NOAA Data Report ERL AOML-34

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

CHEMICAL AND HYDROGRAPHIC MEASUREMENTS DURING THE INDIAN OCEAN 18 REPEAT CRUISE (IR8N) IN SEPTEMBER AND OCTOBER, 1995

E. Peltola
R. Wanninkhof
R. Molinari
B. Huss
R. Feely
J. Bullister
J-Z. Zhang
F. Chavez
A. Dickson
A. Ffield
D. Hansell
F. Millero
P. Quay
R. Castle
G. Thomas
R. Roddy
T. Lantry
M. Roberts
H. Chen
D. Greeley
K. Lee
M. Roche
J.A. Goen
F. Millero III
K. Buck
M. Kelly
F. Menzia
A. Huston
T. Waterhouse
S. Becker
C. Mordy

Atlantic Oceanographic and Meteorological Laboratory
Miami, Florida
December 1998

---

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

NOAA Data Report ERL AOML-34

CHEMICAL AND HYDROGRAPHIC MEASUREMENTS DURING THE INDIAN OCEAN 18 REPEAT CRUISE (IR8N) IN SEPTEMBER AND OCTOBER, 1995

E. Peltola
R. Wanninkhof
R. Molinari
B. Huss
R. Feely
J. Bullister
J-Z. Zhang
F. Chavez
A. Dickson
A. Ffield
D. Hansell
F. Millero
P. Quay
R. Castle
G. Thomas
R. Roddy
T. Lantry
M. Roberts
H. Chen
D. Greeley
K. Lee
M. Roche
J.A. Goen
F. Millero III
K. Buck
M. Kelly
F. Menzia
A. Huston
T. Waterhouse
S. Becker
C. Mordy

Atlantic Oceanographic and Meteorological Laboratory
Miami, Florida
December 1998

UNITED STATES
DEPARTMENT OF COMMERCE

William M. Daley
Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

D. JAMES BAKER
Under Secretary for Oceans
and Atmosphere/Administrator

Environmental Research
Laboratories

James L. Rasmussen
Director

NOTICE

REMOTE ACCESS TO DATA LISTED IN THIS REPORT

The data presented in this report is available on Internet FTP and the World Wide Web (WWW). For information regarding electronic access to the data sets contact:

Ms. Betty E. Huss
Data Manager, OACES
at: U.S. Dept. of Commerce
NOAA/AOML/OCD
4301 Rickenbacker Causeway
Miami, Florida 33149-1026

Telephone: (305) 361-4395
Internet address: huss@aoml.noaa.gov
WWW address: http://www.aoml.noaa.gov/ocd/oaces/ftp/io95l8.html
CTD data: http://whpo.ucsd.edu/whp_data.html
ADCP data: http://ilikai.soest.hawaii.edu/sadcp
LADCP data: http://www.nodc.noaa.gov
UWpCO2 data: ftp://ftp.aoml.noaa.gov/pub/ocd/carbon/uwpco295

PRINCIPAL INVESTIGATORS

Project	Name	Institution
Chlorofluorocarbons	John Bullister	PMEL/OCRD
Bio./Productivity	Francisco Chavez	MBARI
UW pH	Andrew Dickson	SIO
CTD/Hydrography	Amy Ffield	LDEO
CTD/Hydrography	Robert Molinari	AOML/PhOD
TOC/TON	Dennis Hansell	BBSR
TA/pH	Frank Millero	UM/RSMAS
^{13}C	Paul Quay	UW
fCO_2/DIC	Rik Wanninkhof	AOML/OCD
fCO_2/DIC	Richard Feely	PMEL/OCRD
Nutrients	Jia-Zhong Zhang	AOML/OCD/CIMAS
Nutrients	Calvin Mordy	PMEL/OCRD/JISAO

LIST OF PARTICIPANTS

Function	Name	Institution
Chief Scientist	Robert Molinari	AOML/PhOD
Co-chief Scientist	Rik Wanninkhof	AOML/OCD
Data Management	Robert Castle	AOML/OCD
CTD	Paula Gilbert	AOML/PhOD
CTD/ET	Douglas Anderson	AOML/PhOD
Salinity	Gregg Thomas	AOML/PhOD
Oxygen	Robert Roddy	AOML/PhOD
L/ADCP	Ryan Smith	AOML/PhOD/META
L/ADCP	David Fratantoni	UM/RSMAS
DIC	Thomas Landry	AOML/OCD
DIC	Marilyn Roberts	PMEL/OCRD
fCO_2	Hua Chen	AOML/OCD/CIMAS
fCO_2	Dana Greeley	PMEL/OCRD
UW pH	Andrew Dickson	SIO
TA/pH	Kitack Lee	UM/RSMAS
TA/pH	Mary Roche	UM/RSMAS
TA/pH	Jamie Ann Goen	UM/RSMAS
TA/pH	Frank Millero III	UM/RSMAS
Biology/Productivity	Kurt Buck	MBARI
Biology/Productivity	Michael Kelly	MBARI
Chlorofluorocarbons	Fred Menzia	PMEL/OCRD
C-13/Data	Adrienne Huston	UW
TOC	Tye Waterhouse	BBSR
TOC	Susan Becker	BBSR
Nutrients	Jia-Zhong Zhang	AOML/OCD/CIMAS
Nutrients	Calvin Mordy	PMEL/OCRD/JISAO

The Chief Survey Technician aboard the R/V BALDRIDGE for the cruise was Dennis Sweeney.

Institutional Abbreviation	Institution	Address
AOML	Atlantic Oceanographic and Meteorological Laboratory,	4301 Rickenbacker Cwy, Miami, FL 33149-1098
- OCD	Ocean Chemistry Division	
- PhOD	Physical Oceanography Division	
- META	Maria Elena Torano Associates	
BBSR	Bermuda Biological Station for Research	St. Georges, GE-01, Bermuda
LDEO	Lamont-Doherty Earth Observatory	Palisades, NY 10964-8000
MBARI	Monterey Bay Aquarium Research Institute	7700 Sandholdt Road, Moss Landing, CA 95039-0628
PMEL	Pacific Marine Environmental Laboratory	7600 Sand Point Way NE, Seattle, WA 98115-0070
- OCRD	Ocean Climate Research Division	
SIO	Scripps Institution of Oceanography	San Diego, La Jolla, CA 92093-0208
UM/RSMAS	University of Miami/ Rosenstiel School of Marine and Atmospheric Science	4600 Rickenbacker Cwy, Miami, FL 33149-1098
- CIMAS	Cooperative Institute for Marine and Atmospheric Studies	
UW	University of Washington	Box 357940, Seattle, WA 98195-7940
- JISAO	Joint Institute for Study of the Atmosphere and Ocean	

CONTENTS

FIGURES

TABLES

APPENDICES

CHEMICAL AND HYDROGRAPHIC MEASUREMENTS DURING THE INDIAN OCEAN I8 REPEAT CRUISE (IR8N) IN SEPTEMBER AND OCTOBER, 1995

E. Peltola, R. Wanninkhof, R. Molinari, B. Huss, R. Feely, J. Bullister, J-Z. Zhang, F. Chavez, A. Dickson, A. Ffield, D. Hansell, F. Millero, P. Quay, R. Castle, G. Thomas, R. Roddy, T. Landry, M. Roberts, H. Chen, D. Greeley, K. Lee, M. Roche, J.A. Goen, F. Millero III, K. Buck, M. Kelly, F. Menzia, A. Huston, T. Waterhouse, S. Becker, and C. Mordy

ABSTRACT

This document contains data and metadata from the I8 repeat cruise in the Indian Ocean cruise in 1995 from Fremantle, Australia to Male in the Maldives. From September 22 to October 25, 1995, the National Oceanic and Atmospheric Administration's (NOAA) sponsored an oceanographic research cruise conducted aboard the NOAA Ship MALCOLM BALDRIGE. This report presents the analytical and quality control procedures and data from the cruise that was conducted for the Ocean-Atmosphere Carbon Exchange Study (OACES). Samples were taken at 101 stations.

