive
c: DEC TK50 cartridge tape drive
d: DEC RX50 floppy disk drive
3: CRT Terminals
a: Ampex 219 system terminal
b: VT100 user graphics terminal
4: Plotters
a: Zeta Corporation Zeta-8 plotter
b: Hewlett Packard HP 7475A plotter
5: Printers
a: Epson FX-85 system printer
b: Hewlett Packard Thinkjet image printer
6: RS232 switch box : 9T to Cartridge tape
7: NBIS CTD/O2 sensors #8 and *9
8: Rosette firing deck unit
9: NBIS Model 1150 CTD deck unit
10: Tascam audio tape recorder
11: Hewlett Packard HP-85 Personal computer

Fig. 2 Block diagrams of the CTD data collection and processing systems employed on the RRS Charles Darwin trans-Indian cruise.

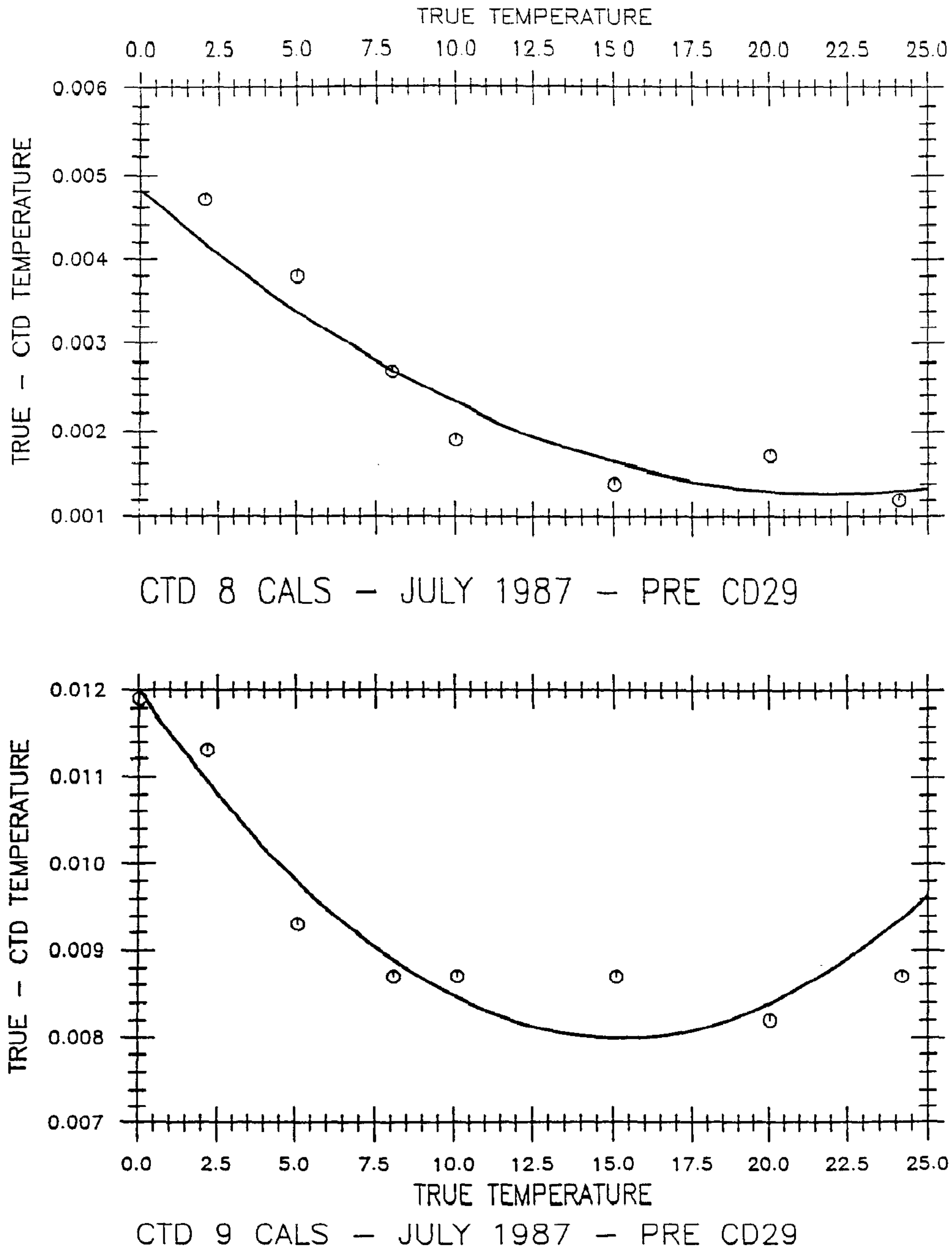


Fig. 3 Laboratory calibration data for the CTD temperature sensors along with quadratic least-square fits to the data used to reduce the CTD data.

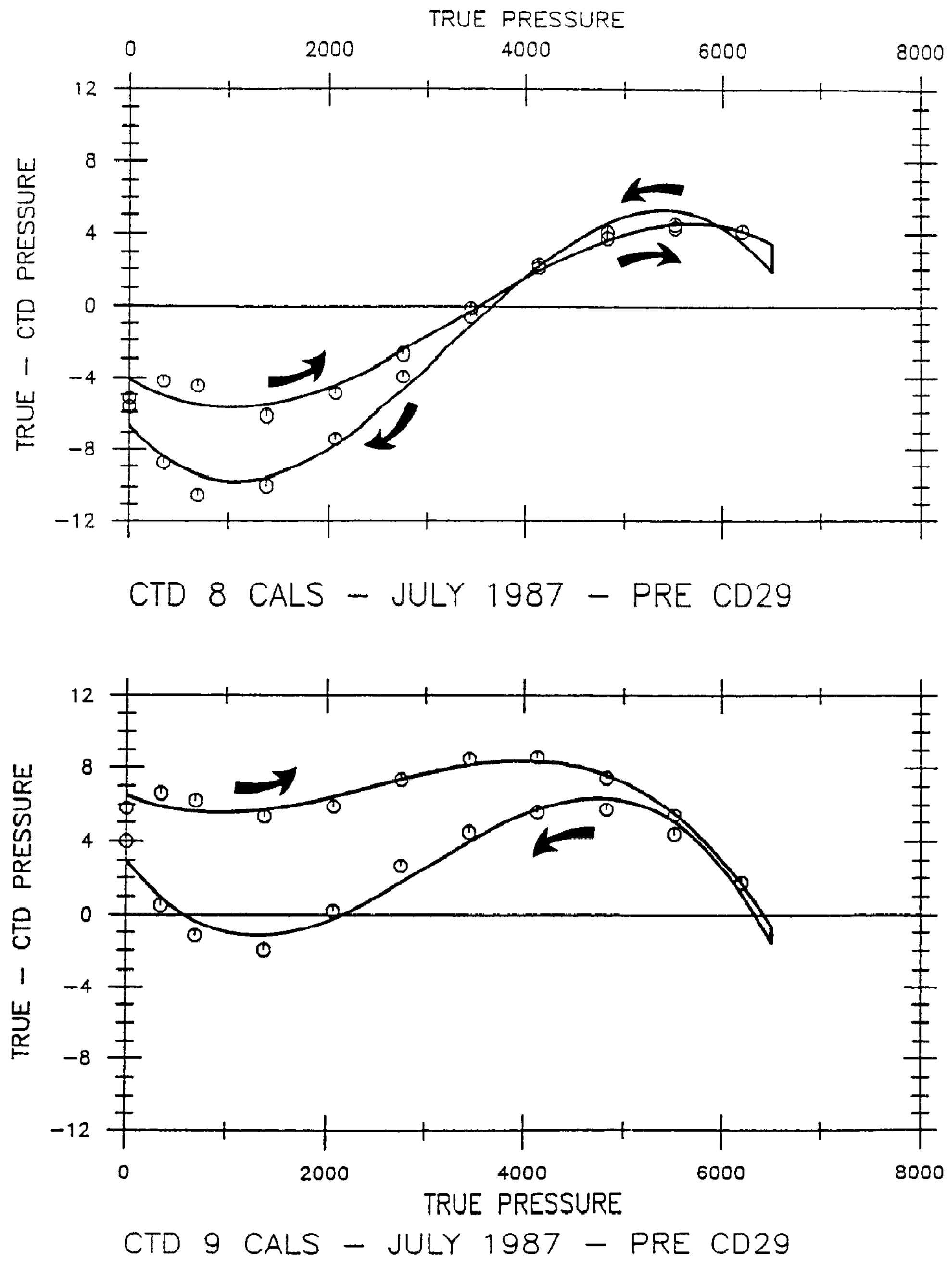


Fig. 4 Laboratory calibration data for the CTD pressure sensors along with cubic least-square fits to the data used to reduce the CTD data.

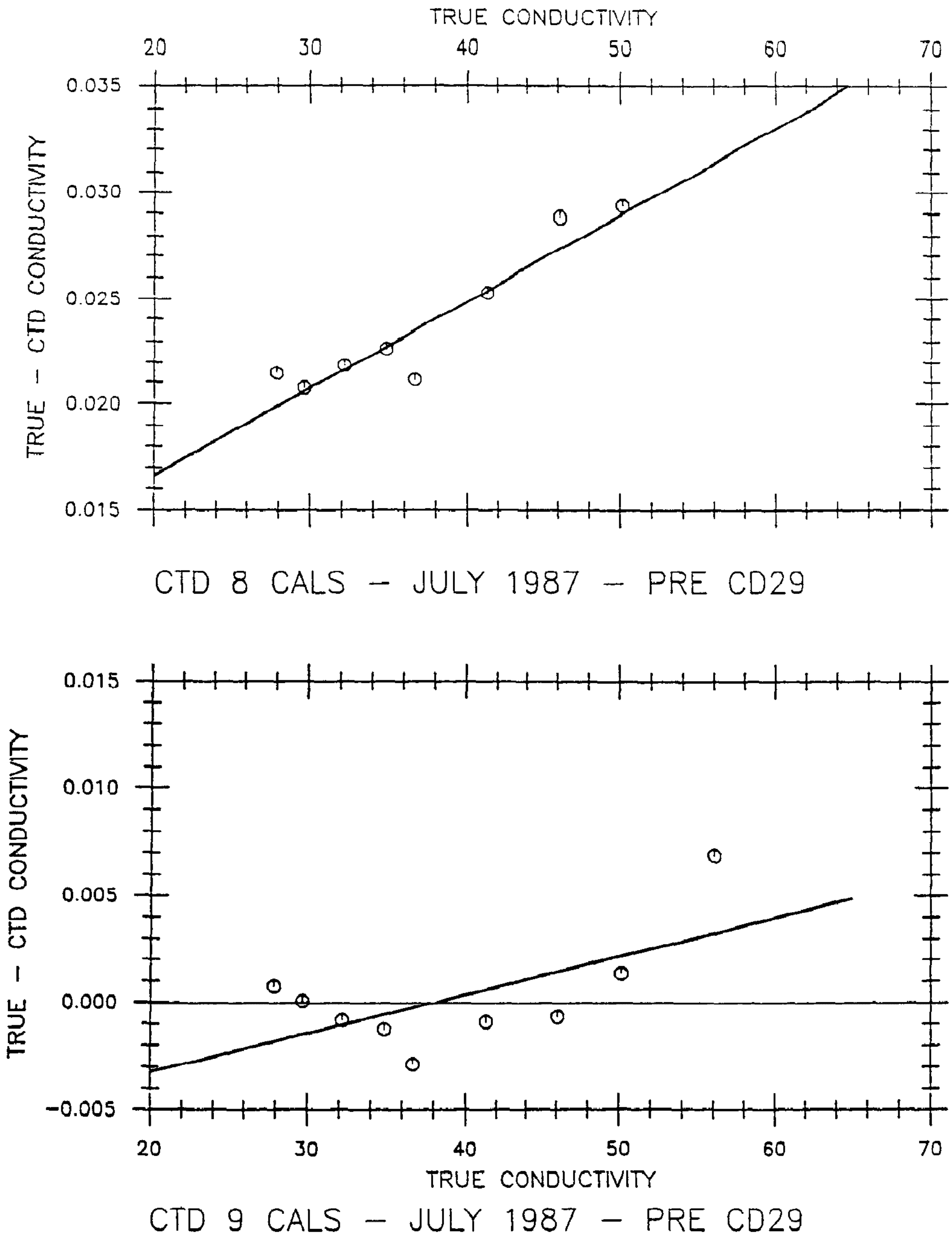


Fig. 5 Laboratory calibration data for the CTD conductivity sensors along with linear least-square fits to the data used to reduce the CTD data.

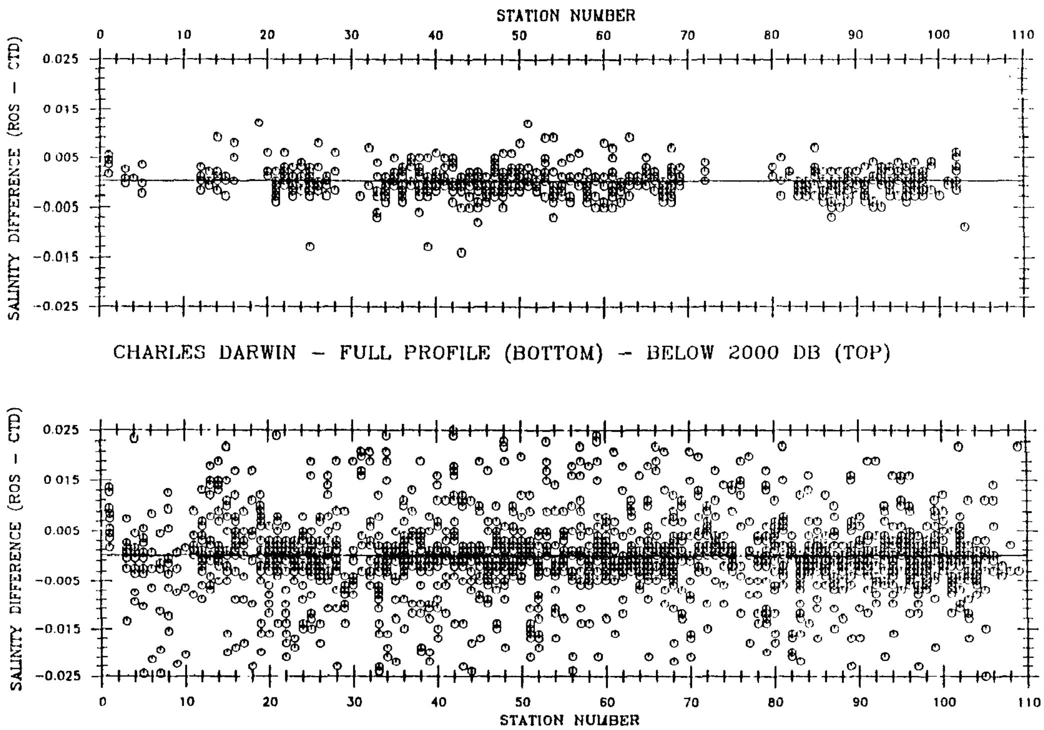


Fig. 6 Below: Differences between calibrated CTD salinity data and associated rosette data over the entire ocean profile: RRS Charles Darwin cruise #29. Above: Differences between deep (greater than 2000 db) calibrated CTD salinity data and associated rosette data: RRS Charles Darwin cruise #29.

