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CTD/O_2 measurements collected on a Climate and Global Change cruise along 24°N in the Atlantic Ocean (WOCE Section A6) during January–February 1998

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Abstract. Summaries of CTD/O_2 measurements and hydrographic data acquired on a Climate and Global Change cruise during the winter of 1998 aboard the NOAA ship *Ronald H. Brown* are presented. The majority of these data were collected along 24.5°N from 23.5°W to 69°W. Completing the transatlantic section are data collected along a NE–SW dogleg off the coast of Africa, and along a second, short, zonal section along 26.5°N off the coast of Abaco Island from 69°W to 77°W, jogging north along 27°N in the Straits of Florida to 80°W. Data acquisition and processing systems are described and calibration procedures are documented. Station location, meteorological conditions, CTD/O_2 summary data listings, profiles, and potential temperature-salinity diagrams are included for each cast. Section plots of oceanographic variables and hydrographic data listings are also given.

1. Introduction

The NOAA Office of Global Programs (OGP) sponsors the Atlantic Climate Change Program (ACCP) and the Ocean-Atmosphere Carbon Exchange Study (OACES) as elements under the Climate and Global Change Program. The long-term objective of the Climate and Global Change Program is to provide reliable predictions of climate change and associated regional implications on time scales ranging from seasons to centuries. Large uncertainties in current predictions include the sources and sinks of greenhouse gases like carbon dioxide and the role of the ocean in mitigating or changing the timing of regional patterns associated with warmer climate. Hydrographic and direct velocity measurements collected during this cruise will help to quantify the water masses and determine the meridional overturning circulation responsible for the redistribution of heat, fresh water, and carbon in the center of the subtropical gyre and estimate the remineralization component of the CO_2 increase in order to quantify the anthropogenic CO_2 burden.

The 24°N transatlantic section has been previously occupied in 1957, 1981, and 1992, revealing long-term variability in mid-depth temperature, salinity, and oxygen. This new data set extends this time series through a time when relatively large mid-depth changes due to decadal variations in the air-sea interaction for Labrador Sea Water formation have already been observed. In addition, this data set complements those from other seasons, allowing for investigation into seasonal variations in fluxes of mass, heat, and freshwater.

CTD/O_2 stations were occupied during leg 2. Stations were spaced

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roughly 55–85 km apart across the basin, closer near the coastlines. Full water column CTD/O_2 profiles were collected at all stations and Lowered Acoustic Doppler Current Profiler (LADCP) measurements were taken on all but five stations prior to station 85. Underway salinity, temperature, shipboard ADCP, and carbon partial pressures were taken along the cruise track. Water samples were analyzed for a suite of natural and anthropogenic tracers including salinity, dissolved oxygen, inorganic nutrients, CFCs, dissolved inorganic carbon, total alkalinity, pH, pCO_2, dissolved organic carbon, and carbon isotopes. Figure 1 shows station locations. Table 1 provides a summary of cast information.

Leg 2 stations began with a NE–SW dogleg off the coast of Africa from station 1 at 28°N, 15°W in 130 m of water to station 22 at 24.5°N, 23.5°W in nearly 5000 m of water. Stations continued westward in a long zonal section along 24.5°N from station 22 to station 89 at 69°W across the Mid-Atlantic Ridge. The trackline jogged northwestward and stations were occupied along 26.5°N from 71°W at station 94 to 79°W at station 121. The remaining stations, 122–130, were along 27°N across the Straits of Florida. Leg 1 followed this same trackline in the opposite direction, deploying only XBTs to sample the temperature in the upper 750 m.

2. Standards and Pre-Cruise Calibrations

The CTD/O_2 system is a real-time data acquisition system with the data from a Sea-Bird Electronics, Inc. (SBE) 9plus underwater unit transmitted via a conducting cable to a SBE 11plus deck unit. The serial data from the underwater unit is sent to the deck unit in RS-232 NRZ format. The deck unit decodes the serial data and sends it to a personal computer for display and storage in a disk file using Sea-Bird SEASOFT software.

The SBE 911plus system transmits data from primary and auxiliary sensors in the form of binary number equivalents of the frequency or voltage outputs from those sensors. These are referred to as the raw data. The calculations required to convert raw data to engineering units are performed by software.

The SBE 911plus system is electrically and mechanically compatible with standard unmodified rosette water samplers made by General Oceanics (GO), including the 1016 36-position sampler, which was used for all stations on this cruise. A modem and rosette interface allows the 911plus system to control the operation of the rosette directly without interrupting the flow of data from the CTD.

The SBE 9plus underwater unit is configured with dual standard modular temperature (SBE 3) and conductivity (SBE 4) sensors which are mounted near the lower end cap. The conductivity cell entrance is co-planar with the tip of the temperature sensor probe. The pressure sensor is mounted inside the underwater unit main housing. A centrifugal pump module flushes water through sensor tubing at a constant rate independent of the CTD's motion to improve dynamic performance. A dissolved oxygen sensor is added to the pumped sensor configuration following the temperature-conductivity (TC) pair.

2.1 Conductivity

The flow-through conductivity-sensing element is a glass tube (cell) with three platinum electrodes. The resistance measured between the center electrode and end electrode pair is determined by the cell geometry and the specific conductance of the fluid within the cell, and controls the output frequency of a Wien Bridge circuit. The sensor has a frequency output of approximately 3 to 12 kHz corresponding to conductivity from 0 to 7 Siemens/meter (0 to 70 mmho/cm). The SBE 4 has a typical accuracy/stability of ±0.0003 S/m/month and resolution of 0.00004 S/m at 24 samples per second.

Pre-cruise sensor calibrations were performed at Sea-Bird Electronics, Inc. in Bellevue, Washington. The following coefficients were entered into SEASOFT using software module SEACON:

s/n 1346 December 6, 1997	s/n 1347 December 6, 1997
g = –4.16857251e+00	g = –4.05527033e+00
h = 5.48731172e–01	h = 5.32990229e–01
i = 1.14301642e–04	i = 1.34295790e–05
j = 2.71673254e–05	j = 3.14203119e–05
ctcor = 3.2500e–06	*ctcor* = 3.2500e–06
cpcor = –9.5700e–08	*cpcor* = –9.5700e–08

Conductivity calibration certificates show an equation containing the appropriate pressure-dependent correction term to account for the effect of hydrostatic loading (pressure) on the conductivity cell:

$$C(\mathrm{S/m}) = (g + hf^2 + if^3 + jf^4)/[10(1 + ctcor * t + cpcor * p)]$$

where g, h, i, j, *ctcor*, and *cpcor* are the calibration coefficients above, f is the instrument frequency (kHz), t is the water temperature (degrees Celsius), and p is the water pressure (dbar). SEASOFT automatically implements this equation.

2.2 Temperature

The temperature-sensing element is a glass-coated thermistor bead, pressure-protected by a stainless steel tube. The sensor output frequency ranges from approximately 5 to 13 kHz corresponding to temperature from –5 to 35°C. The output frequency is inversely proportional to the square root of the thermistor resistance which controls the output of a patented Wien Bridge circuit. The thermistor resistance is exponentially related to temperature. The SBE 3 thermometer has a typical accuracy/stability of ±0.004°C per year and resolution of 0.0003°C at 24 samples per second. The SBE 3 thermometer has a fast response time of 0.070 seconds.

Pre-cruise sensor calibrations were performed at Sea-Bird Electronics, Inc. in Bellevue, Washington. The following coefficients were entered into SEASOFT using software module SEACON:

s/n 1701 December 4, 1997	s/n 1075 December 4, 1997
g = 4.78998172e–03	g = 4.81195547e–03
h = 6.52982992e–04	h = 6.70417903e–04
i = 1.81051274e–05	i = 2.58445709e–05
j = 9.53750998e–07	j = 2.09728302e–06
$f0$ = 1000.0	$f0$ = 1000.0

Temperature (ITS-90) is computed according to

$$T(\mathrm{C}) = 1/g + h[\ln(f0/f)] + i[\ln^2(f0/f)] + j[\ln^3(f0/f)] - 273.15$$

where g, h, i, j, and $f0$ are the calibration coefficients above and f is the instrument frequency (kHz). SEASOFT automatically implements this equation and converts between ITS-90 and IPTS-68 temperature scales as desired.

2.3 Pressure

The Paroscientific series 4000 Digiquartz high pressure transducer uses a quartz crystal resonator whose frequency of oscillation varies with pressure induced stress measuring changes in pressure as small as 0.01 parts per million with an absolute range of 0 to 10,000 psia (0 to 6885 dbar). Repeatability, hysteresis, and pressure conformance are 0.005% FS. The nominal pressure frequency (0 to full scale) is 34 to 38 kHz. The nominal temperature frequency is 172 kHz + 50 ppm/°C.

Pre-cruise sensor calibrations were performed at Sea-Bird Electronics, Inc. in Bellevue, Washington. The following coefficients were entered into SEASOFT using software module SEACON:

s/n 58808 August 9, 1994
$c1$ = –4.583844e+04
$c2$ = –1.96344e–01
$c3$ = 1.27804e–02
$d1$ = 3.7796e–02
$d2$ = 0.0
$t1$ = 3.010293e+01
$t2$ = –2.93260e–04
$t3$ = 3.61082e–06
$t4$ = 3.74863e–09

Pressure coefficients are first formulated into

$$\begin{aligned} c &= c1 + c2 * U + c3 * U^2 \\ d &= d1 + d2 * U \\ t0 &= t1 + t2 * U + t3 * U^2 + t4 * U^3 \end{aligned}$$

where U is temperature in degrees Celsius. Then pressure is computed according to

$$P(psia) = c * [1 - (t0^2/t^2)] * \{1 - d[1 - (t0^2/t^2)]\}$$

where t is pressure period (μs). SEASOFT automatically implements this equation.

2.4 Oxygen

The SBE 13 dissolved oxygen sensor uses a Beckman polarographic element. Oxygen sensors determine the dissolved oxygen concentration by counting the number of oxygen molecules per second (flux) that diffuse through a membrane. By knowing the flux of oxygen and the geometry of the diffusion path the concentration of oxygen can be computed. The permeability of the membrane to oxygen is a function of temperature and ambient pressure. The interface electronics outputs voltages proportional to membrane current (oxygen current) and membrane temperature (oxygen temperature). Oxygen temperature is used for internal temperature compensation. Initial computation of dissolved oxygen in engineering units is done in the software. The range for dissolved oxygen is 0 to 650 μmol/kg; nominal accuracy is 4 μmol/kg; resolution is 0.4 μmol/kg. Response times are roughly 2 s at 25°C and 5 s at 0°C.