The data presented in this report includes: hydrography, nutrients, total dissolved inorganic carbon dioxide (DIC), fugacity of carbon dioxide (fCO_2), total alkalinity (TA), pH, total organic carbon and nitrogen data (TOC/TON), chlorofluorocarbons, ^{13}C, and biological parameters.

1. INTRODUCTION

Probably the most significant environmental issue of the next century will be the systematic changes in the earth's climate due to increase in the atmospheric burden of radiatively important trace gases, or " greenhouse gases". CO_2, as well as other "greenhouse gases" (e.g., water vapor, methane, ozone, chlorofluorocarbons, carbon monoxide and nitrous oxide), serve to reduce radiation of heat from the earth to the stratosphere and space. At present, CO_2 accounts for about 50 % of this effect. This phenomenon has a tight coupling to climate in that it exerts significant controls on the temperature of the troposphere and the Earth's surface. It is, in fact, this "greenhouse" control on temperature that makes the Earth habitable to man, and its variability during glacial and interglacial periods has altered that habitability.

In light of these questions, the NOAA/OGP Ocean-Atmosphere Carbon Dioxide Exchange Study (OACES) was started to determine how the ocean/atmosphere carbon system is functioning, i.e., determine how much carbon, of what origin, is going where. That is the first step required if we are to determine the extent of the CO_2 increases in our global system and their climate impacts. Although coupled ocean/atmosphere models appear the best means of predicting long-term climate impacts resulting from increases of "greenhouse gases" (such as CO_2) and have already given some provocative projections, they lack sufficient data and information about relevant processes to constrain them adequately for reliable prediction. Data from the field work will be used to test and correct the models so that they result in a proper understanding of the global system and it's various components. Models include: (1) atmosphere-ocean CO_2 transport models; and (2) process models of air-sea CO_2 exchange and invasion into the deep ocean.

The National Oceanic and Atmospheric Administration's (NOAA) OACES program sponsored an oceanographic research cruise conducted aboard the NOAA Ship MALCOLM BALDRIGE from September 22 to October 25, 1995. The primary objectives of the cruise were to: (1) extend the data base for carbon fugacity (fCO_2) in the surface ocean and overlying atmosphere, (2) perform measurements of total dissolved inorganic CO_2 (DIC), and discrete fCO_2 in the surface and deep ocean water masses to provide better estimates of CO_2 exchange and ventilation on seasonal to decadal time scales; and (3) provide a better understanding of physical and biological processes that affect seasonal variations in the distribution of carbon species in the ocean. The data presented in this report includes: hydrography, nutrients, total dissolved inorganic carbon dioxide (DIC), discrete fugacity of carbon dioxide (fCO_2), discrete partial pressure of carbon dioxide (pCO_2), total alkalinity (TA), pH, total organic carbon and nitrogen data (TOC/TON), chlorofluorocarbons, ^{13}C, and biological parameters.

Detailed information of the CTD operations can be found in LDEO-98-1 technical report (Ffield et al, 1998). A description of the analyses and procedures of the underway fCO_2 data has been described by Masters et al. (1997) and total alkalinity (TA) and pH data by Millero et al. (1997).

1.1. DESCRIPTION OF STUDY AREA

Samples were taken at 101 stations along a south-north transit. The cruise can be divided into three sections - the 95° E line (stations 3-17), the middle section steaming from the 95° E line to the 80° E line (stations 18-35), and the 80° E line (stations 36-101). The 95° E line was followed from 43° S to 31.65° S latitude with 1° spacing except for the last four stations near the Mid-Indian Ridge which were closer together. The 80° E line was followed from 34° S to 5.8° N with 1° spacing to 15° S and 0.5° spacing nortward except for the section from 1° S to 1° N, where 0.25° spacing was used. The cruise track and station locations are presented in Figure 1 and Table 1.

2. DATA COLLECTION AND ANALYTICAL METHODS

One hundred and one CTD (Conductivity-Temperature- Depth) hydrographic stations were occupied to collect discrete water samples and hydrographic data. A CTD/Rosette unit with a Seabird-911 CTD instrument equipped with 24, specially designed 10-L samples bottles was utilized for these casts. These bottles have the same outer dimensions as standard Niskin bottles, but are modified to reduce chlorofluorocarbon sample contamination. Water samples were collected for salinity, oxygen, nutrients, chlorofluorocarbons, ^{13}C, biological parameters, as well as carbon related parameters including total dissolved inorganic CO_2 (DIC), discrete fugacity of CO_2 (fCO_2), total alkalinity (TA), pH, and total organic carbon/nitrogen (TOC/TON) on all casts during the cruise using these modified “Niskin” style bottles. In the data tables the missing values are assigned a value of -9.0. The WOCE quality control flags have been listed in Appendix A. All the cruise data have been presented in Appendix B. Detailed information on individual data collection, or analyses procedures may be found in the respective method sections.

2.1. HYDROGRAPHIC METHODS

2.1.1. CTD AND HYDROGRAPHIC OPERATIONS

Description of Measurement Techniques and Calibrations

CTD and in situ O_2

Depth profiles were obtained with a Seabird 911 plus CTD, deck unit, and rosette pylon. The CTD included 2 temperature sensors, 2 conductivity sensors, 1 Beckman oxygen sensor, 1 Paroscientific pressure transducer, and 2 pumps to decrease the response time. Twenty-four 10 liter PVC bottles were mounted on the frame, along with the CTD, pinger, Lowered Acoustic Doppler Current Profiler (LADCP), and LADCP external battery pack. The bottles were specially designed to reduce chlorofluorocarbon contamination. These bottles have the same outer dimensions as standard 10 liter "Niskin" bottles, but use a modified end-cap design to minimize the contact of the water sample with the end-cap O-rings after closing. The O-rings used in these water sample bottles were vacuum-baked prior to the first station. Stainless steel springs covered with a nylon powder coat were substituted for the internal elastic tubing standardly used to close "Niskin" bottles. Seabird software was used to acquire, plot, and process the CTD data on PC's. Raw data were stored on VHS tapes, PC hard drives, and SyQuest drives. Typically each cast sampled to within 10 meters of the sea floor as indicated by the pinger signal. A small subset of stations on this cruise were sampled to 3000 db, rather than the full water column. The CTD/0_2 data were processed and calibrated following Seabird recommendations (CTD Data Acquisition Software and Technical Notes, Sea-Bird Electronics, Inc., 1808 - 136th Place NE, Bellevue, Washington 98005). Exceptional items are noted below. Details can be found in the LDEO-98-1 technical report (Ffield et al, 1998) .