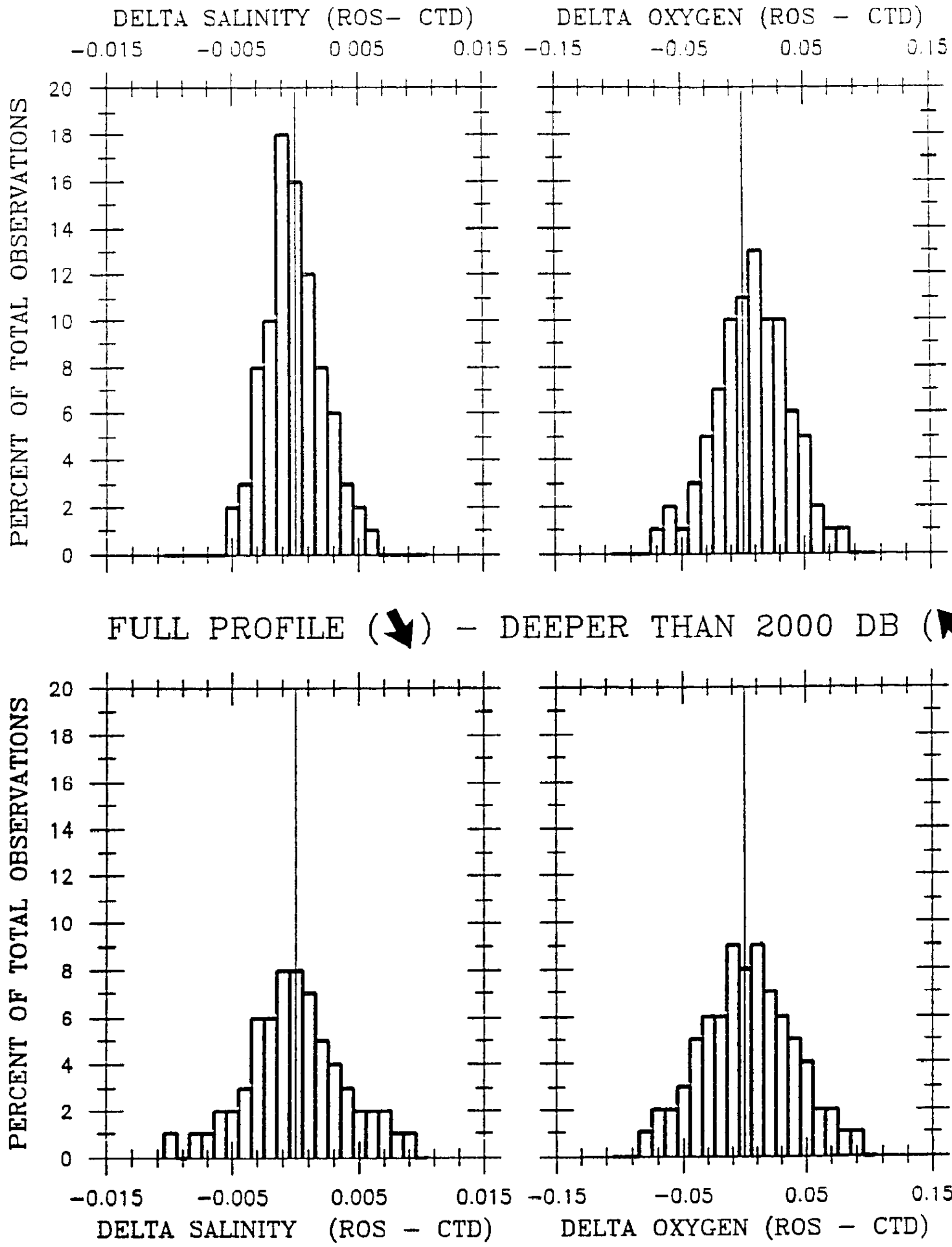


Fig. 7 Histograms showing the distribution of the salt and oxygen differences (CTD vs. rosette samples) for: Below: all stations at all depths. Above: all stations at depths greater than 2000 db.

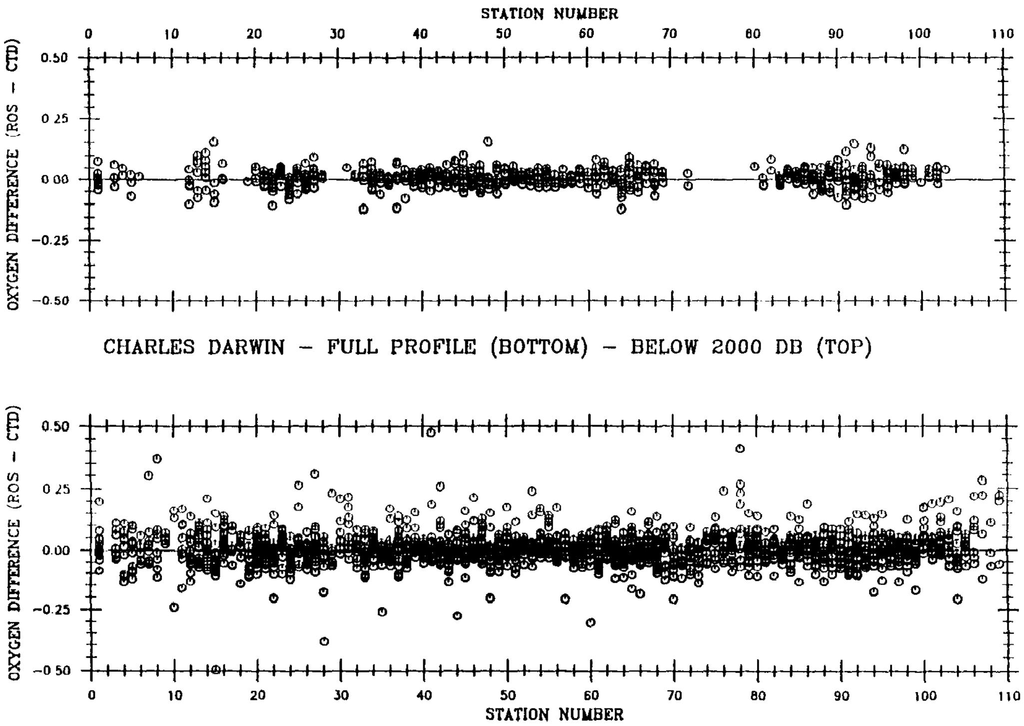


Fig. 8 Below: Differences between calibrated CTD oxygen data and associated rosette data over the entire ocean profile: RRS Charles Darwin cruise #29. Above: Differences between deep (greater than 2000 db) calibrated CTD oxygen data and associated rosette data: RRS Charles Darwin cruise #29.

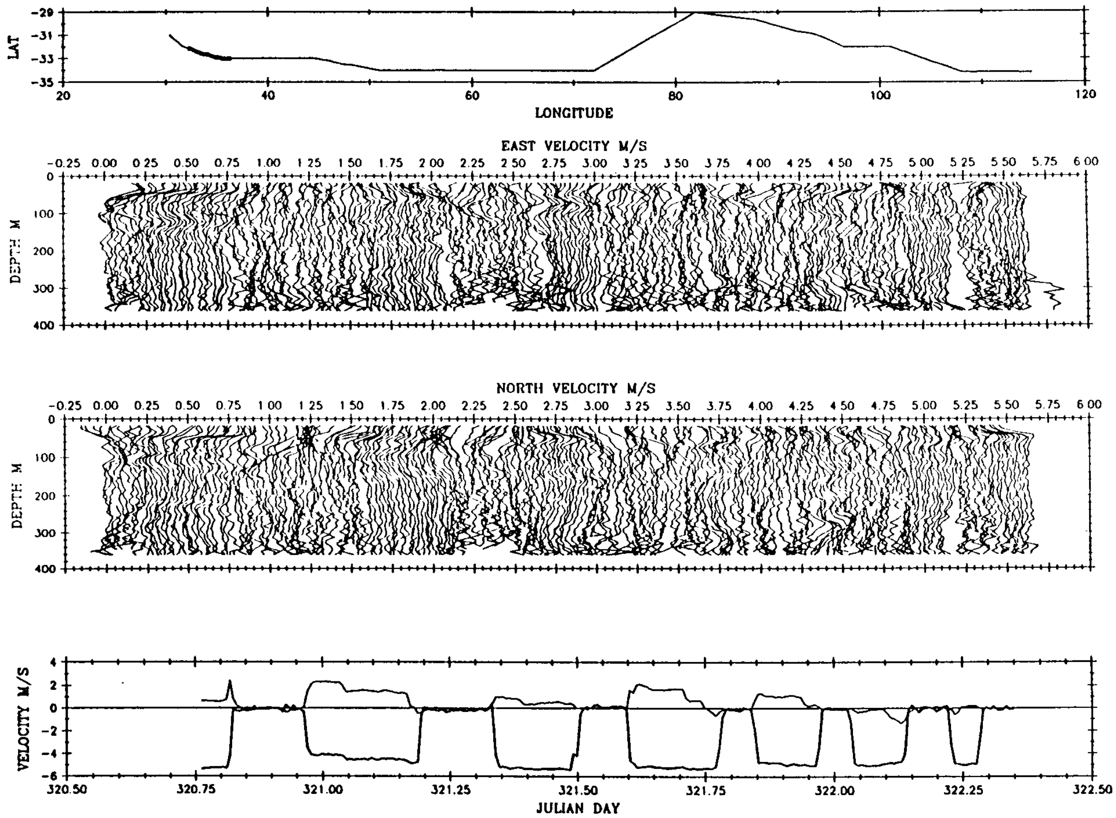


Fig. 9 (a). Representative displays of the Acoustic Doppler Current Profiler data obtained on the trans-Indian cruise. Four subsections of the data set are presented (Figures 9a, b, c, and d). In each case, the top panel denotes with bold line where along the cruise track the data were collected. Panels 2 and 3 contain the relative east and north velocity profiles in "waterfall" format where successive profiles are offset to the right. The profiles were biased to have zero vertical mean. The bottom panels give the east (bold line) and north (thin line) components of the depth-averaged relative velocity.

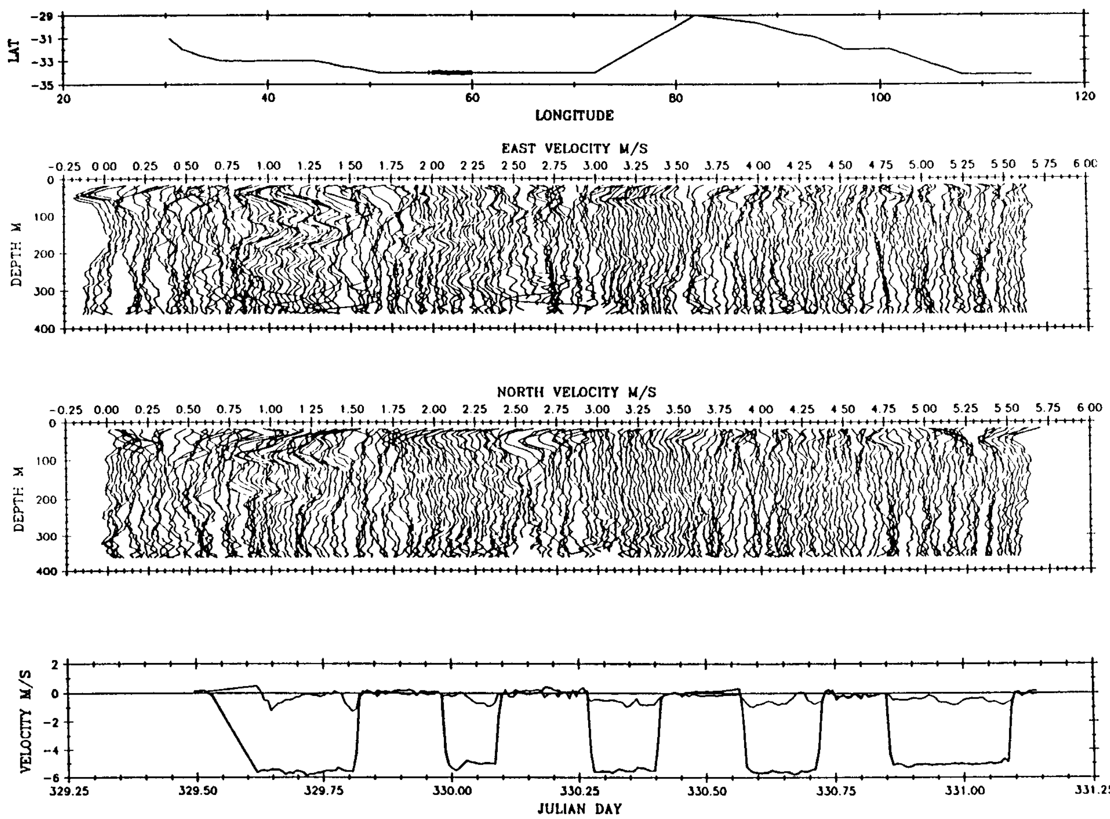


Fig. 9 (b). Representative displays of the Acoustic Doppler Current Profiler data obtained on the trans-Indian cruise. Four subsections of the data set are presented (Figures 9a, b, c, and d). In each case, the top panel denotes with bold line where along the cruise track the data were collected. Panels 2 and 3 contain the relative east and north velocity profiles in "waterfall" format where successive profiles are offset to the right. The profiles were biased to have zero vertical mean. The bottom panels give the east (bold line) and north (thin line) components of the depth-averaged relative velocity.

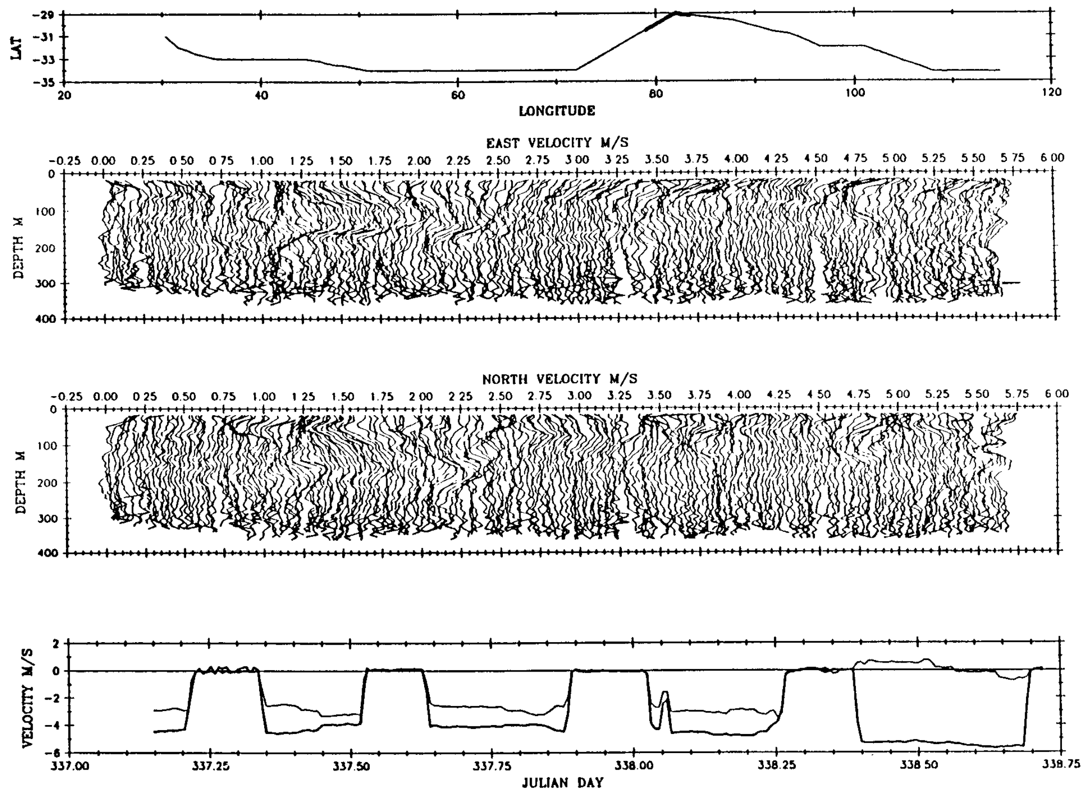


Fig. 9 (c). Representative displays of the Acoustic Doppler Current Profiler data obtained on the trans-Indian cruise. Four subsections of the data set are presented (Figures 9a, b, c, and d). In each case, the top panel denotes with bold line where along the cruise track the data were collected. Panels 2 and 3 contain the relative east and north velocity profiles in "waterfall" format where successive profiles are offset to the right. The profiles were biased to have zero vertical mean. The bottom panels give the east (bold line) and north (thin line) components of the depth-averaged relative velocity.