The following oxygen calibrations were entered into SEASOFT using SEACON:

s/n 130364 December 10, 1997	s/n 130353 December 11, 1997	s/n 130381 December 12, 1997
m = 2.4614e–07	m = 2.4624e–07	m = 2.4496e–07
b = –5.0212e–10	b = –5.6634e–10	b = –2.7680e–10
soc = 3.4185	soc = 3.2070	soc = 3.2309
boc = –0.0210	boc = –0.0290	boc = –0.0260
$tcor$ = –3.3e–02	$tcor$ = –3.3e–02	$tcor$ = –3.3e-02
$pcor$ = 1.5e–04	$pcor$ = 1.5e–04	$pcor$ = 1.5e–04
tau = 2.0	tau = 2.0	tau = 2.0
wt = 0.67	wt = 0.67	wt = 0.67
k = 9.0037	k = 8.9643	k = 9.0214
c = –6.8110	c = –6.8963	c = –6.7355

The use of these constants in linear equations of the form $I = mV + b$ and $T = kV + c$ will yield sensor membrane current and temperature (with a maximum error of about 0.5°C) as a function of sensor output voltage.

3. Data Acquisition

CTD/O_2 measurements were made using a SBE 9plus CTD with dual sensor configuration. Each set of sensors included a temperature, conductivity, and dissolved oxygen sensor. The sets were placed as mirror images to each other mounted low on the CTD main housing with the intakes approximately 6–8 inches apart. The TC pairs were monitored for calibration drift and shifts by examining the differences between the two pairs on each CTD and comparing CTD salinities with bottle salinity measurements.

AOML's SBE 9plus CTD/O_2 s/n 09P10779-0363 (sampling rate 24 Hz) was mounted in a 36-position frame and employed as the primary package. Auxiliary sensors included an LADCP and Benthos altimeter. Water samples were collected using a GO 36-bottle rosette and 10-liter Nisken bottles. The primary package was used for all casts during this cruise.

The package entered the water from the starboard side of the ship and was held within 10 m of the surface for 1 minute in order to activate the pump. The package was lowered at a rate of 30 m/min to 50 m, 45 m/min to 200 m, and 60 m/min generally to within 10 m of the bottom, slowing gradually on the approach. The position of the package relative to the bottom was monitored by the ship's Precision Depth Recorder (PDR) and the altimeter. A bottom depth was estimated from bathymetric charts and the PDR ran during the bottom 1000 m of the cast. Figure 2 shows the pressures of bottle closures during the upcast.

Upon completion of the cast, sensors were flushed repeatedly and stored with a dilute Triton-X solution in the plumbing. Nisken bottles were then sampled for various water properties detailed in the introduction. Sample protocols conformed to those specified by the WOCE Hydrographic Programme.

A SBE 11plus deck unit received the data signal from the CTD. The analog data stream was recorded onto video cassette tape as a backup. Digitized data were forwarded to a personal computer equipped with SEASOFT acquisition and processing software version 4.230. Preliminary temperature, salinity, and oxygen profiles were displayed in real time. Raw data files were archived to Syquest tapes.

3.1 Data Acquisition Problems

All of the three oxygen sensors employed during this cruise were problematic owing to the age of the modules. Oxygen sensor s/n 364 associated with the primary TC pair was replaced with oxygen sensor s/n 381 prior to station 33. S/n 364 had drifted more than 15 μmol/kg from its calibration and was exhibiting numerous shifts in oxygen current throughout the water column. Redundant oxygen sensor s/n 353 associated with the secondary TC pair was removed prior to station 45 in an effort to conserve its usefulness in case primary oxygen sensor s/n 381 failed later in the cruise. Also, secondary sensor s/n 353 was exhibiting multiple shifts in oxygen current at varying depths and thought to be more difficult to calibrate. Primary sensor s/n 381 was better behaved although much noisier.

There was no primary oxygen data from sensor s/n 381 collected for station 34 owing to a poor connection of the dissolved oxygen module.

3.2 Salinity Analyses

Bottle salinity analyses were performed in the ship's temperature-controlled salinity laboratory using two Guildline Model 8400B inductive autosalinometers, and a dedicated personal computer. Software allowed the user to standardize the autosal, and perform a second standardization using a fresher standard (30 PSS) for a linearity check. IAPSO Standard Seawater batch #133 was used as the primary standard. IAPSO Standard Seawater batch #30L5 was used as the second, fresher standard. The autosalinometer in use was standardized before each cast of samples were analyzed, or every 36 samples. The software limits set required that each successive reading be within ±0.002 PSS or the program would reject that reading and seek another. Stable room temperature and high performance of the autosalinometers allowed these limits to be so strictly set.

Duplicate samples usually taken from the deepest bottle on each cast were analyzed on a subsequent day. Bottle salinities were compared with preliminary CTD salinities to aid in the identification of leaking bottles as well as to monitor the CTD conductivity cells' performance and drift. The expected precision of the autosalinometer with an accomplished operator is 0.001 PSS, with an accuracy of 0.003. The standard deviation of the duplicate differences is 0.0003 PSS. This value is far below the expected precision.

Calibrated CTD salinities replace missing bottle salinities in the hydrographic data listing and are indicated by an asterisk.

4. At Sea Processing

SEASOFT consists of modular menu driven routines for acquisition, display, processing, and archiving of oceanographic data acquired with SBE equipment and is designed to work with an IBM or compatible personal computer. Raw data are acquired from the instruments and are stored unmodified. The conversion module DATCNV uses the instrument configuration and pre-cruise calibration coefficients to create a converted engineering unit data file that is operated on by all SEASOFT post processing modules.

The following is the SEASOFT processing module sequence and specifications used in the reduction of CTD/O_2 data from this cruise:

- DATCNV converted the raw data to pressure, temperature, conductivity, oxygen current, and oxygen temperature; and computed salinity, the time rate of change of oxygen current, and preliminary oxygen. DATCNV also extracted bottle information where scans were marked with the bottle confirm bit during acquisition.

- ROSSUM created a summary of the bottle data. Bottle position, date, and time were automatically output. Pressure, temperature, conductivity, salinity, oxygen current, oxygen temperature, time rate of change of oxygen current, and preliminary oxygen values were averaged over a 2-s interval (48 scans) from 5 to 3 s prior to the confirm bit in order to avoid spikes in conductivity and oxygen current owing to minor incompatibilities between the SBE 911plus CTD/O_2 system and GO 1016 rosette. ROSSUM computed potential temperature and sigma-theta.

- WILDEDIT marked extreme outliers in the data files. The first pass of WILDEDIT obtained an accurate estimate of the true standard deviation of the data. The data were read in blocks of 200 scans. Data greater than two standard deviations were flagged. The second pass computed a standard deviation over the same 200 scans excluding the flagged values. Values greater than 16 standard deviations were marked bad.

- SPLIT removed decreasing pressure records from the data files leaving only the downcast.

- FILTER performed a low pass filter on pressure with a time constant of 0.15 s. In order to produce zero phase (no time shift) the filter first runs forward through the file and then runs backward through the file.

- Measurements can be misaligned due to the inherent time delay of the sensor response, the water transit time delay in the pumped plumbing line, and the sensors being physically misaligned in depth. ALIGNCTD aligns conductivity, temperature, and oxygen in time relative to pressure to ensure that all calculations were made using measurements from the same parcel of water minimizing salinity spiking and density errors. Primary conductivity was not advanced in ALIGNCTD because it is done in the factory setting of the 11plus deck unit. Secondary conductivity, however, is not advanced in the deck unit and so was advanced 0.073 s in ALIGNCTD. Because SBE 3 temperature sensor response is fast (0.06 s), it was not necessary to advance temperature relative to pressure. Oxygen sensors s/n 364 and s/n 353 were advanced 3.0 s in ALIGNCTD; s/n 381 was not advanced in the software.

- CELLTM used a recursive filter to remove conductivity cell thermal mass effects from measured conductivity. Both conductivity cells were epoxy coated and therefore the thermal anomaly amplitude (alpha) and the time constant (1/beta) were 0.03 and 9.0 respectively for each sensor.

- DERIVE was used to recompute doxc/dt and oxygen with a time window size of 2.0 seconds.

- LOOPEDIT marked scans where the CTD was moving less than a minimum velocity of 0.25 m/s or travelling backwards due to ship roll.

- BINAVG averaged the data into 1-dbar pressure bins starting at 1 dbar with no surface bin. The center value of the first bin was set equal to the bin size. The bin minimum and maximum values are the center value ± half the bin size. Scans with pressures greater than the minimum and less than or equal to the maximum were averaged.

Scans were interpolated so that a data record exists every decibar. The number of points averaged in each bin was added to the variables listed in the data file.

- DERIVE recomputed salinity.

- STRIP removed scan number; and salinity, time rate of change of oxygen current, and preliminary oxygen computed in DATCNV from the data files.

- TRANS converted the data file format from binary to ASCII format.

In addition to the Seasoft processing modules, several PMEL programs were used to further reduce the CTD/O_2 data:

- Because the pump does not turn on until 60 seconds after the CTD package is in the water, measurements of near-surface conductivity and oxygen values are inaccurate. FILLSFC was used to copy the first good value of salinity, potential temperature, oxygen, and oxygen current back to the surface. FILLSFC then back-calculated temperature and conductivity, and zeroed the time rate of change of oxygen current for those records. Filled salinities ranged from 3 to 9 dbar, usually 5 dbar. There were only 7 stations where surface potential temperatures had to be filled in 1–2 dbar. Filled oxygens also ranged from 3 to 9 dbar, usually 5 dbar. WOCE flags for the affected parameters were changed to "7" for extrapolation.

- DESPIKE1 removed spikes from primary oxygen current and primary oxygen temperature data. DESPIKE1 also removed spikes from primary salinity data. Data were linearly interpolated over despiked records and the associated WOCE flags were changed to "6" for interpolation. Conductivity was back-calculated, and potential temperature and sigma-theta were recomputed for the interpolated records.

- DESPIKE2 removed spikes from secondary data in the same fashion as DESPIKE1.

- Package slowdowns and reversals owing to ship roll can move mixed water in tow to in front of the CTD sensors and create artificial density inversions and other artifacts. In addition to SEASOFT module LOOPEDIT, PMEL program DELOOP computed values of density locally referenced between every 1 dbar of pressure to compute $N^2 = (-g/\rho)(d\rho/dz)$ and linearly interpolated measured parameters over those records where $N^2 \leq -1.0e - 05s^{-2}$. WOCE flags were changed to "6" for interpolation and derived variables were recomputed over interpolated intervals.