The pressure sensor was calibrated by using the pre-cruise laboratory calibration with a linear offset drift of approximately 0.5 db/year. The linear offset was determined by analyzing CTD pressure measurements at the sea surface.

Pre- and post-cruise laboratory calibrations were obtained for the temperature sensors. The temperature sensors were calibrated using both pre- and post-cruise laboratory calibrations with a linear offset drift over time determined from these calibrations. The reported temperature is an average of the two independently calibrated temperature sensors used on each cast.

Pre- and post-cruise laboratory calibrations were also obtained for the conductivity sensors. The conductivity sensors were calibrated using both pre- and post-cruise laboratory calibrations, with slope and offset drifts determined from the differences between the rosette bottle salinity measurements and the uptrace conductivity sensor measurements converted to salinity. To determine slope and offset drifts, all good bottles below 300 db and within 5 days of each station were used. The nominal Seabird temperature and pressure corrections for the conductivity sensors were used. The calculated drifts were smoothed by a 5 station running mean (Figures 2 and 3). The reported salinity is an average of the salinities calculated from the two calibrated conductivity-temperature sensor pairs used on each cast. A small temperature dependency in the surface values and a small pressure dependency in the deep values remain in the final data. However, the above procedure produced the best overall fit to the rosette bottle salinity measurements. For a few stations there was a problem with one of the conductivity sensors. In these cases, the reported salinity values are only determined from the optimally performing conductivity sensor. The most significant case was the failure of the "C_l" conductivity sensor between CTD casts 268 and 291.

The oxygen sensor was calibrated by using the pre-cruise laboratory calibration, with slope and offset drifts determined from the rosette oxygen measurements and the uptrace oxygen sensor measurements. A better overall fit was obtained when using the uptrace oxygen sensor measurements, rather than the downtrace measurements as is often the procedure for the oxygen calibration. To determine slope and offset drifts, all good bottles within 5 days of each station were used. Rather than using the Seabird nominal temperature and pressure corrections for the oxygen sensor, the values were adjusted slightly for each sensor. The calculated slopes and drifts were smoothed by a 5 station running mean (Figure 4). Apparent oxygen utilization (AOU) is defined as O_2 measured-O_2 sat., where O_2 sat. is the saturation value at potential temperature and salinity of the sample determined according to Weiss (1970)

Pressure plots and histograms of the differences between the calibrated CTD/02 sensors and the rosette bottle measurements are shown for all stations for salinity (Figures 5 and 6) and for oxygen (Figures 7 and 8). The average differences meet WOCE criteria. The CTD data are available through internet address http://whpo.ucsd.edu/whp_data.html

Measurement of Currents

A hull-mounted RD Instruments 150 kHz narrowband acoustic Doppler current profiler (ADCP) operated continuously during the cruise. Velocity data, averaged in earth coordinates using gyrocompass heading, were logged in three-minute (approximately 180 pings) ensembles using RDI Data Acquisition Software (DAS) version 2.48. Vertical bin size was 8 meters. The center of the first bin was located at 16 meters. Range varied from

200 to 400 meters, depending primarily on sea state. A user exit program (UE4, provided by Eric Firing, U. Hawaii) was used to interface navigation and heading equipment. Position was logged at the beginning and end of each ensemble from a Trimble Centurion P-code GPS receiver (estimated position accuracy of 5 - 10 meters). Mean gyrocompass corrections for each ensemble were recorded from an Ashtech 3DF GPS attitude determination system; 3DF array orientation was calibrated using P-code GPS and ADCP bottom track comparison. These data are used in post-processing to calculate mean ship velocity to reference ensemble means, and to compensate for dynamic gyrocompass errors. Estimated errors for an ensemble are 1-2 cm/s for relative velocity and 3-4 cm/s for ship speed errors due to position inaccuracy; errors induced by heading inaccuracies are reduced to less than 1 cm/s using GPS heading data. This total error of 4-6 cm/s over a three minute ensemble is reduced further by averaging during postprocessing; fifteen minute averages commonly used represent an average over five kilometers at cruising speed, and should be accurate to 1-3 cm/s. The ADCP data will be available through internet address http://ilikai.soest.hawaii.edu/sadcp

On-station velocity profiles were obtained using a RDI 150 kHz Narrowband ADCP (Lowered or LADCP) mounted looking downward from the CTD frame. This technique measures and records velocity shear profiles extending 150 to 350 meters below the instrument approximately once per second. In postprocessing, the individual shear profiles are averaged by depth to produce a full-depth shear profile, which is integrated to estimate the depth dependent (baroclinic) component of the velocity field. The depth-independent (barotropic) component of velocity can be recovered if positions at the start and end of the cast are known; positions were logged on this cruise using a Trimble Centurion P-code GPS receiver, accurate to 5 - 10 meters. Readers are advised to refer to Fischer and Visbeck (1993) for a full explanation of methods and standard processing procedures. The LADCP data will be available through internet address http://www.nodc.noaa.gov

Salinity Technique

A Guildline 8400B autosal was used for the salinity analysis with batch P125 standard water. The autosal van was maintained at 22 °C, and the autosal was set at 24 °C.

Oxygen Technique

An automatic titration system was used for the oxygen analysis with the Carpenter modification of the Winkler method using a photometric determined endpoint described by Friederich and Codispoti (1991). Reagents for the Carpenter method titration were mixed by the AOML/OCD Group of George Berberian as specified in Friederich's MBARI Technical Report #91-6 (Friederich et al, 1991). Apparent oxygen utilization

(AOU) is defined as O_2 measured- O_2 sat., where O_2 sat. is the saturation value at potential temperature and salinity of the sample determined according to Weiss (1970)

2.1.2. NUTRIENT ANALYSIS METHODS

Sampling and analytical methods

Nutrient samples were collected from 10-L "Niskin" bottles in acid washed 25-mL linear polyethylene bottles after three complete seawater rinses and analyzed within 1 hour of sample collection. Measurements were made in a temperature-controlled van ($20 \pm 2^{o}C$). Concentrations of dissolved nitrite (NO_2^-), dissolved nitrate (NO_3^-), phosphate (PO_4^{3-}) and silicic acid (H_4SiO_4) were determined using an Alpkem Flow Solution Auto-Analyzer aboard the ship. The following analytical methods were employed:

Nitrate and Nitrite:

Nitrite was determined by diazotizing with sulfanilamide and coupling with N-1 naphthyl ethylenediamine dihydrochloride to form an azo dye. The color produced is measured at 540 nm (Armstrong et al., 1967; Atlas et al.,1971). Samples for nitrate analysis were passed through an Open Tubular Cadmium Reactor (OTCR, Alpkem) coil, which reduced nitrate to nitrite and the resulting nitrite concentration was then determined as described above. Nitrate concentration was determined from the difference of nitrate + nitrite and nitrite.