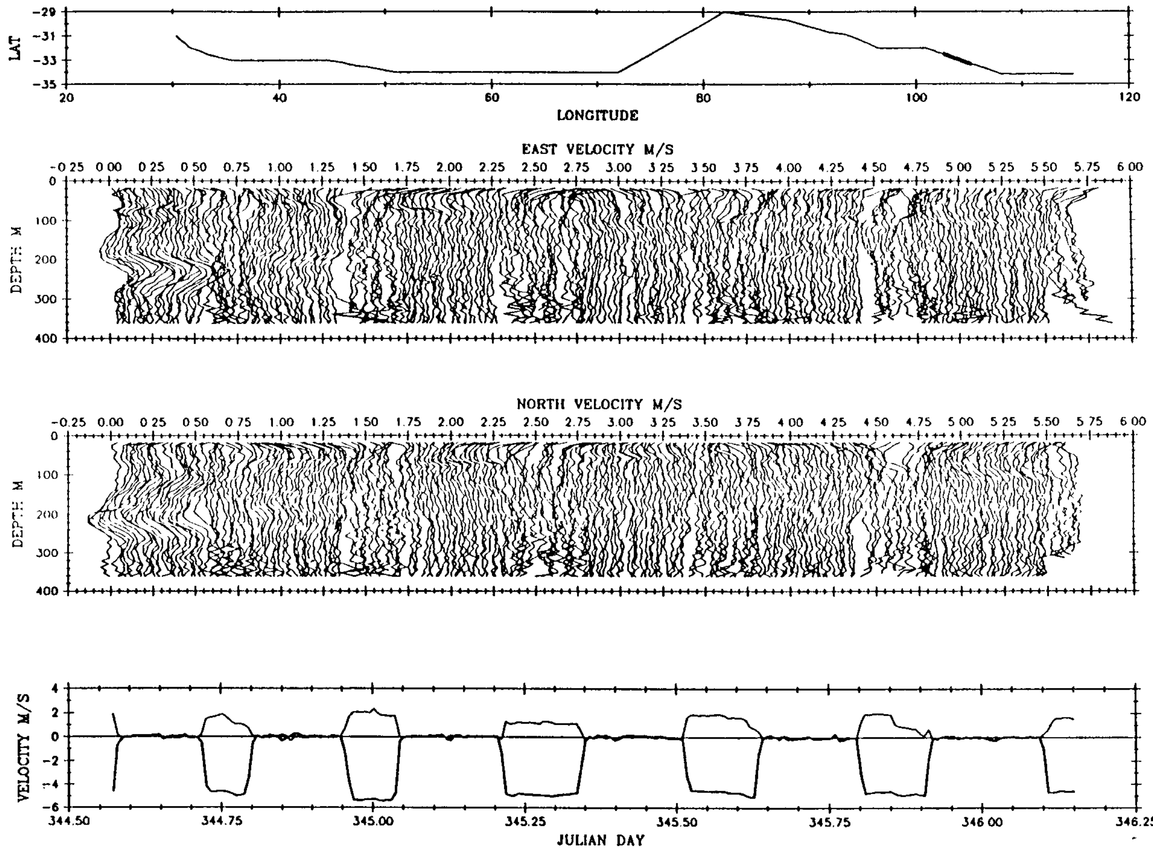


Fig. 9 (d). Representative displays of the Acoustic Doppler Current Profiler data obtained on the trans-Indian cruise. Four subsections of the data set are presented (Figures 9a, b, c, and d). In each case, the top panel denotes with bold line where along the cruise track the data were collected. Panels 2 and 3 contain the relative east and north velocity profiles in "waterfall" format where successive profiles are offset to the right. The profiles were biased to have zero vertical mean. The bottom panels give the east (bold line) and north (thin line) components of the depth-averaged relative velocity.

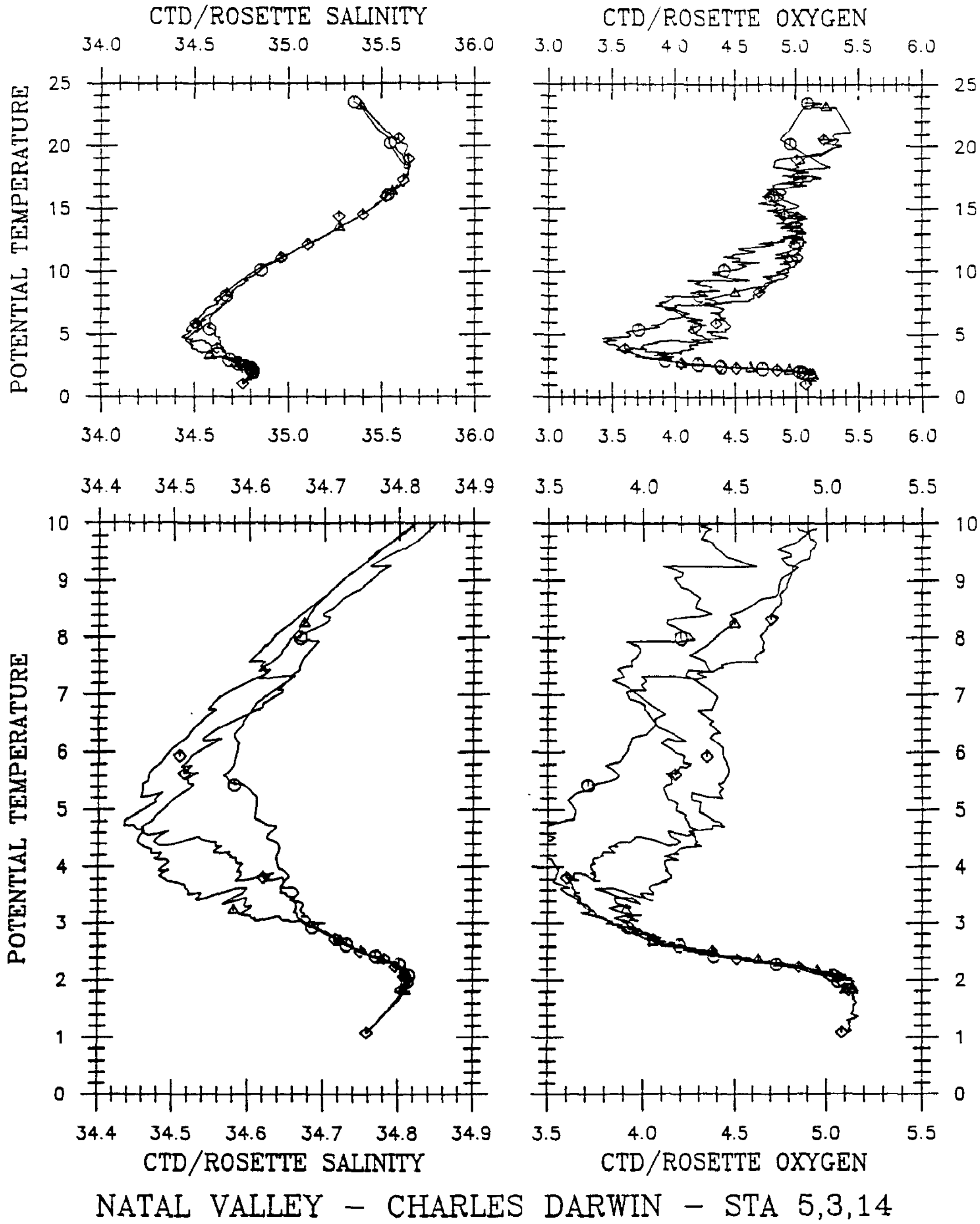


Fig.10 Typical potential temperature vs. salinity and oxygen plots from the Natal Valley during RRS Charles Darwin cruise #29. Symbols represent rosette water sample data for those particular casts. The bottom plots are expanded scale to show deep theta/property consistency.

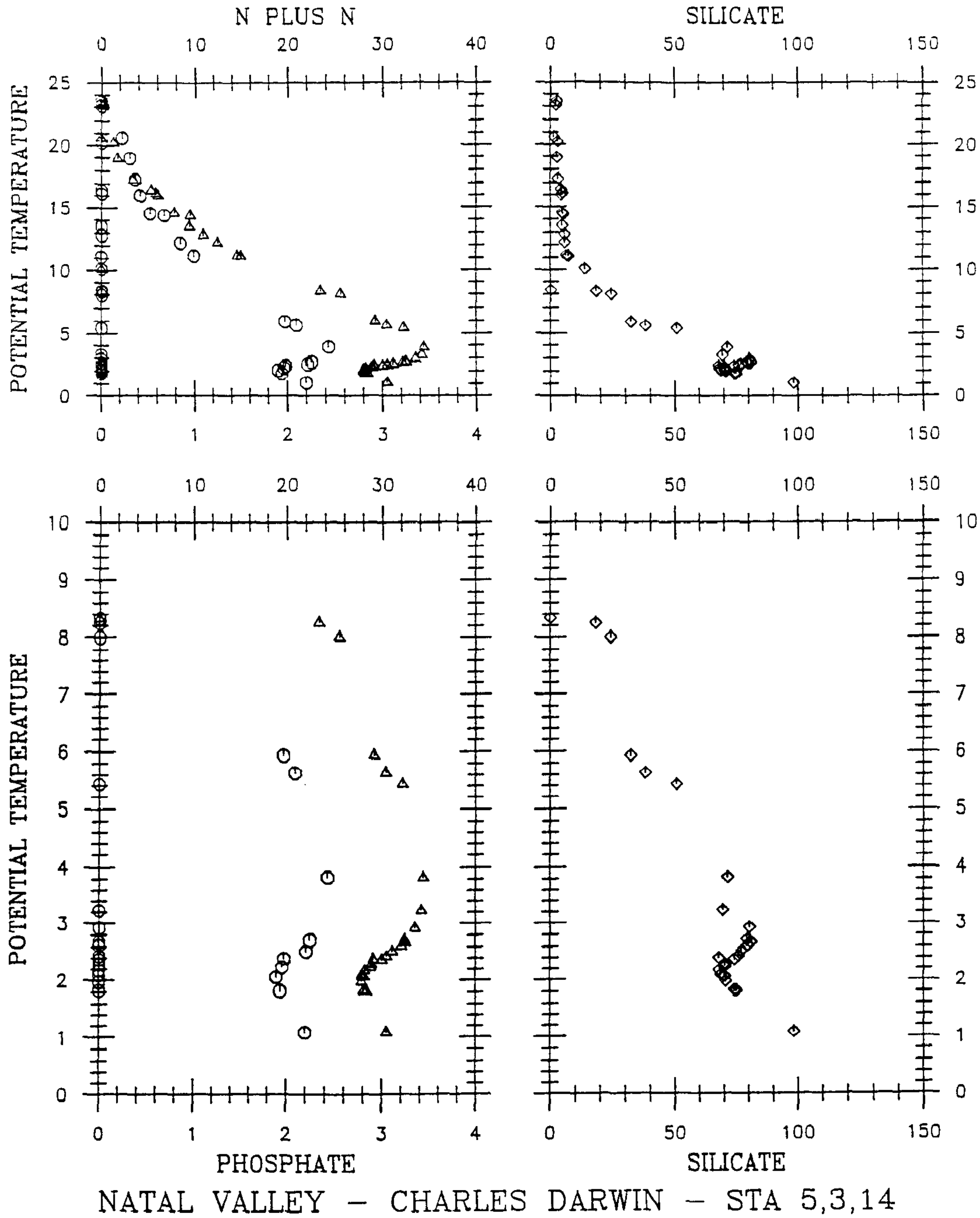


Fig.11 Typical potential temperature vs. nutrient data plots from the Natal Valley during RRS Charles Darwin cruise #29. Phosphate data are represented by triangles, N+N by circles, and silicate by diamonds. The ordinates (potential temperature axes) are at the same scales as Figure 10.

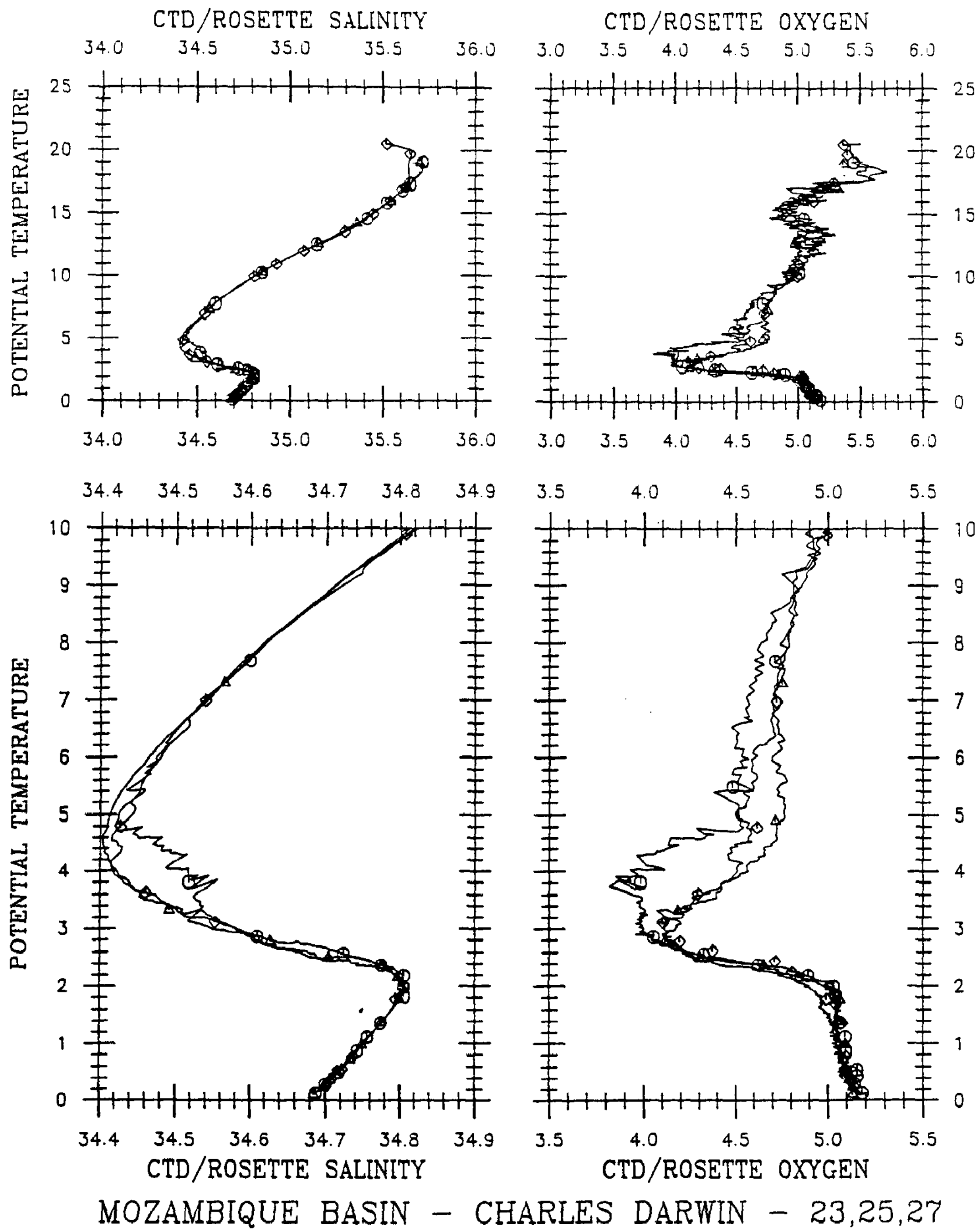


Fig.12 Typical potential temperature vs. salinity and oxygen plots from the Mozambique Basin during RRS Charles Darwin cruise #29. Symbols represent rosette water sample data for those particular casts. The bottom plots are expanded scale to show deep theta/property consistency.

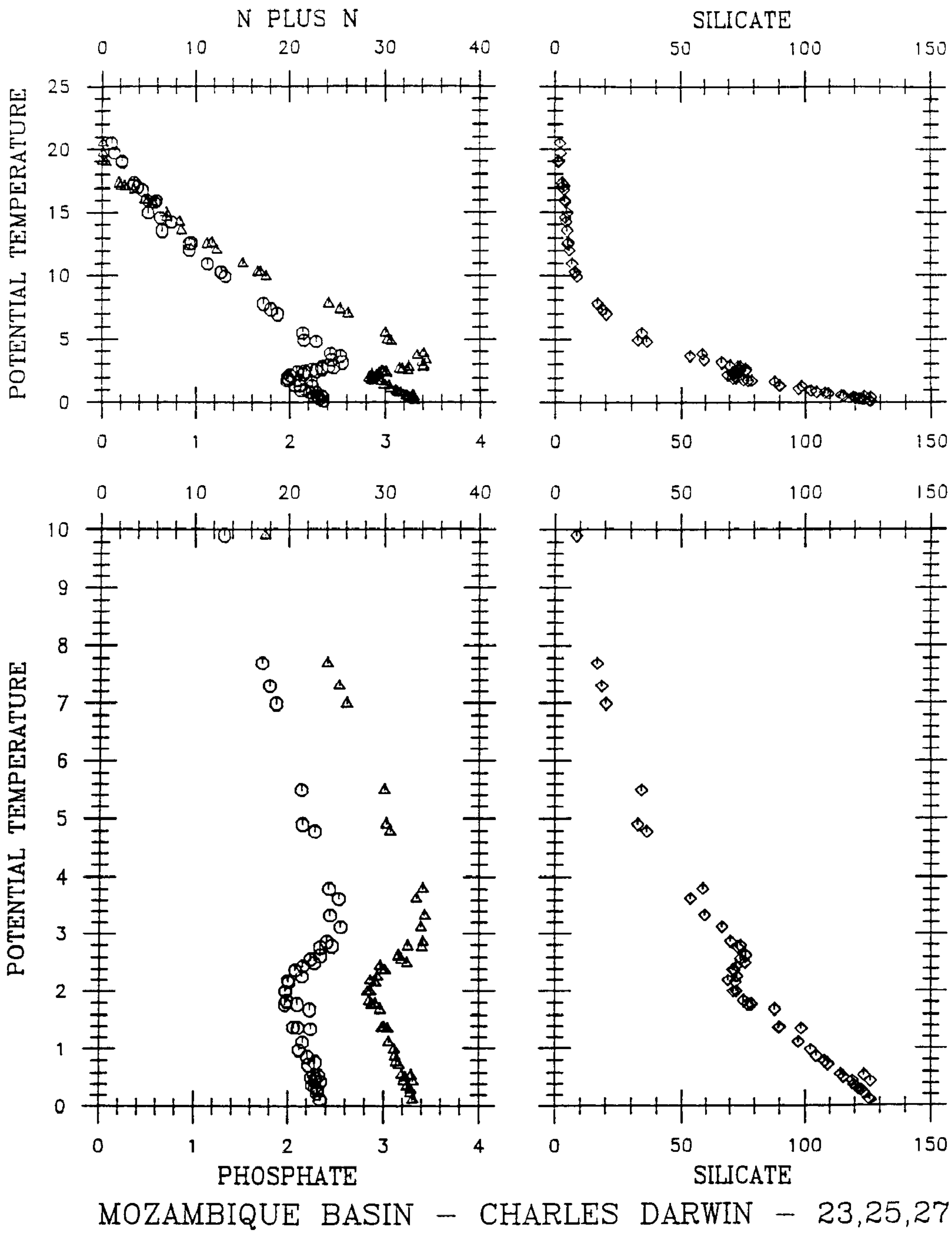


Fig.13 Typical potential temperature vs. nutrient data plots from the Mozambique Basin during RRS Charles Darwin cruise #29. Phosphate data are represented by triangles, N+N by circles, and silicate by diamonds. The ordinates (potential temperature axes) are at the same scales as Figure 12.