- FILTDOC applied a median filter of width 5 dbar to the time rate of change in oxygen current.

- FIX353 added a positive shift to secondary oxygen current (s/n 353) at user selected depths, usually deeper than 3500 dbar, and recomputed oxygen. This shift was applied to stations 16–44 to correct an odd but persistent behavior of the aged oxygen module.

- FIX381 added a negative shift to primary oxygen current (s/n 381) at user selected depths, usually around 2900 dbar, and recomputed oxygen. This shift was applied to stations 50–118 to correct an odd but persistent behavior of the aged oxygen module.

5. Post-Cruise Calibrations

Post-cruise sensor calibrations were done at Sea-Bird Electronics, Inc. during March and May 1998. Secondary sensor pair T1075 and C1347 were selected for final data reduction for all stations for two reasons based on post-cruise temperature calibration information. First, T1075 has a drift of 0.3e–03°C/year with an uncertainty of 0.3e–03°C based on five calibrations between August 1996 and May 1998, whereas T1701 has a drift of 1.5e–03°C/year with an uncertainty of 0.4e–03°C based on seven calibrations between May 1996 and May 1998. Second, T1075 was determined by Sea-Bird to have no pressure correction, whereas T1701 has a pressure correction of –1.4e–03°C/5000 dbar.

Secondary oxygen data from sensor s/n 353 was retained for stations 1-32 and 34; primary oxygen data from sensor s/n 381 was retained for stations 33 and 35–130.

Post-cruise calibrations were applied to CTD data associated with bottle data using PMEL program CALBOT. WOCE quality flags were appended to bottle data records using PMEL program FLAG. Quality flags were determined by plotting the absolute value of sample residuals versus pressure and selecting a cutoff value for bad flags. The value of 2.8 standard deviations of the remaining residuals was the cutoff for questionable flags. Of the 4313 sample salinities, 0.4% were flagged as bad and 3.6% were flagged as questionable. Of the 4130 sample oxygens, 1.2% were flagged as bad and 4.9% were flagged as questionable.

5.1 Conductivity

Conductivity slope and bias, along with a linear pressure term (modified beta), were computed by a least-squares minimization of CTD and bottle conductivity differences. The function minimized was

$$BC - m * CC - b - \beta * CP$$

where BC is bottle conductivity (S/m), CC is pre-cruise calibrated CTD conductivity (S/m), CP is the CTD pressure (dbar), m is the conductivity slope, b is the bias (S/m), and β is a linear pressure term (S/m/dbar). The final CTD conductivity (S/m) is

$$m * CC + b + \beta * CP$$

The slope term m is a fourth-order polynomial function of station number to allow the entire cruise to be fit at once with a smoothly-varying station-dependent slope correction. For sensor C1347 a series of fits were made, each fit throwing out bottle values for locations having a residual between CTD and bottle conductivity greater than three standard deviations. This procedure was repeated with the remaining bottle values until no more bottle values were thrown out.

For C1347, the slope correction ranged from 0.99993647 to 0.99998722, the bias applied was –1.3e-04 S/m, and the beta term was –1.41e–08 S/m/dbar. Of 4313 bottles, the percentage of bottles retained in the fit was 75.65 with a standard deviation of 1.144e–04 S/m. PMEL program CALCTD applied these calibrations.

CTD-bottle conductivity differences are plotted against station number to show the stability of the calibrated CTD conductivities relative to the bottle conductivities (Fig. 3, upper panel). CTD-bottle conductivity differences are plotted against pressure to show the tight fit below 500 m and the increasing scatter above 500 m (Fig. 3, lower panel).

5.2 Temperature

The pre-cruise calibration of T1075 is the mean of the two post-cruise calibrations, and is within 0.05e–03°C of the overall drift trajectory over the duration of the cruise as determined by the calibration history of the sensor. Therefore, the pre-cruise calibration was used in the final processing. The pressure correction for this sensor was determined by Sea-Bird to be zero. However, a bias of –0.6e–03°C was applied to temperature data in program CALCTD to account for the effect of viscous heating on SBE 3 sensors. An adjustment of –0.6e–03°C results in errors of no more than ±0.15e–03°C from this effect for the full range of oceanographic temperature and salinity.

5.3 Oxygen

In situ oxygen samples collected during CTD/O_2 profiles are used for post-measurement calibration. Because the dissolved oxygen sensor has an obvious hysteresis, PMEL program OXDWNP replaced up-profile water sample data with corresponding processed (see section 4) down-profile CTD/O_2 data at common pressure levels. Oxygen saturation values were computed according to Benson and Krausse (1984) in units of μmol/kg.

The algorithm used for converting oxygen sensor current and probe temperature measurements to oxygen as described by Owens and Millard (1985) requires a non-linear least squares regression technique in order to determine the best-fit coefficients of the model for oxygen sensor behavior to the water sample observations. WHOI program OXFITMR uses Numerical Recipes (Press *et al.*, 1986) Fortran routines MRQMIN, MRQCOF, GAUSSJ, and COVSRT to perform non-linear least squares regression using the Levenberg-Marquardt method. A Fortran subroutine FOXY describes the oxygen model with the derivatives of the model with respect to six coefficients in the following order: oxygen current slope, temperature correction, pressure correction, weight, oxygen current bias, and oxygen current lag.

Program OXFITMR reads the data for a group of stations. The data are edited to remove spurious points where values are less than zero or greater than 1.2 times the saturation value. The routine varies the six (or fewer) parameters of the model in such a way as to produce the minimum sum of squares in the difference between the calibration oxygens and the computed values. Individual differences between the calibration oxygens and the computed oxygen values (residuals) are then compared with the standard deviation of the residuals. Any residual exceeding an edit factor of 2.8 standard deviations is rejected. A factor of 2.8 will have a 0.5% chance of rejecting a valid oxygen value for a normally distributed set of residuals. The iterative fitting process is continued until none of the data fail the edit criteria. The best fit to the oxygen probe model coefficients is then determined. Coefficents were applied using program CAL381 or CAL353 for plotting in Matlab.

By plotting the oxygen residuals versus station, appropriate station groupings for further refinements of fitting are obtained by looking for abrupt station-to-station changes in the residuals. For each grouping, two sets of coefficients were determined, one fitting bottles $\leq$2500 dbar and a second fitting bottles $\geq$2000 dbar. Pressure correction, weight, and lag coefficients were fixed within a reasonable range (noted by asterisks in Table 2) from output of full water column group fits. The two sets of coefficients were blended at 2250 dbar using a pair of hyperbolic tangent functions with 250-dbar decay scales. Final coefficients were applied to downcast data using PMEL program CALC381 and CALC3532. Calibrated oxygens were extracted from the calibrated profiles by pressure to create the final bottle file using CALBOT.

CTD-bottle oxygen differences are plotted against station number to show the stability of the calibrated CTD oxygens relative to the bottle oxygens (Fig. 4, upper panel). Note that the residuals (Table 2 and Fig. 4) are near the nominal WOCE standard accuracy of 0.5% for discrete oxygen titrations. CTD-bottle oxygen differences are plotted against pressure to show the tight fit below 1200 m and the increasing scatter above 1200 m (Fig. 4, lower panel).

6. Data Presentation

PMEL program 24N_EPIC converted finalized CTD/O_2 data files into EPIC format (Soreide *et al.*, 1995); and computed ITS-90 temperature, ITS-90 potential temperature, and dynamic height. EPIC datafiles contain a WOCE quality flag parameter associated with pressure, temperature, CTD salinity, and CTD oxygen. Quality flag definitions can be found in the WOCE Operations Manual (1994).

The final calibrated data in EPIC format were used to produce the plots and listings that follow. The majority of the plots were produced using Plot Plus Scientific Graphics System (Denbo, 1992). Vertical sections of potential temperature, CTD salinity, potential density, and CTD oxygen are contoured with pressure as the vertical axis and latitude as the horizontal axis (Figs. 5–8). Nominal vertical exaggerations are 1000:1 below 1000 dbar (lower panels) and 2500:1 above 1000 dbar (upper panels). Plots and summary listings of the CTD/O_2 data follow for each cast. Hydrographic bottle data at discrete depths are listed in the final section.

The hydrographic listings presented include two-digit WOCE quality flags. The numeric digits are associated with bottle salinity and bottle oxygen. Quality flag definitions can be found in the WOCE Operations Manual (1994).

7. Participating Institutions/Personnel

NOAA Atlantic Oceanographic and Meterological Laboratory (AOML)
NOAA Pacific Marine Environmental Laboratory (PMEL)
Bermuda Biological Station for Research (BBSR)
University of Washington (UW)
University of Miami (UM)/Cooperative Institute for Marine and
Atmospheric Studies (CIMAS)

Measurement	Principal Investigator	Institution
CTD/O_2, LADCP, ADCP	M. Baringer	AOML
Salinity, Oxygen		
CTD/O_2	G. Johnson	PMEL
Total DIC, pCO_2	R. Wanninkhof	AOML
Total CO_2 (DIC), pCO_2	R. Feely	PMEL
Chlorofluorocarbons (CFCs)	J. Bullister	PMEL
Nutrients	C. Mordy	PMEL
	Z. Zhang	AOML
C-13	P. Quay	UW
Total Alkalinity, pH	F. Millero	UM
DOC	D. Hansell	BBSR
Meari	P. Minnett	UM

		Leg 1	Leg 2
Dave Bitterman, AOML	Co-Chief Scientist		x
Kitack Lee, AOML	Co-Chief Scientist		x
Christiane Fleurant, UM/CIMAS	CTD		x
Doug Anderson, AOML	CTD/ET		x
Kristy McTaggart, PMEL	CTD		x
Gregg Thomas, AOML	Chief Scientist	x	
	salinity		x
Robert Roddy, AOML	oxygen/ET		x
George Berberian, AOML	oxygen		x
Ryan Smith, UM/CIMAS	LADCP		x
Richard Sikorski, UM	LADCP		x
Deanna Spindler, UM	LADCP		x
Marilyn Roberts, PMEL	DIC		x
Esa Peltola, CIMAS	DIC		x
Dana Greeley, PMEL	pCO_2	x	x
Hua Chen, AOML	pCO_2		x
Dave Wisegarver, PMEL	CFC		x
Fred Menzia, PMEL	CFC		x
Calvin Mordy, PMEL	nutrients		x

		Leg 1	Leg 2
Charles Fischer, AOML	nutrients		x
Mary Roche, UM	alkalinity	x	
Cindy Moore, UM	alkalinity		x
Xiaorong Zhu, UM	alkalinity		x
Jason Joliff, UM	pH		x
Xuewn Liu, UM	pH		x
Rachel Parsons, BBSR	DOC		x
Amy Richie, BBSR	DOC		x
Tania Westby, UW	C-13		x
Jennifer Hanafin, UM	Maeri	x	
Erica Key, UM	Maeri	x	

8. Acknowledgments

The assistance of the officers, crew, and survey technician Jonathan Shannahoff of the NOAA ship *Ronald H. Brown* is gratefully acknowledged. Gregg Thomas provided very high quality sample salinities and analysis documentation. This cruise was sponsored by NOAA's Office of Global Programs.