Phosphate:

Phosphate in the samples was determined by reacting with molybdenum (VI) and antimony (III) in an acidic medium to form an antimonyphosphomolybdate complex at temperature of 42 °C. This complex was subsequently reduced with ascorbic acid to form a blue complex and the absorbance was measured at 880 nm (Armstrong et al.,1967, Grasshoff et al. ,1983).

Silicic Acid:

Silicic acid in the sample was analyzed by reacting with molybdate in a acidic solution to form β-molybdosilicic acid . The β-molybdosilicic acid was then reduced by stannous chloride to form molybdenum blue (Armstrong et al., 1967; Atlas et al.,1971). The absorbance of the molybdenum blue was measured at 820 nm.

Calibration and standards:

Stock standard solutions were prepared by dissolving high purity standard materials (KNO_3 , $NaNO_2$, KH_2PO_4 and Na_2SiF_6) in deionized water. Working standards were freshly made at each station by diluting the stock solutions in low nutrient seawater. The low nutrient seawater used for the preparation of working standards, determination of blank and wash between samples was filtered seawater obtained from the surface of the central Indian Ocean. Standardizations were performed prior to each sample run with working standard solutions. Five replicate samples were collected from the "Niskin" bottle sampled at deepest depth at each cast. The relative standard deviation from the results of these five replicate samples were used to estimate the overall precision obtained by the sampling and analytical procedures. The precisions of these samples were 0.2 μmol/kg for nitrate, 0.01 μmol/kg for nitrite, 0.01 μmol/kg for phosphate and 0.1 μmol/kg for silicic acid.

2.2. CARBON PARAMETERS

2.2.1. TOTAL DISSOLVED INORGANIC CARBON (DIC)

Sampling

Samples were drawn from 10 l "Niskin" bottles into 0.5 l Pyrex bottles using Tygon tubing. Bottles were rinsed once and filled from the bottom, overflowing half a volume while taking care not to entrain any bubbles. The tube was pinched off and withdrawn, creating a 5 ml headspace volume. 0.2 ml of saturated mercuric chloride ($HgCl_2$) solution was added as a preservative. The sample bottles were sealed with glass stoppers lightly covered with Apiezon-L grease. The samples were stored at room temperature in the dark for a maximum of two days.

Analysis

The DIC analyses were performed by extracting the inorganic carbon in a seawater sample by acidification and subsequent displacement of the gaseous CO_2 into a coulometer cell. Two coulometers (AOML-1 and PMEL-1) were used on the cruise. Both were equipped with the SOMMA (Single Operator Multiparameter Metabolic Analyzer) inlet system developed by Ken Johnson of Brookhaven National Laboratory (BNL).

For analysis on the SOMMA system, a 0.5 l sample bottle was inserted in a water bath at 20°C. Water from the bottle was displaced by pressurization into a thermostatted pipette using compressed air containing 700 parts per million by volume (ppm) CO_2 in air. The sample was injected into an extraction chamber which contained 1 ml 10% H_3PO_4 solution previously stripped of CO_2. The evolved CO_2 gas from the sample was run through a condenser and a magnesium perchlorate drying column to dry the gas stream, and through an ORBO-53™ tube to remove volatile acids, using a carrier stream of CO_2-free ultra high purity nitrogen. In the coulometer cell the CO_2 is absorbed by a proprietary solution procured from Utopia Instrument Company (UIC). This solution changes color from blue to colorless by addition of the (acid) CO_2 gas. A photo diode detects the color change and causes a current to pass through the cell with electrolytic production of hydroxide ions at the cathode. The titration current is turned off when the solution reaches the original color. The current passed through the cell is measured by a counter and is directly proportional to the amount of CO_2 injected. The details of the system can be found in Johnson (1992) and Johnson et al. (1993). The coulometer cell solution was replaced after 30 milligram of carbon was titrated or when the coulometer runs were less then 9 minutes. This typically was after 18-20 hours of continuous use. Typical sample titration times were 9 to 16 minutes.

Both coulometers were calibrated by injecting aliquots of pure CO_2 using an 8-port valve with two sample loops. The CO_2 gas volumes bracketed the amount of CO_2 extracted from the water samples for the two AOML systems. The gas loops were calibrated at BNL. Liquid certified reference materials (CRMs) consisting of poisoned, filtered, and UV irradiated seawater supplied by Dr. A. Dickson of Scripps Institution of Oceanography (SIO) were run on each cell. The results were close to the values determined manometrically by Keeling at SIO as shown below. The CRM results have been presented in Figure 9 and Table 2.

Av. value of CRMs run on AOML-2: 1901.46 μmol/kg ± 1.47 n = 42

Av. value of CRMs run on PMEL-1: 1902.62 μmol/kg ± 1.33 n = 49

The manometric value [SIO reference material batch #29] was
1902.33 μmol/kg ± 1.06 n = 11.

Replicate seawater samples were taken from the deepest "Niskin"™ sample and run at different times during the cell. The first replicate was used at the start of the cell with fresh coulometer solution, the second at the end of the cell after about 30 milligrams of C were titrated, while the third analysis was performed using a new coulometer cell solution. No systematic difference between the replicates was observed. As example, the replicate samples run on SOMMA AOML-2 had an average deviation from the mean of 1 μmol/kg with a standard deviation of 0.6 μmol/kg for 63 sets of duplicates. The deviation is very similar to that observed for the CRMs and suggest no strong dependency of results with amount of carbon titrated for a particular cell. The results of the duplicate samples have been presented in Figure 10 and Table 3.

The data of the two instruments were normalized using the averages of the reference material for the cruise.

Calculations

The instruments were calibrated three times during each cell solution with a set of CO_2 gas loop injections. Calculation of the amount of CO_2 injected was according to the Department of Energy (DOE) CO_2 handbook [DOE, 1994]. The gas loops yielded a calibration factor for the instrument defined as:

$$Cal.\ factor \ = \ \frac{calculated\ moles\ of\ CO_2\ injected\ from\ gas\ loop}{actual\ moles\ of\ CO_2\ injected} \qquad (1)$$

The concentration of CO_2 ($[CO_2]$) in the samples was determined according to:

$$[\,CO_2\,] \ = \ Cal.\ factor\ *\ \frac{(Counts - Blank * Run\ Time) * K\ muMol\ /\ count}{pipette\ volume * density\ of\ sample} \qquad (2)$$

where "Counts" is the instrument reading at the end of the analysis, "Blank" is the counts/minute determined from blank runs performed at least once for each cell of the solution, "Run Time" is the length of coulometric titration (in minutes), and K is the conversion factor from counts to μmol which is dependent on the slope and intercept relation between instrument response and charge. For a unit with Ecal slope of 1 and intercept of 0, the constant is $2.0728 * 10^{-4}$.

The pipette volume was determined by taking aliquots at known temperature of distilled water from the volumes prior to, during, and after the cruise. The weights with the appropriate densities were used to determine the volume of the syringes and pipette.

Calculation of pipette volumes, density, and final CO_2 concentration were performed according to procedures outlined in the DOE CO_2 handbook (DOE, 1994).

All DIC values were corrected for salinity, volume and CRM. Salinity correction was done using CTD salinity. A volume correction was done due to dilution by 200 μl of saturated mercuric chloride solution. The assumed total water volume in the sampling bottles was 540 ml and therefore the correction factor used was 1.00037. Also, the following CRM corrections were applied to the data: AOML-2, + 0.87 µmol/kg; PMEL-1, - 0.29 µmol/kg to normalize results from both SOMMAs to the manometric value.