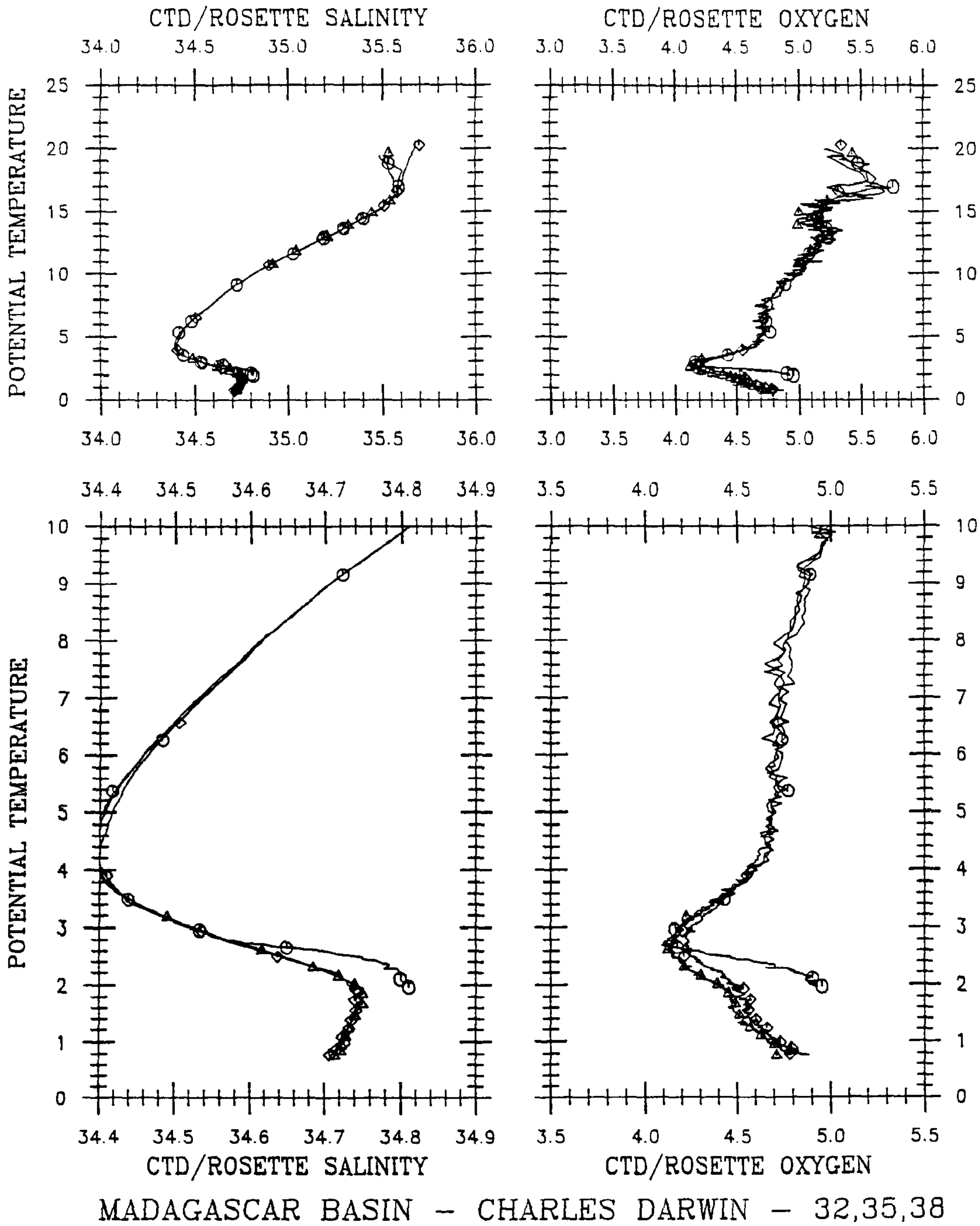


Fig.14 Typical potential temperature vs. salinity and oxygen plots from the Madagascar Basin during RRS Charles Darwin cruise #29. Symbols represent rosette water sample data for those particular casts. The bottom plots are expanded scale to show deep theta/property consistency.

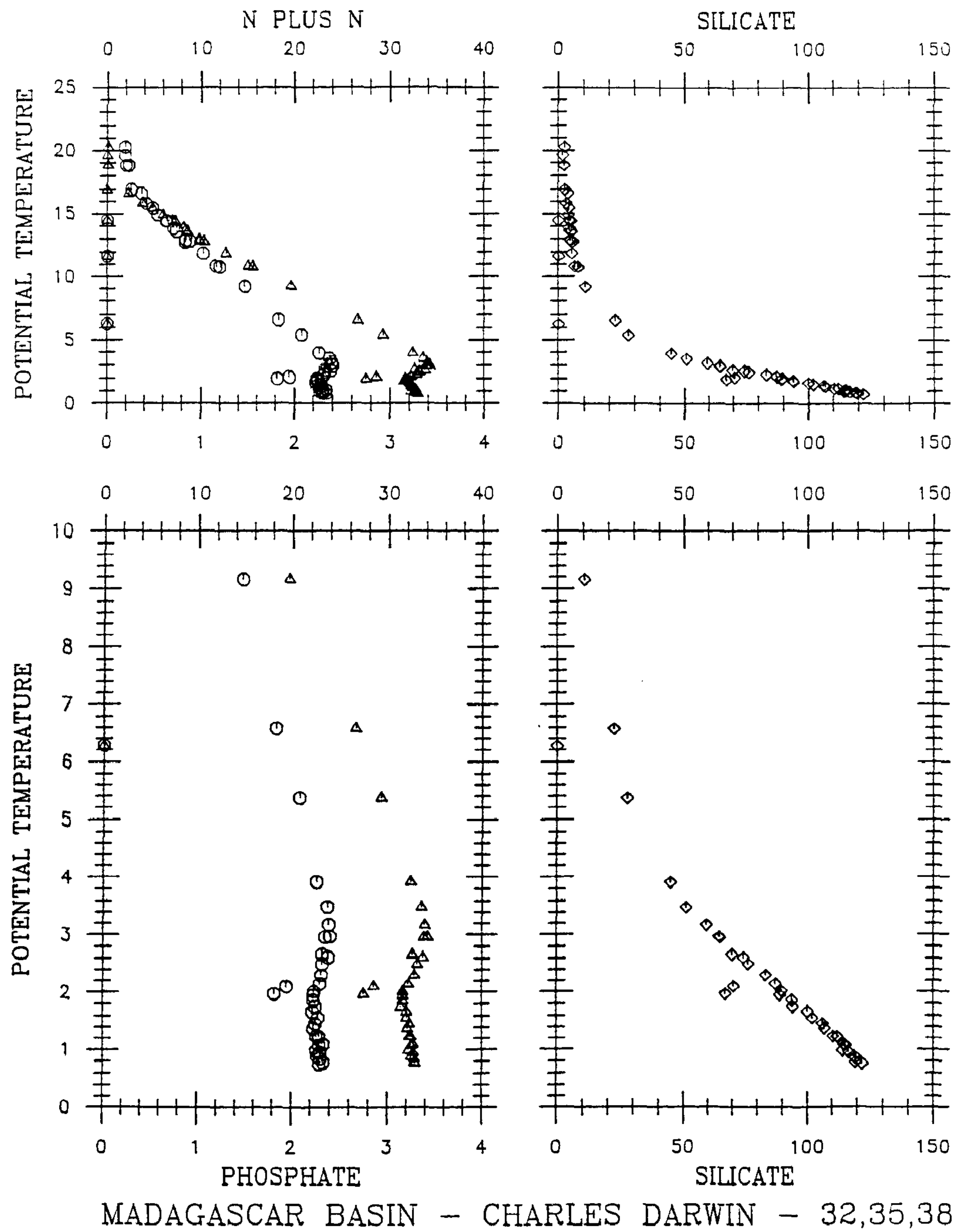


Fig.15 Typical potential temperature vs. nutrient data plots from the Madagascar Basin during RRS Charles Darwin cruise #29. Phosphate data are represented by triangles, N+N by circles, and silicate by diamonds. The ordinates (potential temperature axes) are at the same scales as Figure 14.

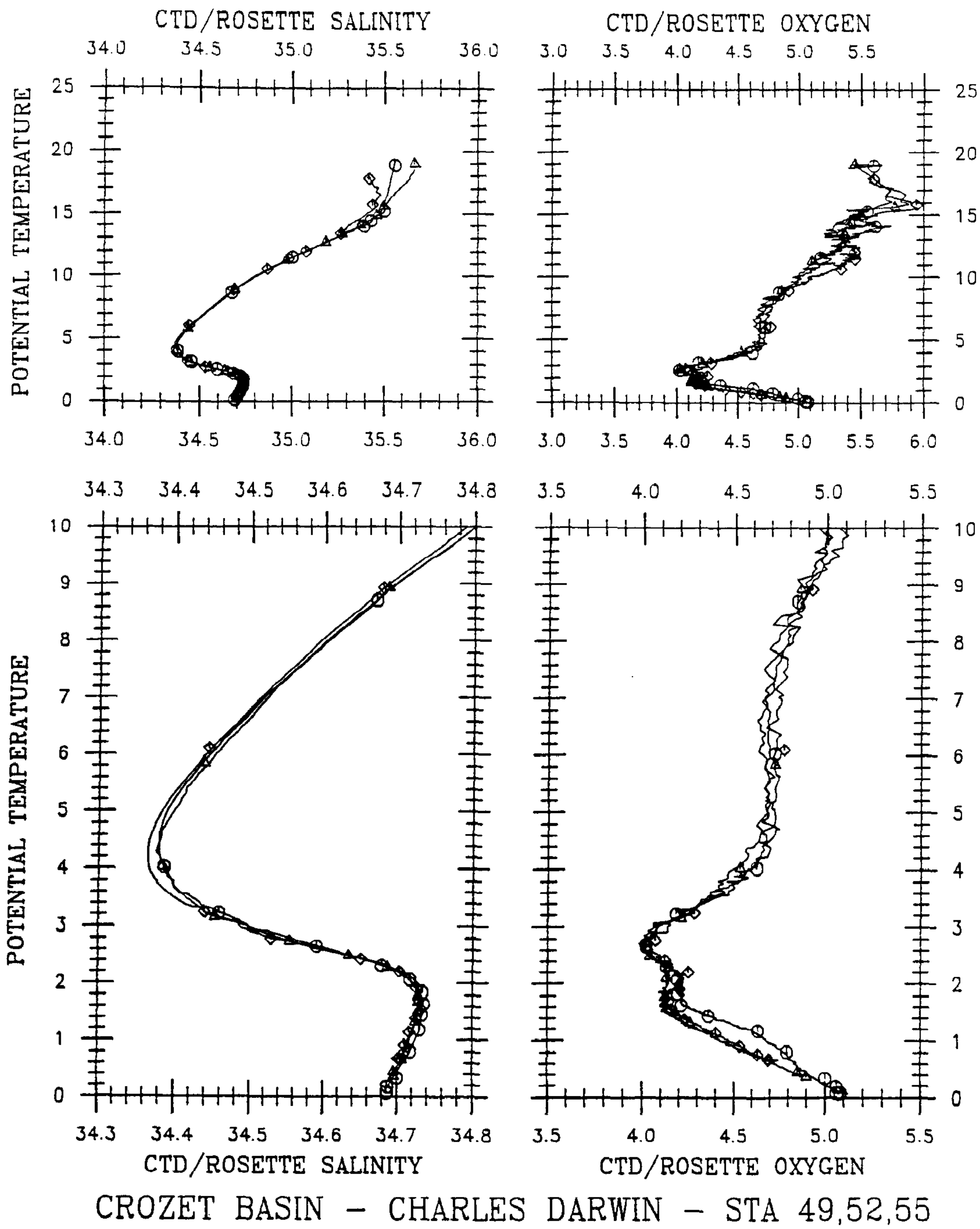


Fig.16 Typical potential temperature vs. salinity and oxygen plots from the Crozet Basin during RRS Charles Darwin cruise #29. Symbols represent rosette water sample data for those particular casts. The bottom plots are expanded scale to show deep theta/property consistency.

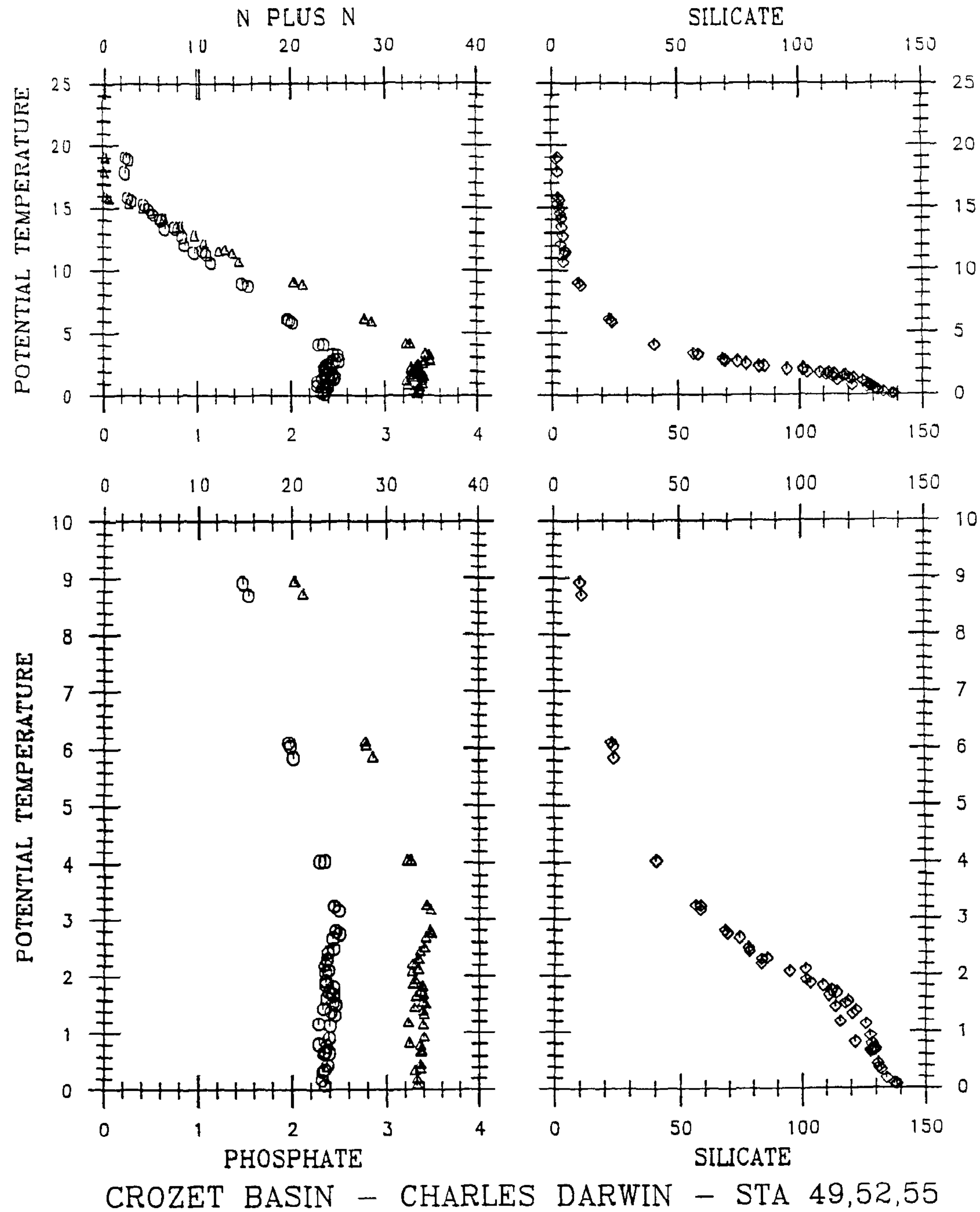


Fig.17 Typical potential temperature vs. nutrient data plots from the Crozet Basin during RRS Charles Darwin cruise #29. Phosphate data are represented by triangles, N+N by circles, and silicate by diamonds. The ordinates (potential temperature axes) are at the same scales as Figure 16.