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Soreide, N.N., M.L. Schall, W.H. Zhu, D.W. Denbo, and D.C. McClurg (1995): EPIC: An oceanographic data management, display and analysis system. Proceedings, 11th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, January 15–20, 1995, Dallas, TX, 316–321.

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FIGURES AND TABLES

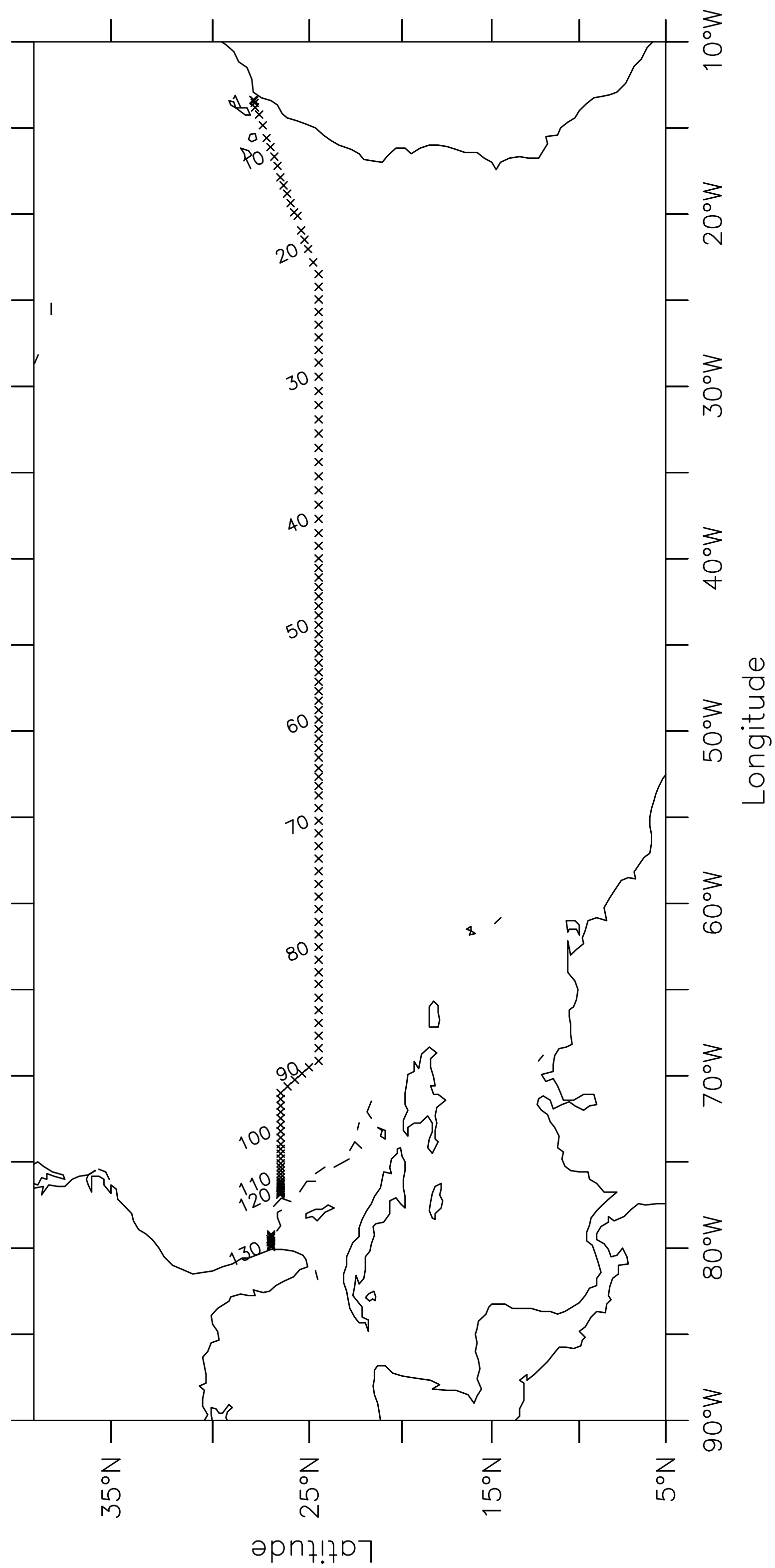

Figure 1: CTD station locations made on the R/V *Ronald H. Brown* from January 24 to February 23, 1998.

Table 1: CTD cast summary.

Station	Latitude	Longitude	Date	Time	Depth (m)	Cast (db)
1	27°55.0′N	13°22.2′W	24 JAN 98	0040	132	125
2	27°54.0′N	13°24.1′W	24 JAN 98	0211	509	516
3	27°52.9′N	13°25.0′W	24 JAN 98	0425	678	655
4	27°51.0′N	13°33.0′W	24 JAN 98	0638	1086	1082
5	27°49.8′N	13°48.7′W	24 JAN 98	0926	1518	1508
6	27°37.3′N	14°13.4′W	24 JAN 98	1309		2037
7	27°26.0′N	14°51.0′W	24 JAN 98	1759	2589	2609
8	27°14.0′N	15°35.2′W	24 JAN 98	2329	3133	3175
9	27° 2.0′N	16° 6.9′W	25 JAN 98	0432	3488	3525
10	26°50.0′N	16°40.0′W	25 JAN 98	0936	3622	3661
11	26°40.0′N	17°11.9′W	25 JAN 98	1440	3660	3705
12	26°31.0′N	17°52.0′W	25 JAN 98	2003	3662	3704
13	26°20.9′N	18°20.0′W	26 JAN 98	0049	3559	3598
14	26°10.0′N	18°49.0′W	26 JAN 98	0558	3495	3533
15	25°59.0′N	19°21.9′W	26 JAN 98	1051	3731	3765
16	25°48.0′N	19°54.0′W	26 JAN 98	1623	4018	4066
17	25°37.0′N	20°26.0′W	26 JAN 98	2156	4303	4364
18	25°25.6′N	20°56.8′W	27 JAN 98	0330	4468	4529
19	25°15.0′N	21°29.0′W	27 JAN 98	0920	4580	4648
20	25° 3.6′N	22° 1.6′W	27 JAN 98	1533	4742	4812
21	24°47.0′N	22°48.0′W	27 JAN 98	2259	4889	4972
22	24°30.0′N	23°29.0′W	28 JAN 98	0549	5017	5091
23	24°29.9′N	24°13.0′W	28 JAN 98	1235	5144	5223
24	24°30.0′N	24°57.0′W	28 JAN 98	1903	5255	5332
25	24°30.0′N	25°41.0′W	29 JAN 98	0145	5330	5411
26	24°30.0′N	26°25.0′W	29 JAN 98	0858	5413	5499
27	24°30.0′N	27° 9.0′W	29 JAN 98	1558	5534	5629
28	24°30.0′N	27°53.0′W	29 JAN 98	2300	5411	5514
29	24°30.0′N	28°37.0′W	30 JAN 98	0559	5670	5760
30	24°30.0′N	29°26.0′W	30 JAN 98	1317	5524	5646
31	24°30.0′N	30°16.0′W	30 JAN 98	2034	5650	5718
32	24°30.0′N	31° 5.0′W	31 JAN 98	0400	6027	6109
33	24°30.0′N	31°55.0′W	31 JAN 98	1149	5998	6048
34	24°30.0′N	32°44.0′W	31 JAN 98	1921	6233	6277
35	24°29.9′N	33°34.0′W	01 FEB 98	0325	6237	6362
36	24°30.1′N	34°23.0′W	01 FEB 98	1116	5142	5234
37	24°30.0′N	35°13.0′W	01 FEB 98	1859	5150	5245
38	24°30.0′N	36° 2.0′W	02 FEB 98	0207	5639	5770
39	24°30.0′N	36°52.0′W	02 FEB 98	0933	5181	5406
40	24°30.0′N	37°41.0′W	02 FEB 98	1650	5499	5558
41	24°30.0′N	38°30.8′W	03 FEB 98	0001	4862	4864
42	24°30.0′N	39°14.9′W	03 FEB 98	0636	5191	5262
43	24°30.0′N	39°59.0′W	03 FEB 98	1323	5105	5173
44	24°30.0′N	40°32.0′W	03 FEB 98	1912	5087	4878
45	24°30.0′N	41° 5.0′W	04 FEB 98	0118	5167	5241
46	24°30.0′N	41°38.0′W	04 FEB 98	0707	4721	4780
47	24°30.0′N	42°11.0′W	04 FEB 98	1254	3829	4039
48	24°30.0′N	42°44.0′W	04 FEB 98	1833	3716	3516
49	24°30.0′N	43°17.0′W	04 FEB 98	2355	3716	3763
50	24°30.0′N	43°50.0′W	05 FEB 98	0528	3759	3800
51	24°30.0′N	44°23.0′W	05 FEB 98	1045	3977	4013
52	24°30.0′N	44°56.0′W	05 FEB 98	1604	3591	3636
53	24°30.0′N	45°29.0′W	05 FEB 98	2101	3109	3346
54	24°30.0′N	46° 2.0′W	06 FEB 98	0152	2724	2765
55	24°30.0′N	46°35.1′W	06 FEB 98	0640	3520	3213

Table 1: (Cont.)