2.2.2. FUGACITY OF CO_2 (fCO_2)

Gas Chromatographic (GC) Method

Approximately 1800 discrete fCO_2 samples from 101 stations were taken and analyzed on the cruise using a newly developed GC based analysis system (Neill et al.,1997). fCO_2 was measured in the headspace of a crimp sealed bottle at constant temperature of 20 °C. Overall precision was 3 µatm over the observed range of 200 to 1500 µatm. A comparison of discrete fCO_2 with the underway fCO_2 values showed correspondence of values to within 1 µatm suggesting a good accuracy of the analyses as well. Discrete fCO_2 values showed a similar pattern as DIC except that the bottom waters were less enriched than DIC. Calcite dissolution increases the alkalinity in the bottom water and thereby suppresses the fCO_2 increase.

2.2.3. TOTAL ALKALINITY (TA)

Titration system

The titration systems used to determine TA consist of a Metrohm 665 Dosimat titrator and an Orion 720A pH meter that is controlled by a personal computer (Millero et al., 1993b). Both the acid titrant in a water jacketed burette and the seawater sample in a water jacketed cell are controlled to a constant temperature of 25 ± 0.1°C with a Neslab constant temperature bath. The plexiglass water jacketed cells used during the cruise are similar to that used by Bradshaw and Brewer (1988) except a larger volume (about 200 ml) is used to increase the precision. This cell is closed off with a fill and drain valve which increase the reproducibility of the cell volume.

A Lab Windows-C program is used to run the titration and record the volume of the added acid and emf of the electrodes using RS232 interfaces. The titration is made by adding HCl to seawater past the carbonic acid end point. A typical titration records the emf reading after the readings become stable (± 0.1 mV) and then adds enough acid to change the voltage to a pre-assigned increment (~ 13 mV). In contrast to the delivery of a fixed volume increment of acid, this method gives data points in the range of a rapid increase in the emf near the endpoint. A full titration (25 points) takes about 20 minutes. Using three systems a 24-bottle station cast can be completed in 3.5 hours.

Electrodes

The electrodes used to measure the emf of the sample during a titration consists of a ROSS glass pH electrode and an Orion double junction Ag, AgCl reference electrode.

Standard acids

The HCl used throughout the cruise were made, standardized, and stored in 0.5 l glass bottles in the laboratory. The 0.2554 M HCl solutions were made from 1 M Mallinckrodt standard solutions in 0.45 M NaCl to yield an ionic strength equivalent to that of average seawater (~ 0.7 M). The acid was standardized using a coulometric technique by our group and Dr. Andrew G. Dickson (Taylor and Smith, 1959; Marinenko and Taylor, 1968). Both results agree to within ± 0.0001 N.

Volume of the cells

The volumes of the cells were determined by comparing the values of TA obtained for Gulf stream seawater with open (weighed amount of seawater) and closed cells (V_{cell} = TA (closed) × V (assigned) / TA(open)). The density of seawater at the temperature of the measurements (25°C) was calculated from the international equation of state of seawater (Millero and Poisson, 1981). The nominal volumes of all cells is approximately 200 ml and the values determined before the start of the cruise were:

cell 4: 202.56 ml   cell 17: 206.01 ml   cell 18: 203.49 ml

Results on CRM 29 obtained in the laboratory and during the cruise indicate that the volumes were not accurately assigned in the laboratory before the cruise. Thus, all cruise data (TA and DIC) have been adjusted by about 2 to 4 μmol/kg lower than the original values collected during the cruise.

Evaluation of the Carbonate Parameters

The total alkalinity of seawater was evaluated from the proton balance at the alkalinity equivalence point, $pH_{equiv} = 4.5$, according to the exact definition of total alkalinity (Dickson, 1981)

$$\begin{aligned} TA = {} & [HCO_3^-] + 2\,[CO_3^{2-}] + [B(OH)_4^-] + [OH^-] + [HPO_4^{2-}] + 2[PO_4^{3-}] \\ & + [SiO(OH)_3^-] + [HS^-] + [NH_3] - [H^+] - [HSO_4^-] - [HF] - [H_3PO_4] \qquad (3) \end{aligned}$$

The full titration is used to evaluate TA from any given experiment. This is accomplished with a program that is patterned after those developed by Dickson (1981), Johansson and Wedborg (1982) and Dickson (DOE, 1994). The program determines pH, E* (for the electrode), TA, DIC and pK_1. The program uses the Levenberg-Marquartd nonlinear least squares algorithm to perform the calculations. The program assumes that the nutrients are negligible in the calculation of TA. Neglecting the concentration of nutrients in the seawater sample little affects the accuracy of TA, but does affect the carbonate alkalinity. The pH and pK_1 of the carbonic acid used in the program are on the seawater scale, $[H^+]_{SW} = [H^+] + [HSO_4^-] + [HF]$ (Dickson, 1984). The dissociation constants used in the program were taken from Dickson and Millero (1987) for carbonic acid, from Dickson (1990a) for boric acid, from Dickson and Riley (1979) for HF, from Dickson (1990b) for HSO_4^- and from Millero (1995) for water. The program requires as input the concentration of acid, volume of the cell, salinity, temperature, measured emf (E), and volume of HCl (V_{HCl}). To obtain a reliable TA from a full titration at least 25 data points should be collected (9 data points between pH 3.0 to 4.5). The precision of the fit is less than 0.4 μmol/kg when pK_1 is allowed to vary and 1.5 μmol/kg when pK_1 is fixed. Our titration program has been compared to the titration programs used by others (Johansson and Wedborg, 1982; Bradshaw *et al.*,1981; Bradshaw and Brewer, 1988) and the values of TA agree to within ± 1 μmol/kg.

Measurements of TA on 72 samples of Certified Reference Materials (CRMs) gave the following results: pH = 8.004 ± 0.006, DIC = 1915.0 ± 2.4 μmol/kg, and TA = 2184.3 ± 1.5 μmol/kg (Figure 11). The TA ranges from 2230 to 2360 μmol kg^{-1} in the Indian Ocean. The ranges of surface normalized alkalinity (NTA = TA × 35 / S) and DIC (NDIC) nominally along 80° E are 2290-2325 and 1940-2100 μmol kg^{-1}, respectively. These values remain constant between 30° S and 10° N and increase toward higher latitudes.

A more detailed description of the analyses and procedures of the total alkalinity (TA) data has been described by Millero et al. (1997).