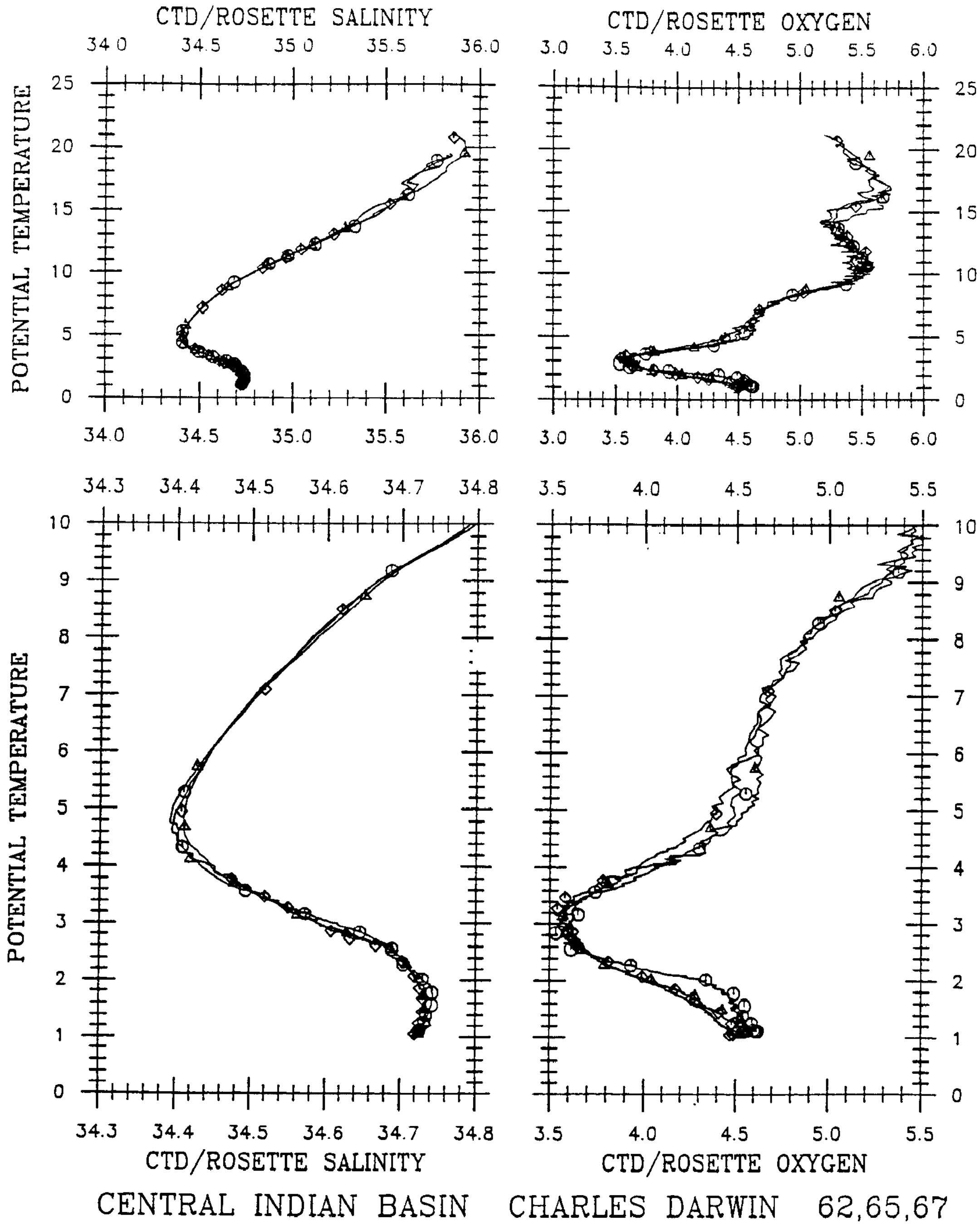


Fig.18 Typical potential temperature vs. salinity and oxygen plots from the Central Indian Basin during RRS Charles Darwin cruise #29. Symbols represent rosette water sample data for those particular casts. The bottom plots are expanded scale to show deep theta/property consistency.

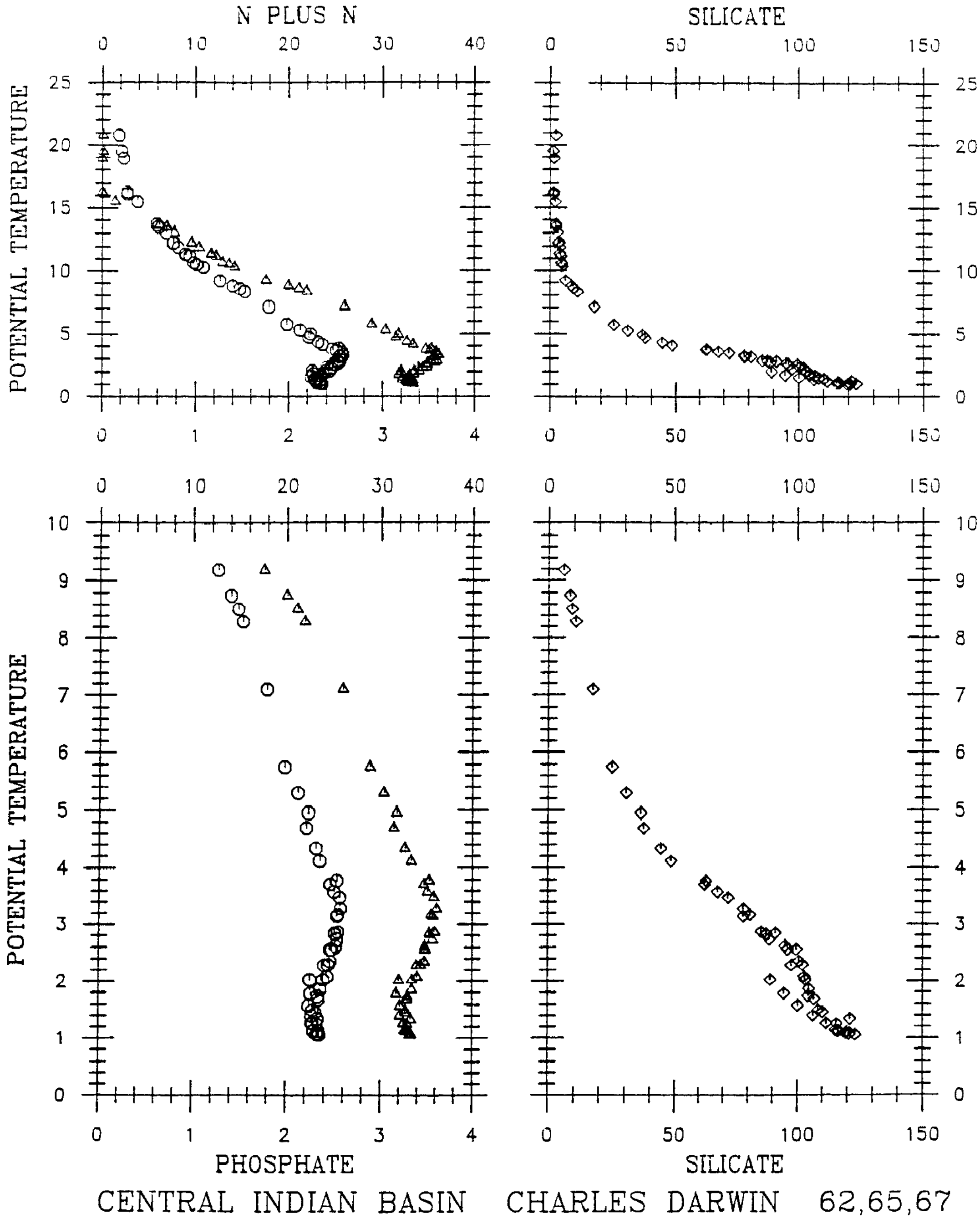


Fig.19 Typical potential temperature vs. nutrient data plots from the Central Indian Basin during RRS Charles Darwin cruise #29. Phosphate data are represented by triangles, N+N by circles, and silicate by diamonds. The ordinates (potential temperature axes) are at the same scales as Figure 18.

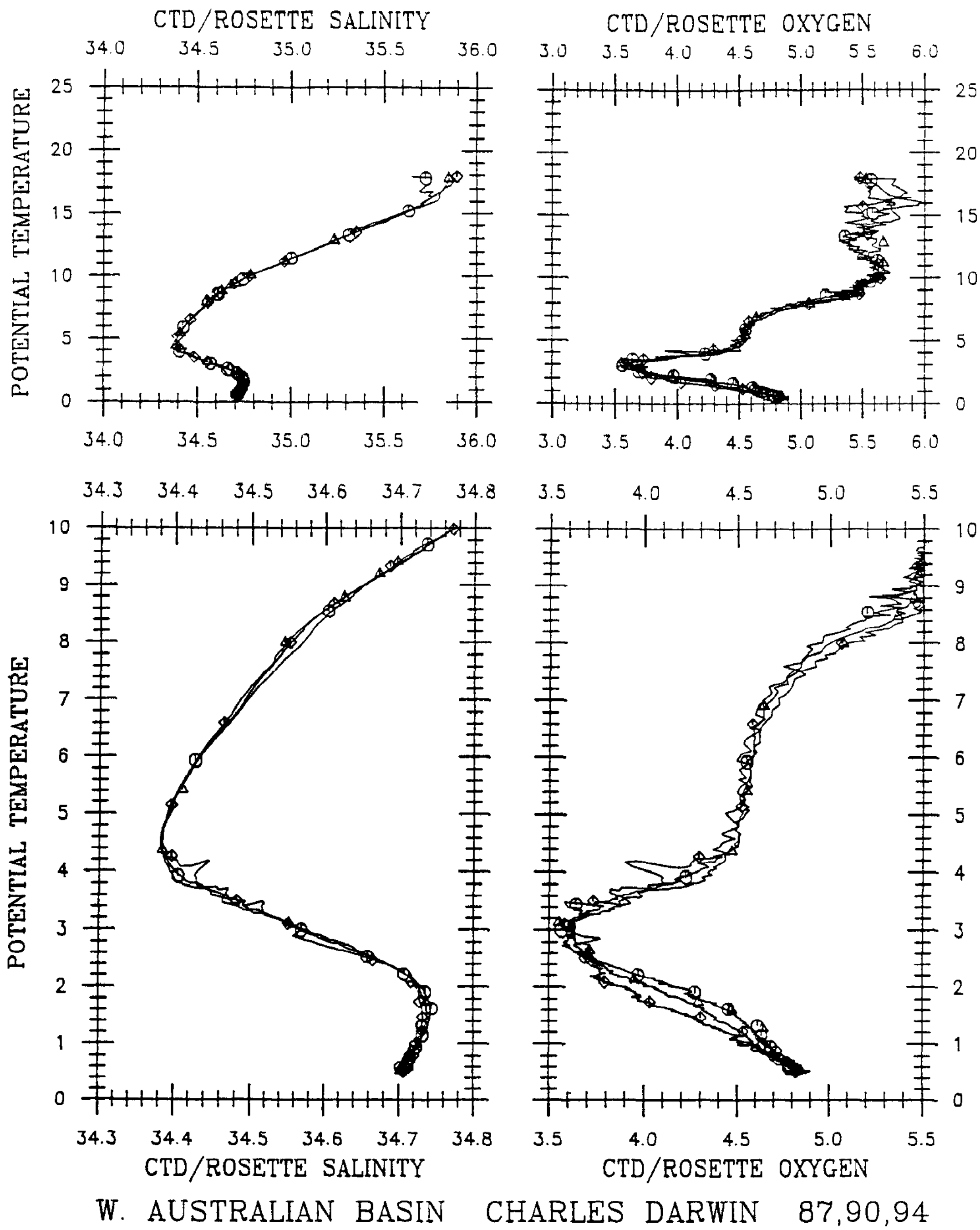


Fig.20 Typical potential temperature vs. salinity and oxygen plots from the West Australian Basin during RRS Charles Darwin cruise #29. Symbols represent rosette water sample data for those particular casts. The bottom plots are expanded scale to show deep theta/property consistency.

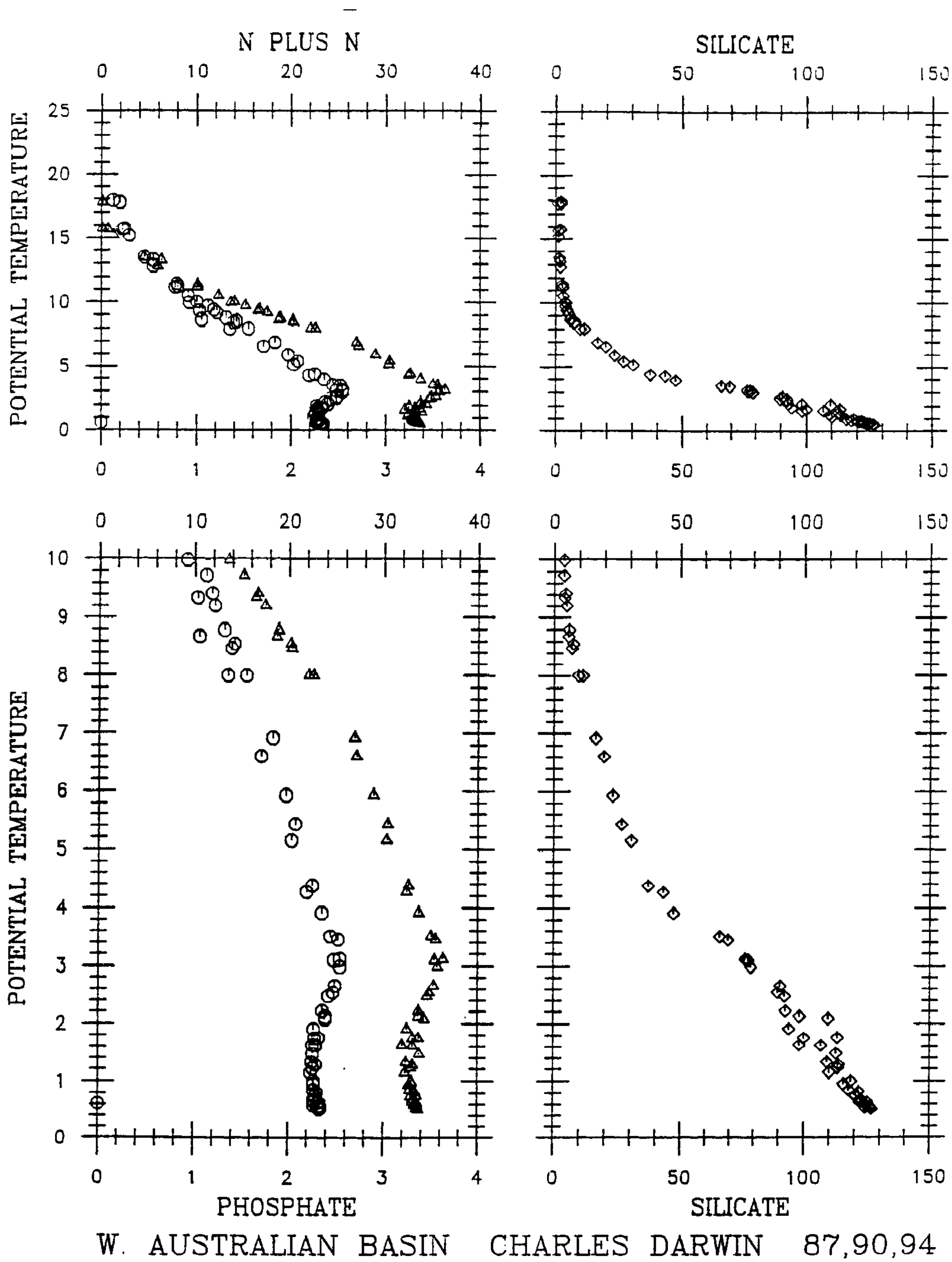


Fig.21 Typical potential temperature vs. nutrient data plots from the West Australian Basin during RRS Charles Darwin cruise #29. Phosphate data are represented by triangles, N+N by circles, and silicate by diamonds. The ordinates (potential temperature axes) are at the same scales as Figure 20.