Station	Latitude	Longitude	Date	Time	Depth (m)	Cast (db)
56	24°30.0′N	47° 8.0′W	06 FEB 98	1137	3619	3628
57	24°30.0′N	47°41.0′W	06 FEB 98	1653	3954	4118
58	24°30.0′N	48°14.0′W	06 FEB 98	2234	3988	3976
59	24°30.0′N	48°46.9′W	07 FEB 98	0529	4343	4313
60	24°30.0′N	49°20.0′W	07 FEB 98	1230	5273	5353
61	24°30.0′N	49°53.0′W	07 FEB 98	1953	4532	4634
62	24°30.0′N	50°26.0′W	08 FEB 98	0257	4762	4823
63	24°30.0′N	50°59.0′W	08 FEB 98	1026	5296	5437
64	24°30.0′N	51°32.0′W	08 FEB 98	1721	5284	5366
65	24°30.0′N	52° 9.0′W	09 FEB 98	0012	5094	5310
66	24°30.0′N	52°38.8′W	09 FEB 98	0651	5281	5369
67	24°30.0′N	53°11.0′W	09 FEB 98	1324	5527	5605
68	24°30.0′N	53°44.0′W	09 FEB 98	1957	6016	6077
69	24°30.0′N	54°28.0′W	10 FEB 98	0330	5657	5245
70	24°29.9′N	55°12.0′W	10 FEB 98	1127	5917	6010
71	24°30.0′N	55°56.0′W	10 FEB 98	1937	6463	6500
72	24°30.0′N	56°40.0′W	11 FEB 98	0308	6012	6129
73	24°30.0′N	57°24.0′W	11 FEB 98	1038	6313	6394
74	24°30.0′N	58° 8.0′W	11 FEB 98	1803	5835	5933
75	24°30.0′N	58°52.0′W	12 FEB 98	0125	5920	6017
76	24°30.0′N	59°36.0′W	12 FEB 98	0857	5813	5912
77	24°30.0′N	60°20.0′W	12 FEB 98	1622	5845	5961
78	24°30.0′N	61° 4.0′W	12 FEB 98	2328	5866	5971
79	24°30.0′N	61°48.0′W	13 FEB 98	0642		5891
80	24°30.0′N	62°32.0′W	13 FEB 98	1345	5866	5970
81	24°29.9′N	63°15.9′W	13 FEB 98	2051	5843	5913
82	24°30.0′N	64° 0.0′W	14 FEB 98	0403	5834	5862
83	24°30.0′N	64°40.0′W	14 FEB 98	1117	5688	5839
84	24°30.1′N	65°28.1′W	14 FEB 98	1817	5548	5651
85	24°30.0′N	66°12.0′W	15 FEB 98	0128	5332	5429
86	24°30.0′N	66°56.0′W	15 FEB 98	0856	5730	5817
87	24°30.0′N	67°40.0′W	15 FEB 98	1603	5741	5804
88	24°30.0′N	68°24.0′W	15 FEB 98	2303	5712	5816
89	24°30.0′N	69° 8.0′W	16 FEB 98	0609	5651	5736
90	25° 1.0′N	69°30.1′W	16 FEB 98	1316	5620	5709
91	25°23.0′N	69°52.0′W	16 FEB 98	1932	5547	5620
92	25°45.5′N	70°14.1′W	17 FEB 98	0142	5515	5606
93	26° 8.4′N	70°36.9′W	17 FEB 98	0806	5506	5596
94	26°30.0′N	71° 0.0′W	17 FEB 98	1423	5491	5580
95	26°30.0′N	71°21.0′W	17 FEB 98	1945	5488	5580
96	26°30.0′N	71°44.0′W	18 FEB 98	0111	5389	5466
97	26°30.0′N	72° 6.0′W	18 FEB 98	0635	5281	5354
98	26°30.0′N	72°28.0′W	18 FEB 98	1150	5159	5263
99	26°30.0′N	72°51.0′W	18 FEB 98	1701	5136	5216
100	26°30.0′N	73°13.0′W	18 FEB 98	2225	5065	5147
101	26°30.0′N	73°35.0′W	19 FEB 98	0340	4932	5007
102	26°29.5′N	73°58.0′W	19 FEB 98	0848	4665	4714
103	26°30.0′N	74°15.0′W	19 FEB 98	1326	4553	4606
104	26°30.0′N	74°31.0′W	19 FEB 98	1742	4559	4563
105	26°30.0′N	74°48.0′W	19 FEB 98	2203	4538	4603
106	26°30.0′N	75° 5.0′W	20 FEB 98	0233	4629	4677
107	26°30.0′N	75°18.0′W	20 FEB 98	0732	4638	4706
108	26°30.0′N	75°30.0′W	20 FEB 98	1149	4688	4751
109	26°30.0′N	75°42.0′W	20 FEB 98	1620	4694	4764

Table 1: (Cont.)

Station	Latitude	Longitude	Date	Time	Depth (m)	Cast (db)
110	26°30.0′N	75°54.0′W	20 FEB 98	2034	4747	4818
111	26°30.0′N	76° 5.0′W	21 FEB 98	0111	4802	4875
112	26°30.0′N	76°12.0′W	21 FEB 98	0521	4819	4889
113	26°30.0′N	76°18.0′W	21 FEB 98	0951	4834	4909
114	26°30.3′N	76°25.3′W	21 FEB 98	1430	4848	4911
115	26°30.0′N	76°31.0′W	21 FEB 98	1911	4848	4919
116	26°30.0′N	76°37.0′W	21 FEB 98	2311	4736	4806
117	26°30.0′N	76°41.0′W	22 FEB 98	0332	4491	4659
118	26°30.0′N	76°45.2′W	22 FEB 98	0803	3815	3912
119	26°30.0′N	76°47.0′W	22 FEB 98	1149	3241	2325
120	26°30.0′N	76°49.0′W	22 FEB 98	1435	1390	1386
121	26°31.2′N	76°54.0′W	22 FEB 98	1714	719	409
122	27° 0.0′N	79°12.0′W	23 FEB 98	0917	477	472
123	27° 0.1′N	79°17.0′W	23 FEB 98	1058	613	611
124	27° 0.1′N	79°22.9′W	23 FEB 98	1245	687	670
125	27° 2.3′N	79°28.9′W	23 FEB 98	1517	766	740
126	27° 0.8′N	79°36.3′W	23 FEB 98	1720	667	667
127	27° 1.2′N	79°40.5′W	23 FEB 98	1906	547	532
128	27° 0.1′N	79°47.3′W	23 FEB 98	2041	384	375
129	27° 0.4′N	79°51.4′W	23 FEB 98	2153	279	270
130	26°59.9′N	79°56.2′W	23 FEB 98	2303	140	130

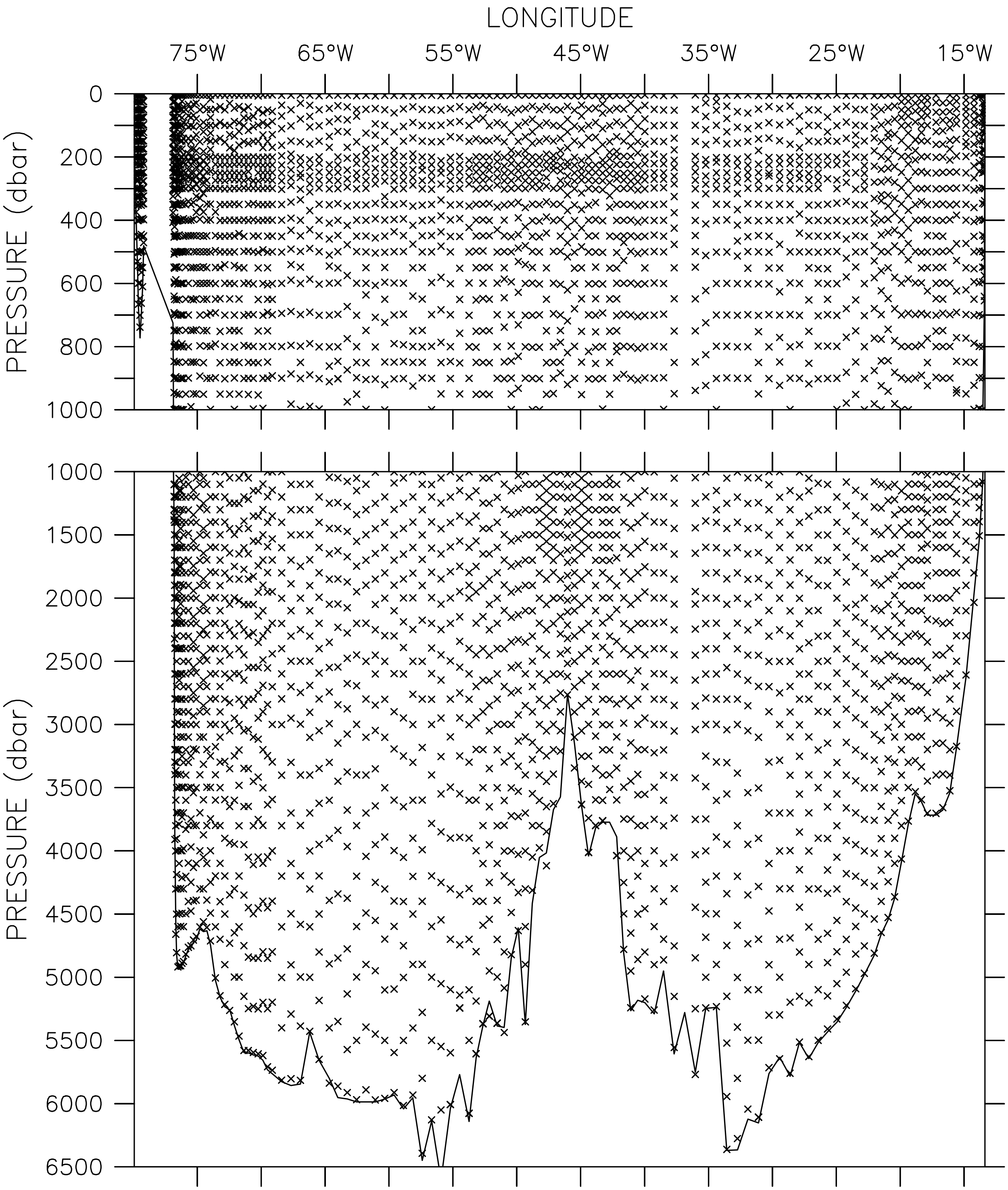

Figure 2: Pressures of bottle closures at each station.