2.2.4. pH

The pH measurements of seawater were made using the spectrophotometric techniques of Clayton and Byrne (1993). The pH of samples using m-cresol purple (mCP) is determined from

$$pH = pK_{ind} + \log [(R - 0.0069) / (2.222 - 0.133 R)] \qquad (4)$$

where pK_{ind} is the dissociation constant for the indicator and R (A_{578}/A_{434}) is the ratio of the absorbance of the acidic and basic forms of the indicator corrected for baseline absorbance at 730 nm. The pH of the samples is perturbed by the addition of an indicator. The magnitude of this perturbation is a function of the difference between the seawater acidity and indicator acidity; this correction was quantified for each batch of dye solution. To a sample of seawater(~ 30 ml), a normal volume of mCP (0.080 ml, in this case) was added and the absorbance ratio was measured. From a second addition of mCP and absorbance ratio measurement, the change in absorbance ratio per ml of added indicator (ΔR) was calculated. From a series of such measurements over a range of seawater pH, ΔR was described as a linear function of the value of the absorbance ratio (R_m) measured subsequent to the initial addition of the indicator (i.e. $R = -0.03540 - 0.1289 R_m$). In the course of routine seawater pH analyses, this correction was applied to every measured absorbance ratio (R_m); i.e. the corrected absorbance ratio is calculated as

$$R = R_m - (-0.03450 - 0.1289 R_m) V_{ind} \qquad (5)$$

Where V_{ind} (0.08 ml) is the volume of mCP used. Clayton and Byrne (1993) calibrated the m-cresol purple indicator using TRIS buffers (Ramette et al., 1977) and the pH equations of Dickson (1993). They found that

$$pK_{ind} = 1245.69/T + 3.8275 + (2.11 \text{ x } 10^{-3}) (35 - S) \qquad (6)$$

where T is temperature in Kelvin and is valid from 293.15 to 303.15 K and S = 30 to 37. The values of pH calculated from equations (4) and (6) are on the total scale in units of moles per kilogram. The total proton scale (Hansson, 1973) defines pH in terms of the sum of the concentrations of free hydrogen ion, $[H^+]$, and bisulfate, $[HSO_4^-]$

$$pH_T = -\log[H^+]_T = -\log\{[H^+] + [HSO_4^-] \} = -\log\{[H^+] (1 + [SO_4^{2-}] / K_{HSO4})\} \qquad (7)$$

where the concentration of total sulfate, $[SO_4^{2-}] = 0.0282 \times 35 / S$, and K_{HSO4} is the dissociation constant for the bisulfate in seawater (Dickson, 1990a).

Lee and Millero (1995) redetermined the value of pK_{ind} from 273.15 to 313.15 K using a 0.04 m TRIS buffer (Ramette et al., 1977). The pH of the TRIS buffer was determined from emf measurements made with the H_2,Pt| AgCl,Ag electrode system (Millero et al., 1993a). At 25°C the buffer had a pH of 8.0760 and yielded spectrophotometric values of pH that were in excellent agreement (~ 0.0001) with those found using equations (4) and (6). Their results from 273.15 to 313.15 K (0 to 40°C) for S = 35 were fitted to the equation

$$pK_{ind} = 35.913 - 216.404 / T - 10.9913 \log (T) + (2.11\times10^{-3})(35-S) \qquad (8)$$

with the standard error of 0.001 in pK_{ind} where the constants are on the total proton scale (moles per kilogram of H_2O). The use of equations (4) and (8) from 0 to 40°C makes the assumption that R is independent of the temperature. The salinity dependence is taken from Clayton and Byrne (1993).

The values of pH calculated from equations (4) and (8) are on the total scale in units of mole per kilogram of H_2O. The conversion of the pH_T (mol (kg-H_2O)$^{-1}$) to the seawater pH_{SWS} (mol (kg-soln)$^{-1}$) can be made using (Dickson and Riley, 1979; Dickson and Millero, 1987)

$$\begin{aligned} pH_{SWS} = {} & pH_T - \log\{(1 + [SO_4^{2-}] / K_{HSO4} + [F^-] / K_{HF}) / \\ & (1 + [SO_4^{-2}] / K_{HSO4}])\} - \log (1 - 1.005 \times 10^{-3} S) \end{aligned} \qquad (9)$$

where the total concentration of fluoride, $[F^-] = 0.000067 \times 35 / S$, and K_{HF} is the dissociation constant for hydrogen fluoride (Dickson and Riley, 1979). The seawater pH_{SWS} scale was used in this paper since the carbonate constants used are on this scale (Dickson and Millero, 1987; Millero et al., 1993a).

The absorbance measurements were made using a Diode Array 8452A spectrophotometer. The temperature was controlled to a constant temperature of 25°C with a Neslab refrigerated circulating temperature bath that regulates the temperature to ± 0.01°C. The temperature was measured using a Guildline 9540 digital platinum resistance thermometer.

Spectrophotometric pH measurements were made on 21 samples of CRMs. The average pH of these measurements was 8.011 ± 0.001 (Figure 12). The values of pH (measured at 25°C) for surface waters range from 7.85 to 8.10.

A more detailed description of the analyses and procedures of the pH data has been described by Millero et al. (1997).

2.2.5. TOTAL ORGANIC CARBON AND NITROGEN METHODS

Total Organic Carbon

All TOC samples were analyzed by high-temperature combustion using a non-commercial system described more fully in Hansell et al., 1997. In brief, a quartz combustion tube (490 mm x 13 mm) was packed with platinum coated alumina beads (Shimadzu, Inc.), Cuprox (Leeman Labs), and Sulfix (Wako Pure Chemical Industries, Inc.). Four platinum pillows were placed 15 cm from the top of the tube. Below the pillows were 2 g of Cuprox and then 10 g of Sulfix and 10 g of platinum catalyst. The catalyst, Cuprox, and Sulfix were each separated by a thin layer of quartz wool. The packing material was supported from below by a platinum screen (one of the pillows unfolded), which in turn was supported by a quartz rod (0.6 mm O.D.) extending to the bottom of the column. The combustion column was maintained at 750 °C in a Thermolyne 21100 tube furnace.

Samples from Stations 2-41 were run at sea during the cruise, while the remainder were stored frozen for analysis in a shore based laboratory. At the time of analysis, the samples were sparged of inorganic CO_2 following acidification with high purity phosphoric acid (50 µl added to 20 ml of sample). Carbon dioxide generated from 100 µl injections was detected using a LICOR Model LI-6252 NDIR analyzer operated in the absolute mode. Data were acquired on a Macintosh computer running Dynamax Macintegrator 1.3 software (Rainin Instruments, Inc.).

Calibrations were performed 2-4 times daily with a 4-point standard curve using glucose in Milli-Q water (0-100 µmol/l C). The system blank (normally 7-8 µmol/ l C) was determined at intervals of approximately 6 seawater samples using vialed Milli-Q water produced at the Bermuda Biological Station for Research, Inc. The organic carbon content of this water (~ 3 µmol/ l C) was determined by intercomparison with the low-carbon water prepared by Dr. Jon Sharp (Univ. of Delaware) for the TOC intercomparison exercises he organized. Vialed seawater, collected from 2600 m at the U.S. JGOFS Bermuda Atlantic Time-Series Study site in the Sargasso Sea, was also analyzed several times each day to monitor the system blank and the behavior of the analyzer. The percent relative standard deviation (RSD) for all 174 TOC samples at depths >1000 m, with a mean concentration of 42.3 µmol/ l, was 2.0%.