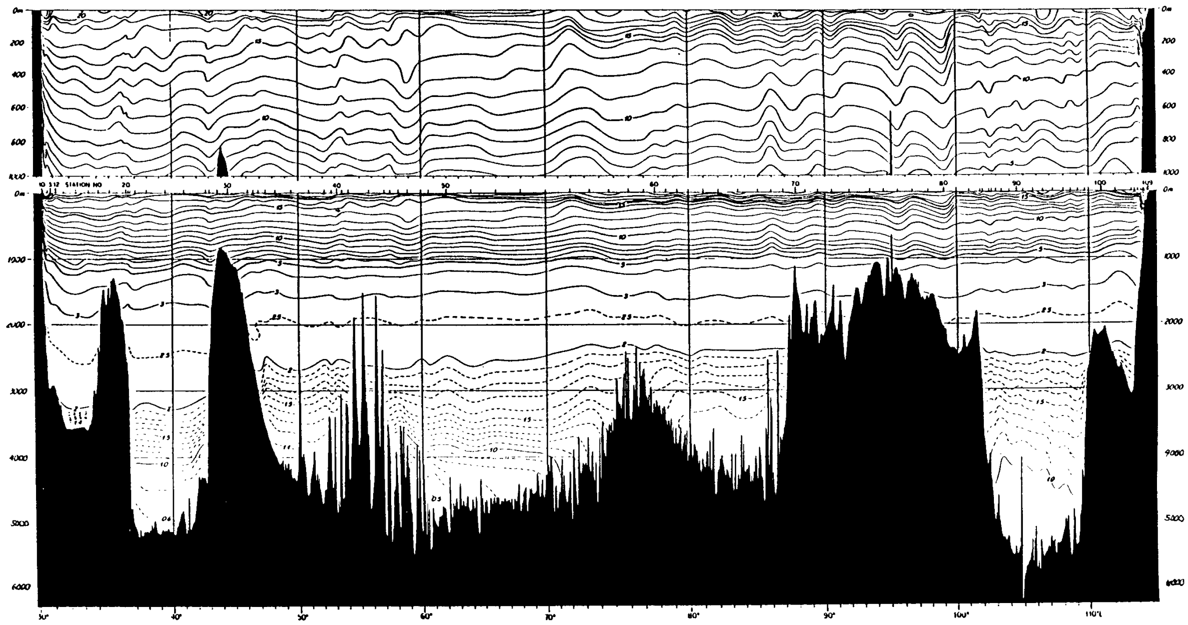


Fig.22 Temperature vs. depth section of trans-Indian Ocean section. Vertical distortion of the full depth profiles is 500:1, while for the expanded shallow sections it is 1250:1.

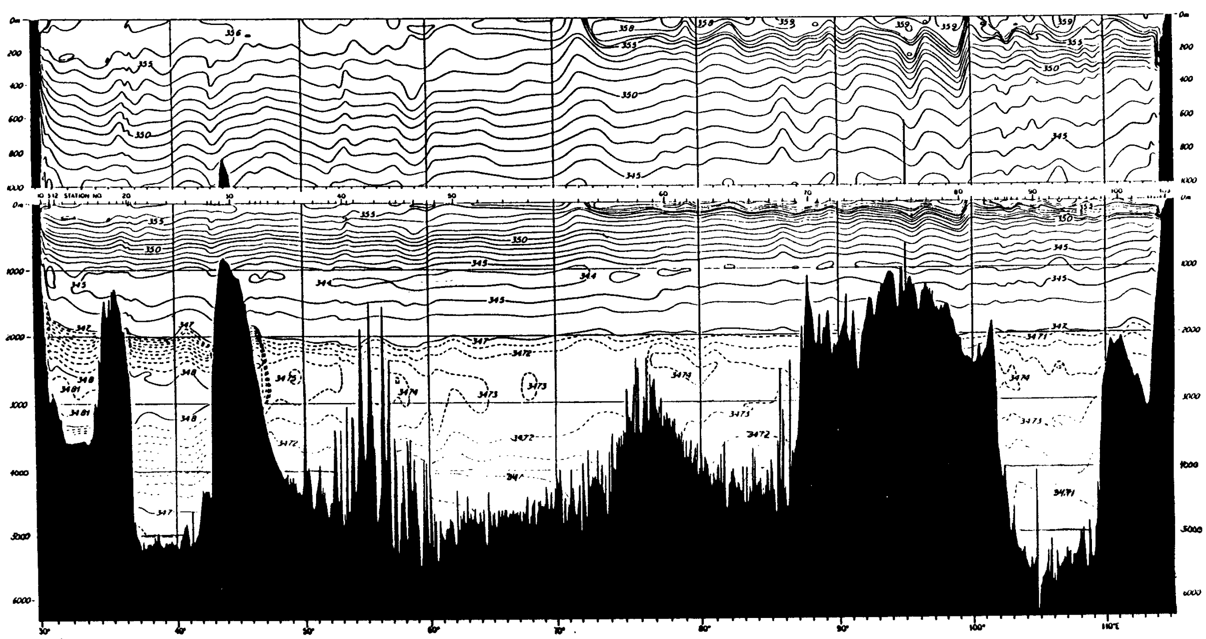


Fig.23 Salinity vs. depth section of trans-Indian Ocean section. Vertical distortion of the full depth profiles is 500:1, while for the expanded shallow sections it is 1250:1.

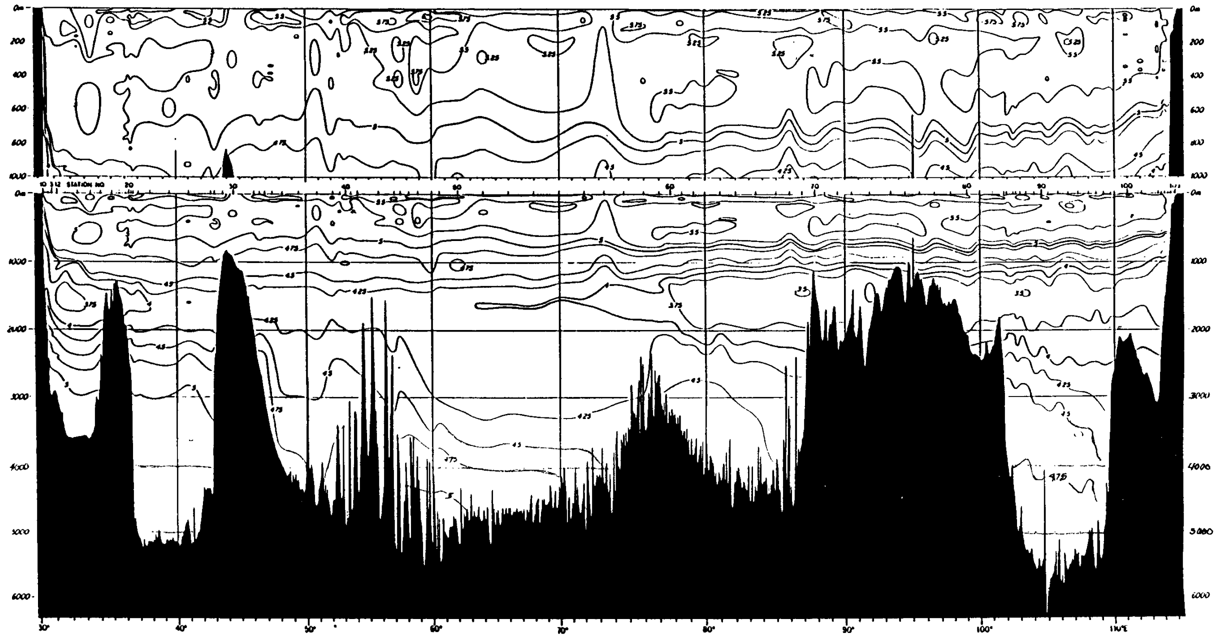


Fig.24 Oxygen vs. depth section of trans-Indian Ocean section. Vertical distortion of the full depth profiles is 500:1, while for the expanded shallow sections it is 1250:1.

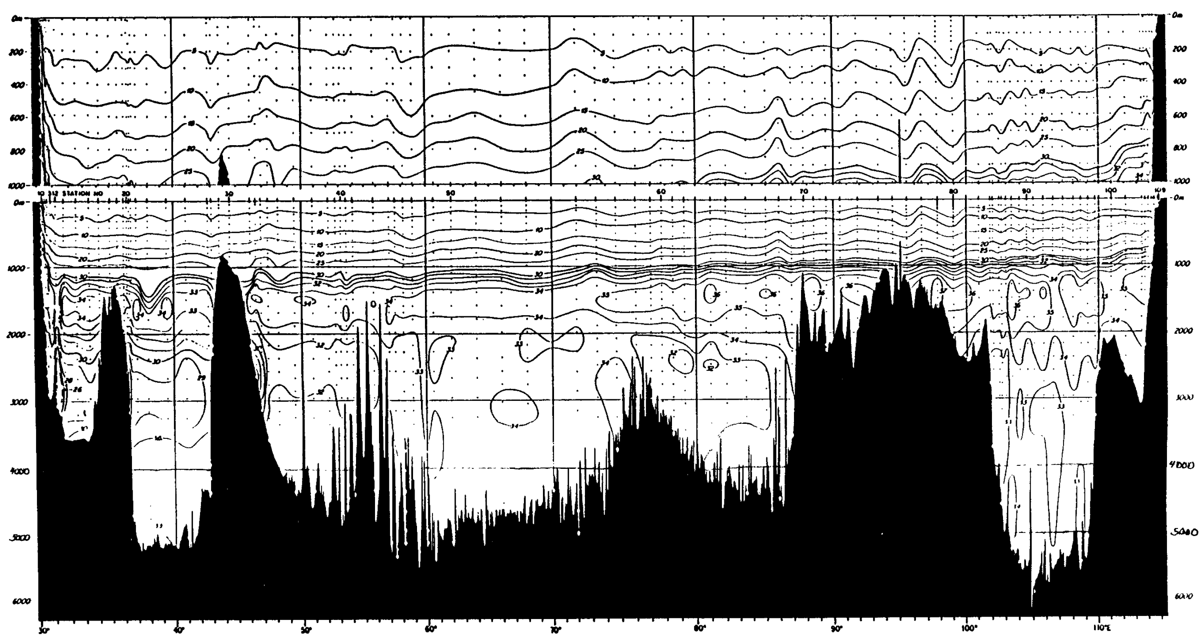


Fig.25 Nitrate vs. depth section of trans-Indian Ocean section. Vertical distortion of the full depth profiles is 500:1, while for the expanded shallow sections it is 1250:1.

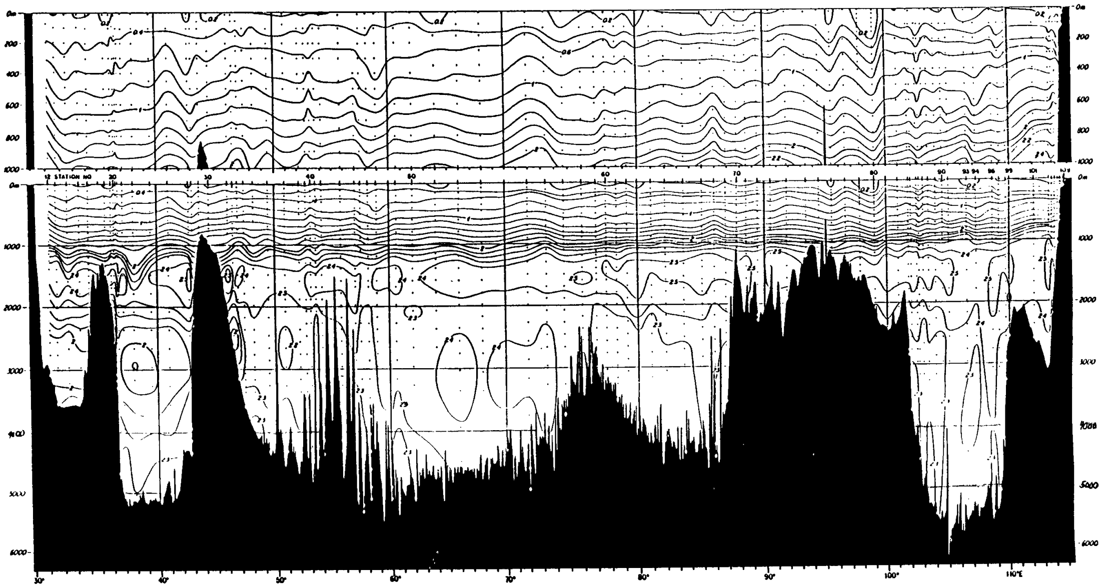


Fig.26 Phosphate vs. depth section of trans-Indian Ocean section. Vertical distortion of the full depth profiles is 500:1, while for the expanded shallow sections it is 1250:1.

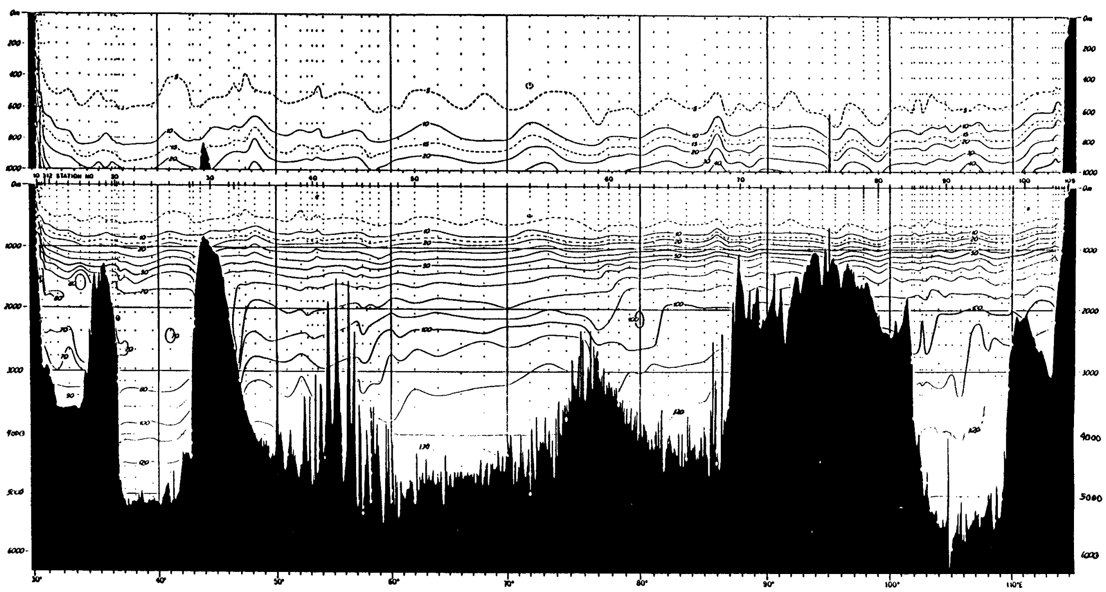


Fig.27 Silicate vs. depth section of trans-Indian Ocean section. Vertical distortion of the full depth profiles is 500:1, while for the expanded shallow sections it is 1250:1.

Appendix A: Description of CTD #9 Data Adjustment

Careful examination of deep (T < 4°C) potential temperature/ salinity data obtained with WHOI CTD #9 on the 320S trans-Indian Ocean section revealed a small discrepancy with the water sample measurements. As depicted in Figure Al, standard CTD data calibration techniques yielded CTD profiles which diverged from the water sample data below 0.8°C potential temperature by upwards of 0.002 psu. Salinity, computed from CTD data, is dependent on temperature, conductivity and pressure observations: each of which is subject to error. The relative sensitivity of calculated salinity to these variables is approximately 0.001°C, 0.001 mmho and 2.5 db per 0.001 psu change (based on EOS 80 and nominal values of 1.5°C, 34.7 psu and 4500 db.)