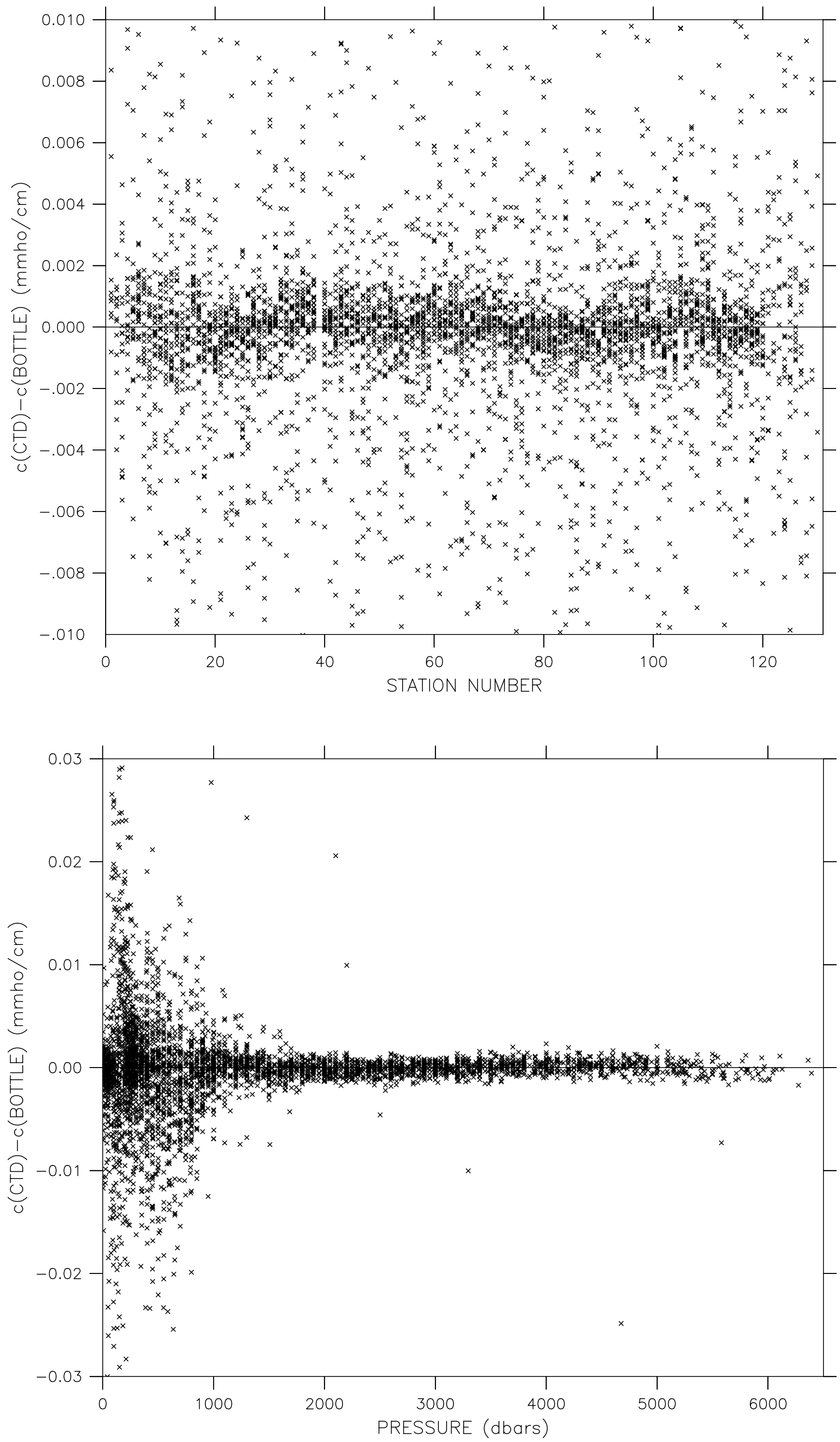

Figure 3: Calibrated CTD-bottle conductivity differences plotted against station number (upper panel). Calibrated CTD-bottle conductivity differences plotted against pressure (lower panel).

Table 2a: Shallow water column station groupings for CTD oxygen algorithm parameters.

Station	Sensor	StdDev	#Obs	2.8*sd	1:Bias	2:Slope	3:Pcor	4:Tcor	5:Wt	6:Lag
1–9	353	0.204	174	0.571	–0.047	0.004728	0.0001642*	–0.02965	0.9699*	–0.2047*
10–24	353	2.686	373	7.521	–0.038	0.004621	0.0001642*	–0.02953	0.9699*	–0.2047*
25–32	353	3.232	203	9.050	–0.045	0.004640	0.0001642*	–0.02960	0.9699*	–0.2047*
33–44	353	3.110	268	8.708	–0.043	0.004635	0.0001642*	–0.02791	0.9699*	–0.2047*
33–35	381	2.076	46	5.813	–0.021	0.004515	0.0001561*	–0.03058	0.7771*	6.927*
36–38	381	2.426	76	6.793	–0.006	0.004751	0.0001451*	–0.03077	0.7908*	6.111*
40–43	381	2.262	96	6.334	–0.013	0.004791	0.0001536*	–0.03068	0.7629*	2.239*
44–46	381	1.704	74	4.771	–0.030	0.004905	0.0001588*	–0.03109	0.7355*	2.040*
47–50	381	3.089	105	8.649	–0.039	0.005125	0.0001538*	–0.03278	0.7243*	5.715*
51–56	381	1.494	177	4.183	–0.018	0.004911	0.0001559*	–0.03079	0.7322*	4.255*
57–59	381	2.124	81	5.947	–0.014	0.004895	0.0001556*	–0.03024	0.7769*	3.391*
60–66	381	1.645	174	4.606	–0.014	0.004978	0.0001520*	–0.03077	0.7619*	5.183*
67–69	381	2.013	71	5.636	0.003	0.004889	0.0001501*	–0.03031	0.7214*	5.801*
70–76	381	1.885	176	5.278	–0.006	0.004983	0.0001498*	–0.03057	0.7582*	3.632*
77–81	381	2.410	125	6.748	–0.018	0.005023	0.0001539*	–0.03074	0.6860*	6.501*
82–90	381	2.222	222	6.222	–0.011	0.005050	0.0001509*	–0.03086	0.7111*	4.469*
91	381	1.834	23	5.135	–0.091	0.005123	0.0001774*	–0.03194	0.7987*	4.997*
92–95	381	2.118	100	5.930	–0.101	0.005101	0.0001780*	–0.03265	0.8516*	8.153*
96–97	381	2.718	52	7.610	–0.103	0.005221	0.0001758*	–0.03319	0.8620*	2.643*
98–99	381	2.177	52	6.096	–0.070	0.005188	0.0001626*	–0.03241	0.8482*	10.850*
100–104	381	1.653	127	4.628	–0.035	0.005013	0.0001575*	–0.03155	0.8902*	9.426*
105–109	381	1.847	127	5.172	0.001	0.004887	0.0001472*	–0.03111	0.9373*	5.558*
110–119	381	2.159	237	6.045	–0.035	0.005059	0.0001587*	–0.03222	0.8042*	6.654*
120–130	381	3.152	195	8.826	0.031	0.004859	0.0001209*	–0.03049	0.9413*	4.374*

*Fixed parameter from full water column fit of all bottles (sensor 353) or each grouping (sensor 381).

Table 2b: Deep water column station groupings for CTD oxygen algorithm parameters.

Station	Sensor	StdDev	#Obs	2.8*sd	1:Bias	2:Slope	3:Pcor	4:Tcor	5:Wt	6:Lag
1–9	353	0.345	17	0.966	–0.033	0.004650	0.0001642*	–0.03072	0.9699*	–0.2047*
10–24	353	1.041	158	2.915	–0.102	0.005428	0.0001642*	–0.04609	0.9699*	–0.2047*
25–32	353	1.049	99	2.937	–0.098	0.005386	0.0001642*	–0.05041	0.9699*	–0.2047*
33–44	353	1.564	142	4.379	–0.088	0.005268	0.0001642*	–0.04460	0.9699*	–0.2047*
33–35	381	1.739	27	4.869	–0.075	0.005122	0.0001561*	–0.04220	0.7771*	6.927*
36–38	381	1.809	41	5.065	–0.043	0.005155	0.0001451*	–0.03588	0.7908*	6.111*
40–43	381	1.151	50	3.223	–0.073	0.005469	0.0001536*	–0.04226	0.7629*	2.239*
44–46	381	0.851	35	2.383	–0.094	0.005693	0.0001588*	–0.04635	0.7355*	2.040*
47–50	381	1.745	32	4.886	–0.221	0.007512	0.0001538*	–0.08644	0.7243*	5.715*
51–56	381	0.627	47	1.756	–0.086	0.005724	0.0001559*	–0.04680	0.7322*	4.255*
57–59	381	1.273	33	3.564	–0.049	0.005230	0.0001556*	–0.03296	0.7769*	3.391*
60–66	381	0.851	81	2.383	–0.041	0.005237	0.0001520*	–0.03243	0.7619*	5.183*
67–69	381	0.796	33	2.229	–0.034	0.005228	0.0001501*	–0.03139	0.7214*	5.801*
70–76	381	1.267	82	3.548	–0.035	0.005273	0.0001498*	–0.03199	0.7582*	3.632*
77–81	381	1.160	60	3.248	–0.039	0.005165	0.0001539*	–0.02756	0.6860*	6.501*
82–90	381	1.114	105	3.119	–0.034	0.005239	0.0001509*	–0.02980	0.7111*	4.469*
91	381	1.125	13	3.150	–0.074	0.004804	0.0001774*	–0.01653	0.7987*	4.997*
92–95	381	1.646	48	4.609	–0.090	0.004880	0.0001780*	–0.02040	0.8516*	8.153*
96–97	381	2.251	23	6.303	–0.099	0.005156	0.0001758*	–0.02914	0.8620*	2.643*
98–99	381	1.849	25	5.177	–0.067	0.005115	0.0001626*	–0.02800	0.8482*	10.850*
100–104	381	1.098	59	3.074	–0.056	0.005207	0.0001575*	–0.03242	0.8902*	9.426*
105–109	381	0.668	56	1.870	–0.025	0.005138	0.0001472*	–0.03311	0.9373*	5.558*
110–119	381	1.105	89	3.094	–0.056	0.005247	0.0001587*	–0.03249	0.8042*	6.654*
120–130	381	3.152	195	8.826	0.031	0.004859	0.0001209*	-0.03049	0.9413*	4.374*

*Fixed parameter from full water column fit of all bottles (sensor 353) or each grouping (sensor 381).