Total Organic Nitrogen

Concentrations of TON were determined by UV photo-oxidation according to the method described by Walsh (1989). Frozen samples were thawed by placing sample bottles in a warm water bath. A 10 ml aliquot was removed from each sample bottle and placed in a 20 ml fused quartz tube equipped with a ground stopper (Quartz Scientific, Inc.). 50 µl of 30% hydrogen peroxide was added to each tube and placed in a homemade irradiation unit overnight (17-20 hours). Testing the recovery of known compounds, such as glycine, showed that inconsistent results were obtained with shorter irradiation periods. The irradiation unit contained a 1200 W UV lamp (Hanovia) protected by a quartz jacket. A 2-tiered aluminum tube holder (40 tubes total) fitted around the lamp and held the samples 8 cm from the lamp. A fan placed at the bottom of the unit blew air across the samples for cooling. A hinged aluminum cylinder, open at the top and bottom, was fitted around the samples to keep stray UV light from leaving the system. This entire unit was placed in a fume hood, the front of which was covered with a black curtain while in use (again to collect stray UV light).

After irradiation, aliquots of the samples (which were refrigerated overnight) that had not been oxidized, and the photo-oxidized aliquots, were analyzed for nitrate plus nitrite using a colorimetric method on a Technicon Autoanalyzer II (Knap et al. 1993). Daily calibration was achieved from 4 point calibration curves using both KNO_3 and KNO_2. Cadmium column efficiency was determined by comparing the slope of the NO_3^- calibration curve with the slope obtained from NO_2^- calibration curve. Due to the photoreduction of NO_3^- to NO_2^- (Walsh 1989), it is imperative that the cadmium column be efficient when analyzing samples containing high concentrations of nitrate. Therefore, a new column (i.e. efficiency >98%) was employed when analyzing nitrate samples >10 µmol/l. The column efficiency was generally > 90% when running the low nitrate samples. Low nutrient seawater (Sargasso Sea surface water) was always processed with the samples as a daily quality control measure.

2.2.6. $^{13}C/^{12}C$ OF DISSOLVED INORGANIC CARBON

Shipboard Sample Collection Methods

Samples were collected in pre-washed and baked (450 ºC) 250 or 0.5 l ground glass-stoppered bottles using the following method. A length of Tygon tubing was attached to the "Niskin" bottle or seawater line and flushed for a few seconds. The end of the tubing was then placed at the bottom of the upright sample bottle and the bottle was filled, then overflowed with an amount equal to its volume if "Niskin" water volume permitted, otherwise with at least half its volume. Flow was stopped as the Tygon tubing was removed from the top of the bottle to avoid any splashing in the top. Using a syringe or turkey baster, 10 to 20 ml were withdrawn off the top of the sample to lower the water level to approximately 1 ml below the neck of the bottle, avoiding backwash of water from the turkey baster into the sample. The ground glass joint of the bottle was wiped dry with Kimwipes. Then 100 µl of a saturated $HgCl_2$ solution (per 250 ml of seawater) was injected beneath the surface of the sample using an Eppendorf pipet. The ground-glass stopper, which had been pre-greased with Apiezon M grease, was then inserted straight into the bottle without twisting. If any air streaked in the grease seal were visible, the stopper was removed, cleaned, and regreased, then the bottle was resealed. Clips (if required for the bottle neck-type) were placed on the necks of the bottles, and two heavy rubber bands were placed around the stopper and bottle to prevent leakage. The sample bottle was then inverted a couple of times to mix the $HgCl_2$ throughout the sample.

Laboratory Methods

CO_2 is extracted from the DIC seawater sample using a modification of the helium stripping technique described by Kroopnick (1974) as described in Quay et al (1992). The stripper is comprised of a glass tube with a stainless steel fitting and silicone-greased glass stopcock at the bottom (which connects to the He line), a glass frit which the He passes through, and a stainless steel fitting containing a 3-layer silicone rubber septum at the top. Approximately 1 ml phosphoric acid is injected into the stripper and bubbled with He for 10 minutes. The gas is then evacuated out of the stripper and the stripper is weighed. Then 80 to 125 ml of the sample is drawn into the stripper and it is weighed again to calculate the weight of water analyzed. A stainless steel needle pierces the septum and connects the stripper to the extraction line, which has been evacuated and filled with helium. The sample is stripped with 99.997% pure He at a flow rate of about 200 ml/min for 20 minutes. Water is trapped out in two glass traps submerged in Dewars containing a slush mixture of dry ice and isopropanol at -70ºC. CO_2 is collected at -196ºC in glass loop traps submerged in liquid N_2. The del ^{13}C is then measured on a Finnigan MAT 251 mass spectrometer. The efficiency of the extraction method is 100 ± 0.5 percent based on gravimetrically prepared Na_2CO_3 standards. The precision of the ^{13}C analysis is ± 0.02 per mil based on a replicate analysis of standards and seawater samples.

2.2.7. CHLOROFLUOROCARBONS (CFC)

CFC samples were drawn from approximately 70 % of 2300 water samples collected during the expedition. When taken, water samples for CFC analysis were usually the first samples drawn from the 10 liter "Niskin" bottles. Care was taken to co-ordinate the sampling of CFCs with other samples to minimize the time between the initial opening of each bottle and the completion of sample drawing. In most cases, dissolved oxygen, total CO_2, alkalinity and pH samples were collected within several minutes of the initial opening of each bottle. To minimize contact with air, the CFC samples were drawn directly through the stopcocks of the 10 liter "Niskin" bottles into 100 ml precision glass syringes equipped with 2-way metal stopcocks. The syringes were immersed in a holding tank of clean surface seawater until analysed.

To reduce the possibility of contamination from high levels of CFCs frequently present in the air inside research vessels, the CFC extraction/analysis system and syringe holding tank were housed in a modified 20' laboratory van on the aft deck of the ship.

For air sampling, a ~100 meter length of 3/8" OD Dekaron tubing was run from the CFC lab van to the bow of the ship. Air was pulled through this line into the CFC van using an Air Cadet pump. The air was compressed in the pump, with the downstream pressure held at about 1.5 atm using a back-pressure regulator. A tee allowed a flow (~100 ml/min) of the compressed air to be directed to the gas sample valves, while the bulk flow of the air (>7 l/minute) was vented through the back pressure regulator. A list of air measurements is given in Table 6 and interpolated values are shown in Table 7.

Concentrations of CFC-11 and CFC-12 in air samples, seawater and gas standards on the cruise were measured by shipboard electron capture gas chromatography (EC-GC), using techniques similar to those described by Bullister and Weiss (1988). For seawater analyses, a ~30-ml aliquot of seawater from the glass syringe was transferred into the glass sparging chamber. The dissolved CFCs in the seawater sample were extracted by passing a supply of CFC-free purge gas through the sparging chamber for a period of 4 minutes at ~70 ml/min. Water vapor was removed from the purge gas during passage through a 7" long x 3/8" diameter glass tube packed with magnesium perchlorate dessicant. The sample gases were concentrated on a cold-trap consisting of a 3-inch section of 1/8-inch stainless steel tubing packed with Porapak N (60-80 mesh) immersed in a bath of isopropanol held at -20 °C. After 4 minutes of purging the seawater sample, the sparging chamber was closed and the trap was held open for an additional one minute to allow nitrous oxide (N_2O) to pass through the trap and thereby minimize its interference with CFC-12. The trap was then isolated, and the cold isopropanol in the bath was forced away from the trap. The trap was then heated electrically to 125 degrees C. The sample gases held in the trap were then injected onto a precolumn (12 inches of 1/8-inch O.D. stainless steel tubing packed with 80-100 mesh Porasil C, held at 90 degrees C), for the initial separation of the CFCs and other rapidly eluting gases from more slowly eluting compounds. The CFCs then passed into the main analytical column (10 feet, 1/8-inch stainless steel tubing packed with Porasil C 80-100 mesh, held at 90 degrees C), and then into the EC detector.