Review of the temperature calibration data for CTD #9 from the pre- and post-cruise laboratory measurements indicated that the salinity discrepancy probably was not the product of error in the temperature calibration. The two laboratory calibrations were internally consistent over the full range of calibration temperatures to better than 0.002°C, and we believe the laboratory measurements have an absolute accuracy of 0.002°C. More importantly, because the salinity error occurred over a rather small temperature interval, the required adjustment of the temperature calibration curve to remove the salinity discrepancy would have induced strong change of curvature to the calibration curve below 1°C. Such structure in a calibration curve is outside our experience with CTD instruments. We therefore concluded that the temperature channel was not the source of the observed salinity problem.

A change in the deep-water conductivity calibration algorithm was also ruled out. In order to match the water sample salinity data, a nonlinear conductivity correction would have been required. The NBIS CTD conductivity sensor, however, is inherently a linear device (N. Brown, personal communication, 1988). Some improvement between CTD and water sample data was obtained by setting to zero the coefficient of conductivity cell deformation with pressure. While full agreement might have been achieved by allowing this coefficient to be negative, we did not pursue this course as it implied non-physical behavior of the CTD sensor (cell expanding with increasing pressure).

Hence by default, we concluded the salinity error was the product of pressure error. Using the figures above, a salinity error of 0.002 psu would result from a pressure error of 5 db. We suspect that residual temperature sensitivity in the pressure sensor was responsible for the pressure error, but we were unable to confirm this in the laboratory. Reduction of the data to final form utilized a modified cubic pressure calibration algorithm. The algorithm agreed with that derived from the polynomial least-square fit to the laboratory data at pressures less than 3000 db. At higher pressures, the final pressures were greater than those generated by the laboratory- derived calibration formula by the amount needed to force the CTD potential temperature/salinity curve to overlie the water sample data; the algorithm is reported in the main section of the text. For the bulk of the deep trans-Indian Ocean data, the adjustment caused an increase of bottom pressure by 10 db or less. Checks were made to insure that the resulting bottom pressure data were consistent with the acoustic depth recorded at each station. The pressure adjustments that were made were within the uncertainty of the acoustic depth data. Finally it should be noted that because this adjustment was made uniformly to all stations occupied with CTD #9, no spurious signal was introduced into the thermal wind shear field of the ocean interior. Potential does exist for shear error at the transitions between stations which used instruments #9 and #8 (station pairs 3-12 and 15-16). However, bottom pressures at these sites were 3000 db or less, levels where the pressure adjustment of CTD #9 was negligible.

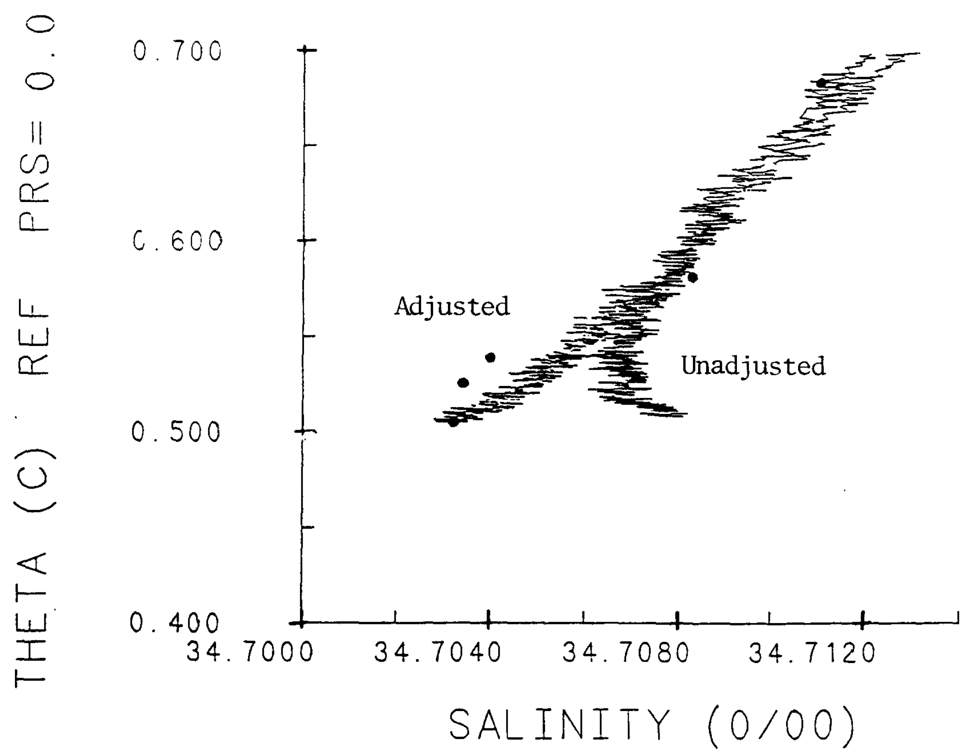


Figure A1: Potential temperature vs. CTD salinity plot showing the discrepancy between CTD#9 data and corresponding rosette data in the very deep water. All CTD #9 data was subsequently adjusted as described in Appendix A.

Appendix B: Station Listing Description

Individual station listings have been created with the following information for the trans-Indian cruise. A description of the Fortran algorithms for computing all parameters except those involving integrals and gradients are documented in Unesco TR 44 "Algorithms for computation of fundamental properties of seawater" by N. P. Fofonoff and R. C. Millard. Starting at the left, the station variables are categorized in four groups as follows. The observed variables: temperature, salinity, and oxygen are vertically filtered values at the pressure level indicated. The standard Woods Hole Oceanographic Institution 2 db pressure-averaged CTD data are centered on odd pressure intervals (1,3,5,7,...) while the adopted pressure listing levels axe at even pressure values with the exception of 75 and 125 db. The 2 db temperature, salinity, and oxygen data were smoothed with a binomial filter (Unesco TR 54) and then linearly interpolated as required to the standard levels. The potential temperature, potential density anomaly, and potential density anomaly referenced to 2000 and 4000 db that follow in the listings were computed using the Fortran algorithms of Unesco TR 44. The dynamic height and potential energy are integral quantities from the surface to the pressure interval indicated. These assume that the value of the specific volume anomaly of the first level of the 2 db CTD data profile can be extrapolated to the sea surface. A trapezoidal integration method was employed. The next quantities: potential temperature and salinity gradients, potential vorticity, and Brunt-Väisälä frequency, involve the calculation of vertical gradients. Gradient quantities were estimated from a centered linear least squares fit calculated over half of the neighboring listing intervals. The calculated depth involves a dynamic height correction and a latitude dependent gravity correction.

The header of each station listing contains the beginning time and position for the station. Positions are determined from a transit satellite navigator or by dead reckoning from last fix. The speed of sound is an average value computed from averaged travel time of the profile (Wilson, 1960). The water depth is from an echo sounder, corrected using the Carter tables.

The columns of the station listing are:

PRES	DBAR	Pressure (P) level in decibars.
TEMP	°C	Temperature (T) in degrees Celsius calibrated on the 1968 International Practical Temperature Scale (IPTS 1968).
SALT	PSU	Salinity (S) computed from conductivity (C), temperature, and pressure according to the 1978 practical salinity scale. (Unesco TR 44, pp. 6-12). C(35,15,0) = 42.914 mmho/cm.
OXYG	ML/L	Oxygen in units of milliliters per liter. The partial pressure of oxygen is computed from the polargraphic electrode measurements using an algorithm described by Owens and Millard (1985).
PTEMP	°C	Potential temperature θ in degrees Celsius computed by integrating the adiabatic lapse rate after Bryden (1973) (see Unesco TR 44, pp. 42-45). The reference level, Pr, for the calculation is 0.0 db. $\theta = \theta$ (S, T, P, Pr).
SIGTH	kg/m^3	Potential density anomaly in $kilograms/m^3$. Obtained by computing the density anomaly γ (S, T, P) (density -1000 kg/m^3) at 0 pressure replacing the *in situ* temperature with potential temperature θ = θ(S, T, P, 0.0) referenced to 0 db. $\gamma_\theta = \gamma$ (S, θ, 0.0).
SIGM2	kg/m^3	Potential density anomaly referenced to 2000 db in $kilograms/m^3$. Obtained by computing the density anomaly γ (density - 1000 kg/m^3) at 2000 db using potential temperature referenced to 2000 db $\theta = \theta$(S, T, P, 2000), $\gamma_\theta = \gamma$ (S, θ, 2000).

SIGM4 kg/m^3 Potential density anomaly referenced to 4000 db in kilograms/m^3. Obtained by computing the density anomaly 7 (density - 1000 kg/m') at 4000 db with potential temperature referenced to 4000 db $\theta = \theta(S, T, P, 4000)$. $\gamma_\theta = \gamma(S, \theta, 4000)$.

DYN-HT 10(J/kg) Dynamic height in units of dynamic meters (10 Joules/kg) is the integral with pressure of specific volume anomaly (see *The Sea*, Volume I, p. 336 by Fofonoff 7 1962).

POT. E $10^{-5}(J/m^2)$ Potential energy anomaly in 10^{-5} Joules/m^2 is the integral with pressure of the specific volume anomaly multiplied by pressure (see *The Sea*, Volume I, p. 338 by Fofonoff, 1962).

GRD-PT 10^3(°C/db) Potential temperature gradient in units of millidegrees Celsius per decibar. Estimated from the least squares temperature gradient over half the surrounding pressure intervals minus the center pressure adiabatic lapse rate.

GRD-S 10^3(psu/db) Salinity gradient in psu per decibar. Estimated from the least squares salinity gradient over half the surrounding pressure intervals.

POT-V 10^{-12} ms^{-1} Planetary potential vorticity in $m^{-1} \cdot s^{-1}$. This is defined as $f\ E$, where f is the Coriolis frequency and E is the stability parameter (Millard *et al*., 1990) estimated over half the surrounding pressure intervals.

B-V (1/hr) Brunt-Väisälä frequency in cycles per hour. This is the natural frequency of oscillation of a water parcel when vertically displaced from a rest position assuming no exchanges of heat or salt with surroundings. This calculation uses the adiabatic leveling of steric anomaly (Fofonoff, 1985; Millard *et al*., 1990).

DEPTH (m) The depth of the pressure interval including the local gravity and dynamic height (see DYN-HT definition) corrections (see Unesco TR 44, pp. 25-28).

Appendix C: Tritium, Helium, and Neon Observations

INDIAN OCEAN 32S ST12

DEPTH db	T pot. deg C	SALINITY permil	DELTA He3 %	He ccSTP/g	DELTA He %	Ne ccSTP/g	DELTA Ne %	TRITIUM TU	T-He3 AGE years
8.8	20.830								
200	17.022	35.631	0.00	3.85	1.9	13.41	4.5	0.640	4.7
598	11.596	35.021						0.338	
949	7.007	34.558						0.016	
1148	4.756	34.465	2.60	4.10	3.5	17.87	4.8		57.0
1400	3.799	34.591						-0.003	
1800	2.795	34.700	5.80	4.15	4.1	17.55	3.8	0.000	
2202	2.417	34.774	6.50	4.28	5.9	18.48	5.5		
2400	2.308	34.792		4.28	7.1	18.62	6.2		

IND OCEAN 32 S ST 15 32 32.7S 33 24E ST 15

100	17.873	35.662	-0.7	3.82	1.2	15.83	2.6	0.910	2.1
200	17.048		-0.5	3.78	3.4	15.63	3.8	0.861	1.3
601	12.606	35.149					0.4	0.420	
901	8.893		6.2	4.16	4.4	18.38	5.1		
1502	3.652	34.546	7.8	4.46	12.0	19.11	10.3		
1804	3.158	34.668							
2001	2.780	34.708	6.2	4.18	4.7	18.45	5.7		
3525	1.142	34.760	7.9	4.14	3.0	18.27	3.2		

INDIAN OCEAN 32S 33 03S, 41 00E ST 26

6.8	19.172	35.706	-1.8	3.75	-0.2	15.79	2.7	0.685	-0.6
100	17.116	35.636	-1.3	3.95	4.2	16.01	3.0	0.793	0.5
200	15.939	35.529	-0.5	3.95	3.7	16.42	4.9	0.840	4.9
300	14.800	35.428	1.0	4.02	5.1	16.37	3.8	0.710	3.5
450	13.228	35.241	2.1	4.04	4.9	16.91	6.3	0.547	5.9
600	11.639	35.021	4.8	4.07	5.0	16.90	4.8	0.440	10.8
800	9.178	34.722	6.3	4.00	2.2	17.15	4.1		
1000	6.225	34.474	6.4	4.11	3.8	17.63	4.2	0.178	
1200	4.278	34.412	5.7	4.19	5.4	18.04	4.7		
1500	3.244	34.553	7.3	4.15	4.0	18.19	4.6		
1800	2.751							0.297	
2100	2.487	34.747						0.123	
2400	2.316	34.793	6.0	4.35	8.8	18.50	5.5		
3300	1.740	34.797						0.005	
4500	0.375	34.705						0.025	
4900	0.229	34.695	5.8	4.41	10.3	18.60	5.9		
5088	0.192	34.691						0.003	

INDIAN OCEAN 32S ST 33 33 22.7S, 46 54E ST 33

0	19.068	35.577		3.77	0.2	15.56	1.1	0.711	0.1
54	17.338	35.580	-1.6	3.95	2.8	16.21	4.4	0.792	0.1
150	15.35	35.496	-1.1	3.98	4.3	16.54	3.6		0.8
350	13.396	35.276	-0.7	3.99	3.7	16.52	4.2	0.644	1.5
450	12.538	35.142	-1.2	4.01	3.9	16.87	5.3	0.402	1.2
850	7.604	34.717	4.3	4.12	4.7	17.72	5.5		
1500	2.927	34.525	8.2	4.14	3.8	18.15	4.0		
2100	2.287	34.724		4.20	5.2	18.31	4.3		
2503	2.052	34.784	14.8	4.31	7.8	18.88	7.1		
2701	1.819	34.784		4.33	8.3				
3090	1.428	34.756	12.2	4.33	8.1	18.84	6.4		

INDIAN OCEAN 32S ST35 33 33.6S, 48 14E ST35

0	19.594	35.532	-1.2	3.85	2.7	16.02	4.3	0.756	0.7
100	15.849	35.539	-2.0	3.87	1.8	16.12	2.9	0.680	-0.4
200	14.884	35.444	0.4	3.84	3.5	16.57	5.2		2.8
300	13.818	35.323	0.4	3.95	3.1	16.33	2.9	0.805	2.4
400	12.936	35.211	0.8	4.02	4.4	16.75	4.9	0.464	4.7

600	10.804	34.919	0.0	4.06	4.5	16.92	4.2	0.409	3.8
1000	5.341	34.461	2.8	4.14	4.3	17.90	5.0		10.9
1200	3.901	34.451	3.2	4.13	3.8	18.02	4.1	0.288	12.0
1400	3.169	34.489	5.2	4.12	3.2	18.09	3.9		
1700	2.608	34.615	6.8	4.18	4.7	18.30	4.6	0.195	
2400	2.004	34.739	16.9	4.30	7.6	18.53	5.3		
2800	1.667	34.749	14.9	4.33	8.2	18.67	5.7		
3200	1.227	34.731	9.6	4.34	8.2	18.88	6.4		
3205	1.227	34.731	10.8	4.36	8.8	18.97	6.9		
3782	0.842	34.721	6.8	4.29	6.8	18.78	5.4	0.000	
4029	0.756	34.713	6.8	4.46	11.3			0.017	

INDIAN OCEAN 32S ST39 33 59.9S, 52 44E ST39

10.1	19.350	35.625	-1.8	3.88	3.3	16.00	4.1	0.794	-0.1
200	15.488	35.507	-1.5	3.87	1.6	16.42	2.9	0.692	0.3
300	14.442	35.404	-1.6	3.97	3.6	16.45	4.1	0.707	0.1
500	12.676	35.172	5.1	4.00	3.7	16.45	2.8		
700	10.373	34.867	4.8	4.04	3.9	16.70	2.5	0.577	8.8
900	7.499	34.569	5.0	4.05	3.0	17.43	4.3		
1300	3.839		6.8	4.09	2.8	18.16	3.9		
1500	3.174	34.482	7.9	4.14	4.0	18.18	4.4	0.144	
1903	2.479	34.646	5.1	4.22	5.6	18.47	5.4	0.178	
2801	1.640	34.742	7.8	4.31	7.8	18.17	4.9		
3400	1.104	34.725	7.1	4.38	9.2	18.78	5.7	0.032	
4001	0.840	34.716	5.6	4.43	10.3	19.30	8.3		
4201	0.802	34.713	5.4	4.34	8.1	18.83	5.6	0.044	
4402	0.773		4.8	4.27	6.4	18.58	4.2		