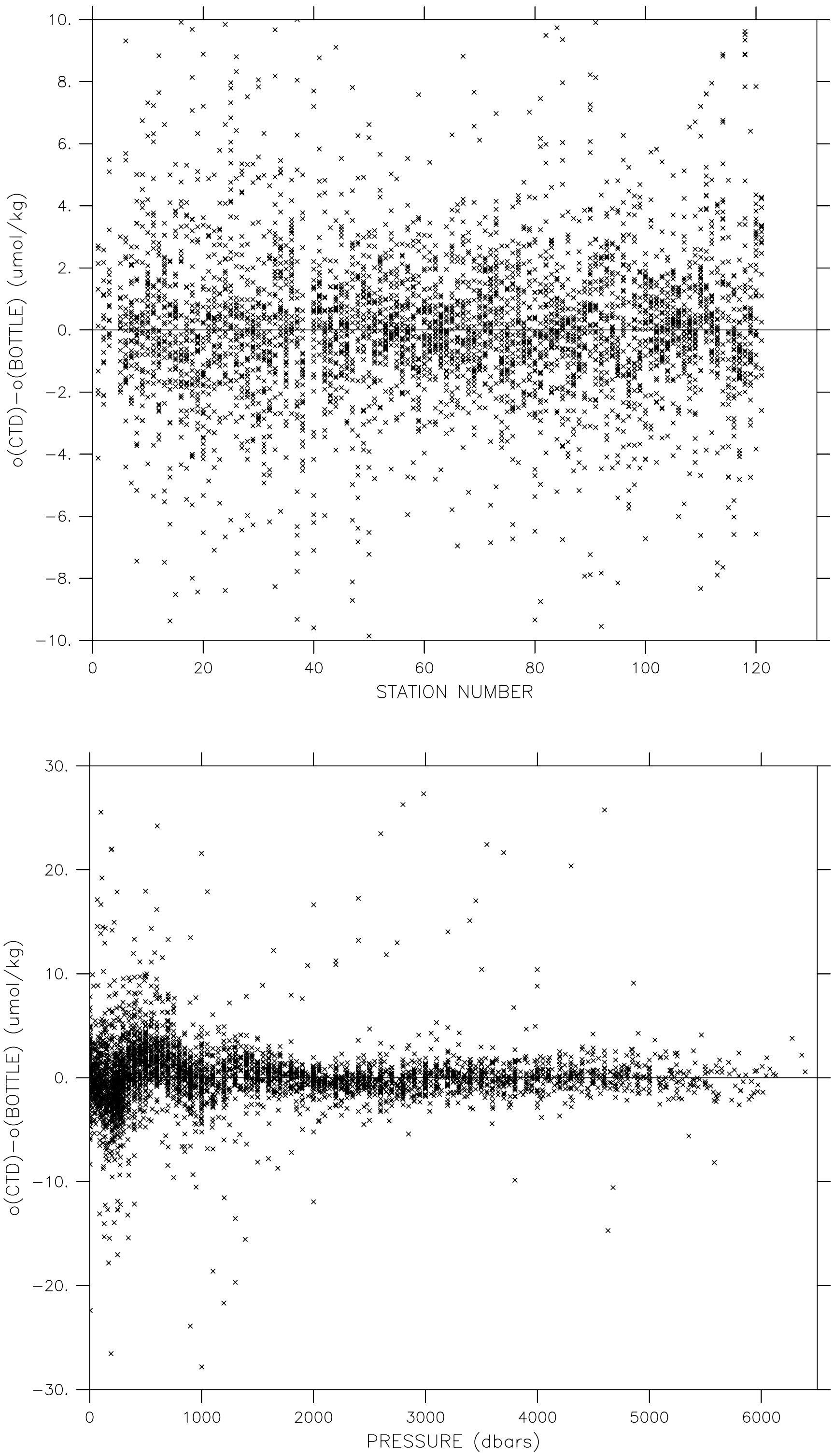

Figure 4: Calibrated CTD-bottle oxygen differences plotted against station number (upper panel). Calibrated CTD-bottle oxygen differences plotted against pressure (lower panel).

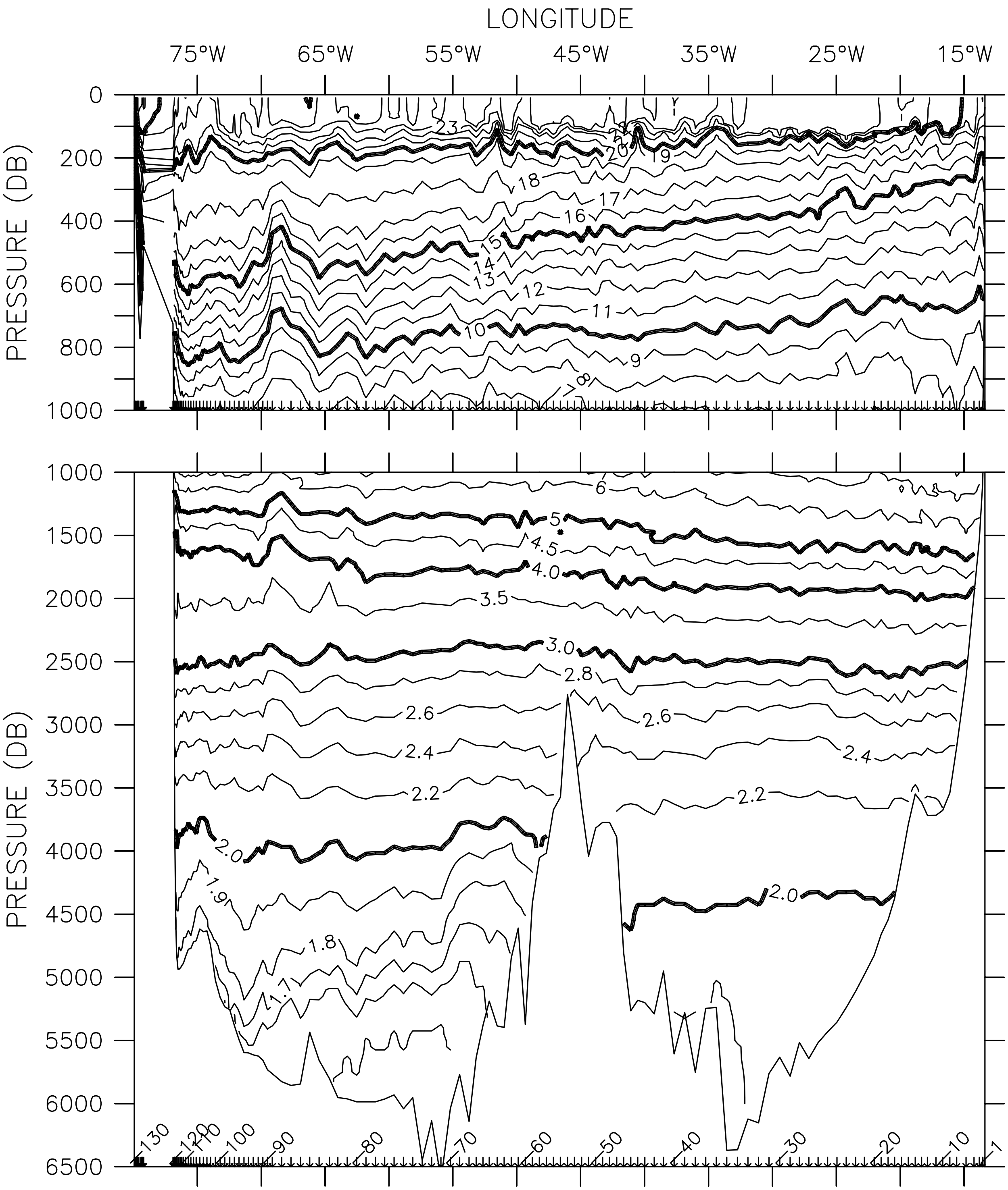

Figure 5: Potential temperature (°C) sections. Contour intervals are 0.1 from 1–2°C, 0.2 from 2–3°C, 0.5 from 3–5°C, and 1 from 5–35°C.

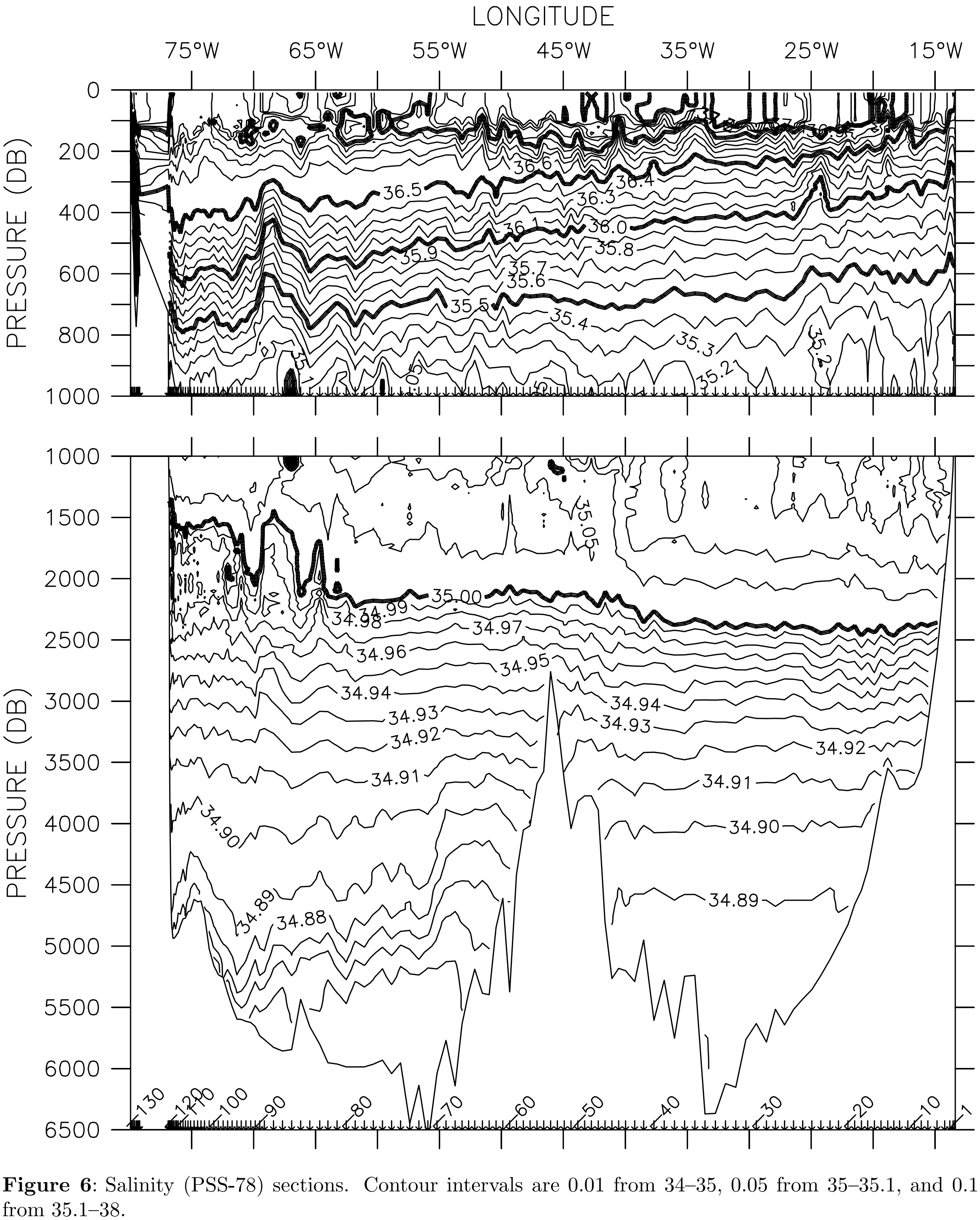

Figure 6: Salinity (PSS-78) sections. Contour intervals are 0.01 from 34–35, 0.05 from 35–35.1, and 0.1 from 35.1–38.