INDIAN OCEAN 32S ST44 33 58.3S, 57 02E ST44

250	14.336	35.398	-0.3	3.90	1.8	15.96	0.9	0.758	1.8
400	13.333	35.276	0.3	3.95	2.7	16.53	3.8	0.742	2.5
500	12.289	35.104	1.6	4.02	4.0	16.78	4.5	0.705	4.2
600	11.308	34.969	1.2	4.00	3.3	16.51	2.1		4.3
800	8.717	34.675	1.8	4.09	4.4	17.18	3.9		5.9
1000	5.918	34.457	1.7	4.16	5.0	17.76	4.7	0.377	7.3
1200	4.350	34.401	3.4	4.07	2.2	17.67	2.6	0.033	40.0
1400	3.399		5.8	4.14	3.9	18.26	5.1	0.177	
1600	2.978	34.525	6.6	4.16	4.3			0.000	
2000	2.355	34.670	6.1	4.19	4.8	18.40	4.9	0.099	
2600	1.908	34.734	6.8	4.26	6.6	18.55	5.3	0.129	
3200	1.333	34.733	7.7	4.31	7.6	18.61	5.0	0.328	
3800	0.533	34.705	6.9	4.33	7.9	19.05	4.8	0.105	
4099	0.465	34.703	6.0	4.37	8.7	18.89	5.6	0.019	56.3
4401	0.376	34.700						0.004	
4741	0.289	34.693	4.7	4.27	6.3	18.78	4.7	0.510	9.8
5103	0.210	34.690	6.0	4.40	9.4	19.09	6.4	0.393	13.2
5197	0.206	34.691		4.43	10.2	19.18	6.8	0.000	
5197	0.209	34.691		4.37	8.7	19.01	5.9		

INDIAN OCEAN 32S ST50 '33 59.3S, 61 59E ST 50

3.2	19.015	35.550	-1.6	3.85	2.4	16.23	5.3	0.898	0.1
200	14.193	35.400	-1.2	3.87	1.1	16.28	2.9	0.774	0.6
300	13.867	35.344	-0.8	4.00	4.3	16.62	4.8	0.481	1.8
600	11.328	34.962	1.8	4.07	5.0	16.89	4.4	0.412	7.0
800	8.718	34.671	2.1	4.11	4.9	17.29	4.6		
1100	4.629	34.372	3.0	4.20	5.8	18.09	5.3	0.040	
1200	3.946	34.368						0.103	
1400	3.183	34.454	6.4	4.09	2.5	18.13	4.1		
2400	1.904	34.726	8.9	4.25	6.3	18.80	6.7		
3000	1.514	34.737	8.8	4.37	9.2	18.75	6.0		
3300	1.352	34.726	7.2	4.30	7.4	18.04	1.8	0.034	
3600	1.070	34.725						0.028	
3900	0.708	34.709	6.6	4.28	6.6	18.76	5.1	0.157	25.0
4200	0.463	34.700	5.8	4.29	6.9	18.60	3.9	0.111	28.0
4500	0.285	34.692						0.010	
4800	0.159		5.6	4.30	7.2	19.09	6.3	0.000	
5187	0.096	34.686	5.9	4.25	5.7	18.69	3.9		

INDIAN OCEAN 32S ST55 34 01S, 71 59E ST55

1.5	17.815	35.416	-1.4	3.86	2.0	16.03	3.4	0.624	0.5
70	15.823	35.437	-1.3	3.88	2.4	16.24	3.6	0.926	0.4
150	13.390	35.262	-1.5	4.00	4.1	16.61	4.3	0.809	0.2
250	12.689	35.224	-2.1	3.97	3.2	16.32	2.0	0.541	-0.1
350	12.102	35.077		4.00	3.6	16.73	4.1	0.333	
450	11.501	34.982	-1.2	3.78	5.3	17.04	5.5		2.4
550	10.653	34.863		4.07	4.7	17.25	6.1		
700	8.920	34.678	1.2	4.10	4.8	17.31	4.9	0.210	10.3
900	6.102	34.444	1.8	4.08	3.2	17.39	2.7		
1300	3.238	34.438	3.8	4.26	6.8	18.33	5.3		
1500	2.789	34.529	7.7	4.20	5.0	18.55	6.2		
2200	1.917	34.726	14.7	4.22	5.4	18.50	5.1		
3500	1.135	34.716	10.3	4.20	4.8	18.72	5.4		
4100	0.771	34.708	7.2	4.31	7.4	18.82	5.5	0.169	24.5
4700	0.672	34.705	7.1	4.29	6.9	18.72	4.8		
5055	0.668	34.705	5.6	4.19	4.3	18.44	3.3		

INDIAN OCEAN 32S ST62 30 22.4S, 79 15E ST62

22	18.897	35.772	-1.4	3.95	5.0	16.13	4.8	0.636	0.5
100	16.265	35.622	3.1	3.88	2.1	16.24	4.0	0.762	5.4
200	13.646	35.335	5.3	3.98	3.8	16.27	2.4	0.645	8.5
300	12.301	35.121	5.7	4.06	5.2	16.45	2.5	0.608	9.3
400	11.377	34.975	8.7	4.06	4.7	16.86	4.4	0.741	10.4
500	10.666	34.875	6.6	4.00	3.0	16.45	1.2	0.603	10.2
700	9.183	34.686	8.8	3.99	2.1	17.59	6.8		
800	8.235		9.8	4.19	6.8	17.30	4.2		
1000	5.294	34.410	9.4	4.14	4.5	17.65	3.5		
1100	4.332	34.408	7.2	4.19	5.3	17.60	2.3		
1300	3.583	34.493	11.1	4.27	7.4	17.78	2.5		

1500	3.169	34.572	9.0	4.20	5.4	18.02	3.5		
2300	2.017	34.729	14.9	4.53	13.2	18.72	6.4		
2700	1.576	34.742	10.9	4.42	10.3	18.69	5.7		
2900	1.400	34.735	8.2	4.46	11.4	19.04	7.5		
3100	1.258	34.732	6.4	4.20	4.9	18.68	5.3		
3500	1.137	34.726	5.0	4.25	6.0	18.25	2.8		
3792	1.121	34.726	5.5	4.32	7.8	18.83	6.0		

INDIAN OCEAN 32S ST65 29 02S, 82E ST65

17	19.482	35.917	-1.2	3.84	2.5	15.93	3.8	0.706	0.7
100	16.089	35.593	3.8	3.87	1.9	15.97	2.3	0.707	6.5
200	13.485	35.283	4.8	4.10	6.8	16.74	5.2	0.679	7.7
301	12.229	35.102	5.5	4.04	5.1			0.782	7.5
400	11.340	34.971	9.4	4.06	4.7	16.77	3.8	0.767	10.6
500	10.539	34.863	6.9	4.09	5.0	16.98	4.3	0.767	8.7
700	8.752	34.651	8.1	4.18	6.6	17.37	5.1		
1001	4.696	34.411	7.0	4.24	6.8	18.09	5.5		
1100	4.110	34.418	6.6	4.21	5.9	18.32	5.8		
1200	3.716	34.477	10.3	4.31	8.2	18.40	6.2		
2000	2.290	34.708	12.4	4.31	7.8	18.56	5.8		
2500	1.737	34.732	11.9	4.28	7.0	18.65	5.7		
3100	1.263	34.735	7.0	4.31	7.6	18.86	6.0		
4000	1.057	34.722	6.8	4.25	5.9	18.72	5.3		
4167	1.049	0	5.9	4.17	4.0	18.65	4.9		

INDIAN OCEAN 32S ST69 29 32.1S, 86 55E ST69

2.6	21.593	36.528	-1.5	3.74	0.9	15.59	2.9	0.599	0.3
100	18.010	35.853	-0.9	3.91	3.6	15.91	3.0	0.635	1.2
200	14.776	35.492	0.6	4.00	4.5	16.50	4.8	0.712	3.0
300	12.632	35.177		4.04	7.4	16.82	5.1	0.652	
400	11.408	34.989	1.8	4.02	3.9	16.84	4.2	0.783	4.0
500	10.519	34.865	0.9	4.04	4.0	17.06	4.8		4.6
600	9.746	34.765	4.3	4.07	4.3	17.10	4.4	0.406	10.8
700	8.971	34.665	5.8	4.09	4.5	17.37	5.2	0.000	
800	7.894	34.567	7.9	4.11	5.0	17.36	4.3		
900	6.339	34.461	9.5	4.13	4.8	17.82	5.5	0.080	
1000	4.808	34.403	9.3	4.24	6.8	18.13	5.8	0.040	
1100	4.238	34.464	10.2	4.14	4.1	17.76	3.1		
1300	3.463	34.529	9.8	4.27	7.2	18.05	3.9	0.058	
1700	2.702	34.653	10.9	4.27	6.9	18.49	5.8	0.340	
2300	1.940	34.724	11.2	4.30	7.5	18.67	6.0	0.086	
2700	1.575	34.730	13.7	4.31	7.8	18.79	6.3		
3300	1.197	34.724	12.0	4.29	7.0	18.85	6.2		
3585	1.069	34.721	11.5	4.33	8.0	18.92	6.6		

INDIAN OCEAN 32S ST80 31 59.8S, 99E ST80

8.4	18.875	35.984	-1.7	3.88	3.3	15.91	3.5	0.674	-0.3
60	17.503	35.961	-1.7	3.85	2.1	16.04	3.6	0.649	-0.3
120	16.482	35.874	-1.1	3.99	5.2	15.99	2.7	0.754	0.8
200	15.846	35.759	-0.3	3.94	4.0	16.51	5.6	0.793	1.7
300	13.651	35.391	4.8	4.09	6.7	16.23	2.2	0.529	9.4
400	11.856	35.089						0.502	
500	10.648	34.871	6.3	4.10	5.4	16.85	3.6	0.345	14.9
700	9.040	34.653	6.3	4.18	6.9	17.43	5.7		
800	8.539	34.595	6.5	4.19	6.6	17.28	4.3		
901	7.324	34.509	6.6	4.14	5.1	17.51	4.6		
1000	5.582	34.415	5.8	4.15	4.8	17.73	4.1		
1198	3.873	34.421						0.000	
1600	2.945	34.584	6.8	4.34	8.8	18.28	4.8	0.401	14.0
1800	2.649	34.645							
1950	2.482	34.674	5.1	4.24	6.1	18.72	6.9		
2104	2.241	34.704	6.9	4.16	4.1	18.35	4.5		

INDIAN OCEAN 32S ST88 32 44.8S 103.24E ST88

9.8	17.530	35.709	-1.4	3.85	1.9	16.05	3.6	0.718	0.4
102	14.208	35.474	-0.4	3.94	2.9	16.36	3.4	0.846	1.5
200	12.434	35.158	1.8	4.08	5.8	16.81	4.9	0.851	3.7
300	10.983	34.923	4.2	4.02	3.6	16.89	4.1		
400	10.352	34.825	7.2	4.17	7.0	17.41	6.8		
500	9.631	34.726	9.7	4.17	6.8	17.37	5.9	0.409	
700	8.323	34.594	8.6	4.11	4.8	17.36	4.7		
898	5.600	34.404	9.3	4.17	5.3	17.83	4.8	0.000	
1100	3.912	34.403	9.6	4.31	8.4	18.26	5.6	0.009	
1300	3.364	34.512	10.1	4.28	7.4	18.21	4.9	0.000	
1500	3.025	34.581							
1797	2.609	34.662	9.6	4.31	7.9	18.52	5.9	0.212	
2101	2.229	34.703							
2401	1.929	34.730	8.4	4.41	10.3	18.87	7.1	0.076	
2703	1.653	34.736							
3000	1.413	34.737	10.0	4.35	8.5	18.83	6.4		
3300	1.131	34.729							
3600	0.929	34.721	8.5	4.38	9.2	18.82	5.7		
3906	0.761	34.717	8.5	4.41	9.9	19.02	6.7	0.009	
4208	0.661	34.711							
4501	0.606	34.707	7.9	4.28	6.7	18.56	4.1		
4806	0.573	34.705							
5102	0.550	34.705	7.5	4.31	7.4	18.81	5.2		
5336	0.539	34.700	8.2	4.35	8.2	19.12	6.9	0.242	21.3

INDIAN OCEAN 32S ST94 33 53.6S. 107 13E ST94

13.4	17.901	35.893	-1.6	3.87	2.8	16.02	3.9	0.649	0.2
100	15.703	35.700	0.0	3.86	1.6	16.17	3.3	0.806	2.0
200	13.466	35.350	2.1	4.01	3.3	16.77	4.2	0.682	4.9
300	11.210	34.963	0.8	4.12	6.4	17.10	5.6	0.060	21.5

400	9.983	34.771	3.7	4.08	4.8	17.14	4.8		
500	9.347	34.686	4.9	4.11	5.2	17.10	4.0		
600	8.687	34.611	7.8	4.18	6.7	17.35	4.9		
700	8.001	34.552	8.4	4.17	6.1	17.52	5.3		
800	6.610	34.464	8.1	4.21	6.6	17.78	5.5		
900	5.147	34.396	7.9	4.22	7.4	18.15	6.2		
1000	4.269	34.396	8.8	4.28	7.7	18.06	4.8		
1200	3.509	34.482	7.6	4.38	9.8	18.55	6.9		
1800	2.475	34.665	7.9	4.21	5.4	18.27	4.3		
2600	1.752	34.728	8.8	4.32	8.1	18.67	5.8		
3400	1.220	34.731	15.0	4.24	5.9	18.86	6.3		
4200	0.817	34.715	6.4	4.29	6.9	18.66	4.7		
4900	0.558	34.705	10.9	4.27	6.3	18.58	3.9		
5375	0.507	34.707	8.6	4.31	7.2	18.86	5.4		

INDIAN OCEAN 32S ST97 34 10S, 109 09E ST97

100	14.903	35.595	-1.0	3.95	3.6	16.40	4.2		
200	13.782	35.394	-0.8	3.94	2.8	16.47	3.8		
300	12.067	35.092	-1.2	4.05	4.9	16.64	3.5		
400	10.084	34.770	-1.6	4.05	3.9	17.10	4.6	0.313	0.3
500	9.479	34.697	0.2	4.15	6.1	17.19	4.7		
600	8.918	34.638	2.3	4.15	6.0	17.43	5.5		
700	8.302	34.563	6.3	4.13	5.5	17.39	4.8		
800	7.186	34.488	7.1	4.23	7.4	17.43	4.0		
900	5.766	0.000	9.1	4.27	7.8	18.01	6.1		
1000	4.508	34.370	10.8	4.30	8.3	18.30	6.4		
1300	3.284	0.000	11.4	4.23	6.2	18.32	5.3	0.055	
1900	2.400	34.677	11.8	4.26	6.7	18.39	4.9		
2500	1.844	34.727	12.4	4.29	7.3	18.54	5.2		
3100	1.453	34.732	12.1	4.23	5.8	18.58	5.0		
3800	1.020	34.725	11.4	4.33	7.9	18.63	4.7		
4000	0.898	34.716	10.5	4.35	8.4	18.92	6.2		
5138	0.515	34.702	9.7	4.27	6.2	18.89	5.6		

INDIAN OCEAN 32S ST105 ST105

2.5	19.145	35.880	-1.8	3.80	1.1	15.65	1.9		
100	16.182	35.696	-1.1	4.09	7.9	16.64	6.6		
200	14.235	35.446	-0.2	4,02	5.1	16.48	4.2		
400	9.452	34.704		4.06	3.9	17.15	4.4		
500	8.643	34.608	-0.6	4.07	4.0	17.17	3.8		
600	7.711	34.524	2.1	4.12	4.8	17.35	4.0		
700	6.156	34.437		4.13	4.4	17.83	5.3		
800	4.902	34.394	8.2	4.13	4.1	17.68	3.3		
900	4.231	34.413	10.4	4.21	5.8	17.74	2.9		
1000	3.999	34.473	10.8	4.12	3.6	17.95	3.9		
1080	3.877	34.482	11.1	4.12	3.6	17.94	3.8		

INDIAN OCEAN 32S ST106 **ST 106**

3.5	19.395	35.855	-1.5	3.86	3.1	15.78	2.8	0.698	0.3
100	16.957	35.769	-0.9	4.10	8.3	16.47	5.9	0.477	1.6
200	16.425	35.734	0.0	4.00	5.4	16.29	4.5	0.341	4.4
300	12.389			4.01	4.2	16.90	4.5		
400	9.542	34.718		4.08	4.6	17.03	3.8		
500	8.659	34.618	0.5	4.12	5.1	17.26	4.3		
600	7.199	34.510	2.5	4.11	4.5	17.41	3.9		
687	6.062	34.437	6.9	4.15	4.9	17.79	5.0		
Precision	+ -		0.2	0.01	1	0.04	1	0.010	

HELIUM AND NEON COLUMNS *1E-8