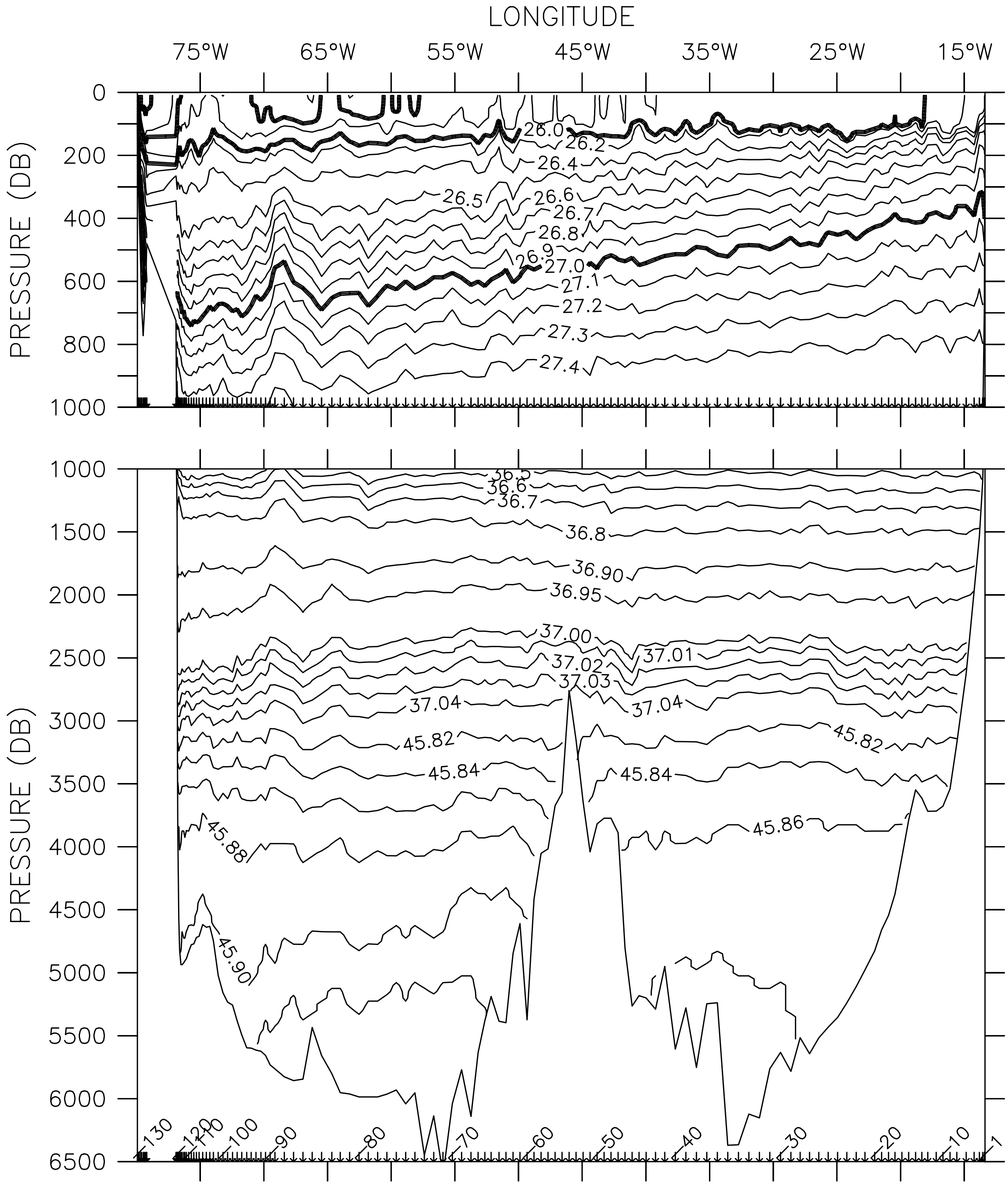

Figure 7: Potential density (kg/m^3) sections. Sigma-theta contour intervals are 0.5 from 22–26, 0.2 from 26–26.4, and 0.1 from 26.5–27.4. Sigma-2 contour intervals are 0.1 from 36.5–36.9, 0.05 from 36.9–37, and 0.01 from 37–37.05. Sigma-4 contour intervals are 0.02 from 45.82–48.

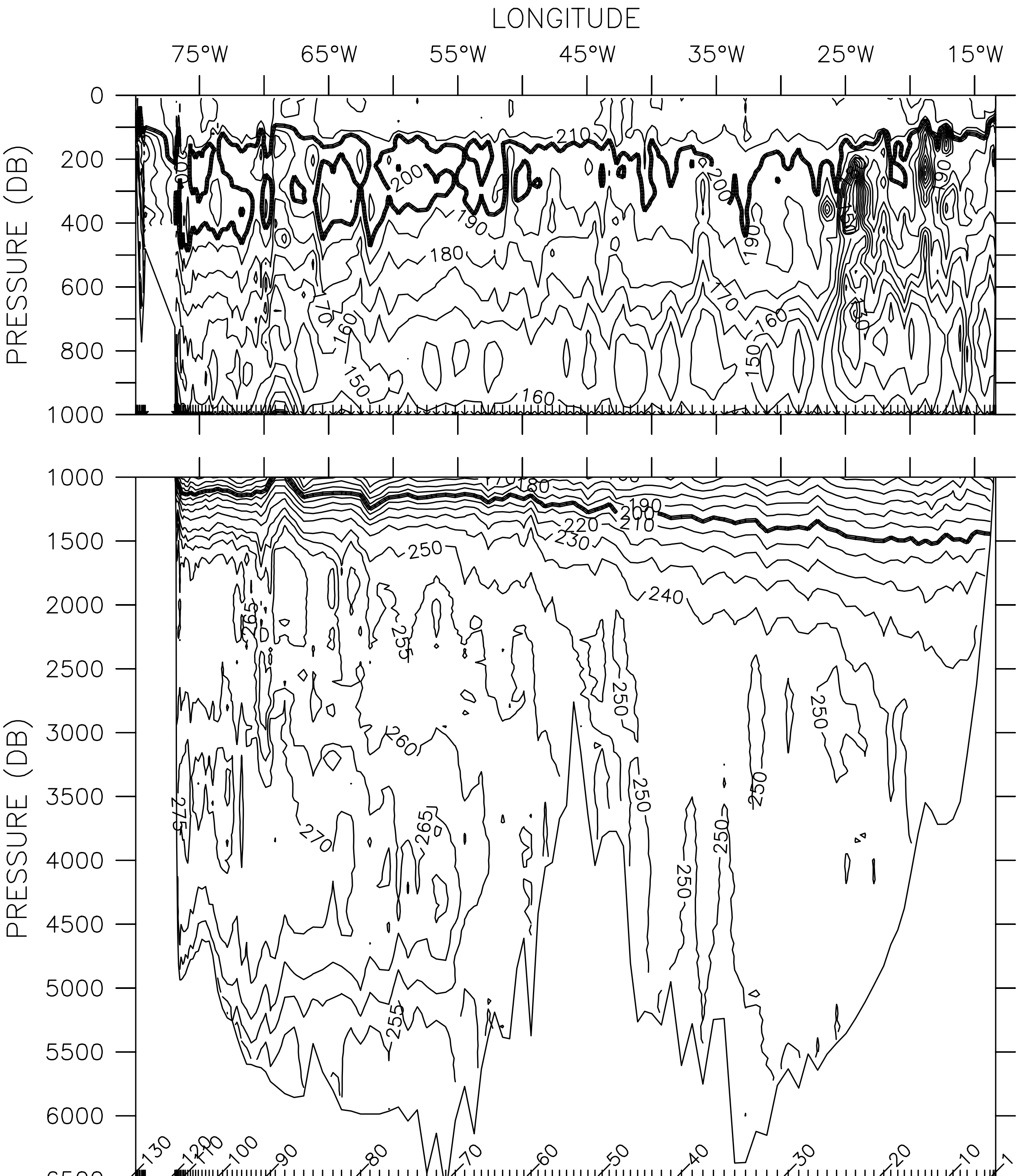

Figure 8: CTD oxygen (μmol/kg) sections. Contour intervals are 10 from 100–300 μmol/kg in the upper panel; 10 from 100–250 μmol/kg, and 5 from 250–300 μmol/kg in the lower panel.

Table 3: Weather condition code used to describe each set of CTD measurements.

Code	Weather Condition
0	Clear (no cloud)
1	Partly cloudy
2	Continuous layer(s) of cloud(s)
3	Sandstorm, dust storm, or blowing snow
4	Fog, thick dust or haze
5	Drizzle
6	Rain
7	Snow, or rain and snow mixed
8	Shower(s)
9	Thunderstorms

Table 4: Sea state code used to describe each set of CTD measurements.

Code	Height (meters)	Description
0	0	Calm-glassy
1	0–0.1	Calm-rippled
2	0.1–0.5	Smooth-wavelet
3	0.5–1.25	Slight
4	1.25–2.5	Moderate
5	2.5–4	Rough
6	4–6	Very rough
7	6–9	High
8	9–14	Very high
9	>14	Phenomenal

Table 5: Visibility code used to describe each set of CTD measurements.

Code	Visibility
0	<50 meters
1	50–200 meters
2	200–500 meters
3	500–1,000 meters
4	1–2 km
5	2–4 km
6	4–10 km
7	10–20 km
8	20–50 km
9	50 km or more

All CTD and Hydrographic Data can be obtained by contacting K.E. McTaggart at kem@pmel.noaa.gov.