The CFC analytical system was calibrated frequently using standard gas of known CFC composition. Gas sample loops of known volume were thoroughly flushed with standard gas and injected into the system. The temperature and pressure was recorded so that the amount of gas injected could be calculated. The procedures used to transfer the standard gas to the trap, precolumn, main chromatographic column and EC detector were similar to those used for analyzing water samples. Two sizes of gas sample loops were present in the analytical system. Multiple injections of these loop volumes could be done to allow the system to be calibrated over a relatively wide range of CFC concentrations. Air samples and system blanks (injections of loops of CFC-free gas) were injected and analyzed in a similar manner. The typical analysis time for a seawater, air, standard or blank sample was about 12 minutes.

Concentrations of CFC-11 and CFC-12 in air, seawater samples and gas standards are reported relative to the SIO93 calibration scale (Cunnold, et. al., 1994). CFC concentrations in air and standard gas are reported in units of mole fraction CFC in dry gas, and are typically in the parts-per-trillion (ppt) range. Dissolved CFC concentrations are given in units of picomoles of CFC per kg seawater (pmol/kg). CFC concentrations in air and seawater samples were determined by fitting their chromatographic peak areas to multi-point calibration curves, generated by injecting multiple sample loops of gas from a CFC working standard (PMEL cylinder 33790) into the analytical instrument. The concentrations of CFC-11 and CFC-12 in this working standard were calibrated before and after the cruise versus a primary standard (36743) (Bullister, 1984). No measurable drift in the concentrations of CFC-11 and CFC-12 in the working standard could be detected during this interval. Full range calibration curves were run at intervals of ~ 3 days during the cruise. Single injections of a fixed volume of standard gas at one atmosphere were run much more frequently (at intervals of 1 to 2 hours) to monitor short term changes in detector sensitivity.

Extremely low (<0.01 pmol/kg) CFC concentrations were measured in deep water (>2000 meters) on the 80E section north of ~30 S. Based on the median of CFC concentration measurements in the deep water of this region, which is believed to be nearly CFC-free, blank corrections of 0.0018 pmol/kg for CFC-11 and 0.0015 pmol/kg for CFC-12 have been applied to the data set.

On this expedition, we estimate precisions (1 standard deviation) of about 1% or 0.005 pmol/kg (whichever is greater) for dissolved CFC-11 and 2% or 0.005 pmol/kg (whichever is greater) for dissolved CFC-12 measurements (see listing of replicate samples given in Tables 4 and 5).

A number of water samples had clearly anomolous CFC-11 and/or CFC-12 concentrations relative to adjacent samples. These anomolous samples appeared to occur more or less randomly during the cruise, and were not clearly associated with other features in the water column (eg. elevated oxygen concentrations, salinity or temperature features, etc.). This suggests that the high values were due to individual, isolated low-level CFC contamination events. Measured concentrations for these samples are included in this report, but are give a quality flag of either 3 (questionable measurement) or 4 (bad measurement). A total ~7 analyses of CFC-11 were assigned a flag of 3 and ~9 analyses of CFC-12 were assigned a flag of 3. A total of ~27 analyses of CFC-11 were assigned a flag of 4 and ~69 CFC-12 samples assigned a flag of 4.

2.3. BIOLOGICAL PARAMETERS

Samples were collected from 31 discrete stations for biological and bio-optical parameters. A total of 306 primary productivity, 428 chlorophyll, 31 particulate organic carbon, 173 ^{15}N uptake, 164 epifluorescence microscopy, 257 flow cytometry, 110 A* (the absorption of light by suspended particles normalized to chlorophyll concentration) and 179 nutrient samples were taken for the characterization of prokaryotic and protistan biomass, growth rates and composition in the upper 300 meters of the water column. The Profiling Reflectance Radiometer was deployed to 100-140 m at the stations which were occupied between 0900 and 1500 hours of local time. In addition underway mapping system continuously measured nitrate concentration, chlorophyll fluorecence, photosynthetically active radiation and transparency, attenuation and absorbance at multiple wavelengths. All the productivity, chlorophyll and much of the epifluorescence microscopy samples have been analyzed aboard ship, however, the A*, ^{15}N, POC, and nutrient samples were analyzed in various laboratories. The data is available through the following internet addresses:
http://www.mbari.org/~reiko/indian/introduction.htm and
http://www.aoml.noaa.gov/ocd/oaces/

2.4. UNDERWAY MEASUREMENT METHODS

2.4.1. UNDERWAY fCO_2

The Underway pCO_2 System version 1.5 (Ho *et al.*. 1997) was used to determine the pCO_2 of surface water and overlaying air on a continuous basis (Keeling 1965, Wanninkhof and Thoning 1993). When in operation, seawater is drawn from the uncontaminated seawater intake from the bow bubble approximately 6 meters below the water line to a shower head equilibrator located in the main laboratory, where the headspace and seawater reach equilibrium on a short time scale. At specific times during an hourly cycle, the content of the headspace is measured by an infrared CO_2 analyzer. Uncontaminated air from the marine boundary layer is drawn continuously from the bow mast to the underway pCO_2 system. At a designated time, air is analyzed by a the infrared CO_2 analyzer, otherwise the air is bled off through a vent .

The CO_2 measurements are made by a Li-Cor differential, non-dispersive, infrared (NDIR) CO_2 analyzer (model 6251), and the result is based on the difference in absorption of infrared (IR) radiation passing through two gas cells. The reference cell is continuously flushed with a gas of known CO_2 concentration using the lowest concentration of three reference gas standards. The sample cell is flushed with one of three reference gas standards, marine boundary layer air, or headspace gas from the equilibrator. Standards were calibrated by NOAA's Climate Monitoring & Diagnostic Laboratory (CMDL) before and after the cruise.

The description of the analyses and procedures of the underway fCO_2 data has been described by Masters et al. (1997). The data may be downloaded via anonymous ftp at <ftp://ftp.aoml.noaa.gov/pub/ocd/carbon/uwpco295>

2.4.2. UNDERWAY pH

Measurements of pH were made throughout the cruise using an automated, spectrophotometric measurement of pH with a sensitivity of better than 0.001 in pH and with a period of approximately 6 min. (0.1 hr). The potential accuracy of pH measurements measured using this technique has been estimated to be about 0.003. However, this is as yet unconfirmed. The probable sources of uncertainty are in the values that are used for the dissociation constant of the indicator dye and for the various extinction coefficient ratios used in calculating the pH.

The system is capable of being operated in one of two modes: constant temperature, or tracking sea surface temperature. In constant temperature mode, the pH of sea water is a sensitive indicator of the ratio of total alkalinity to total dissolved inorganic carbon in the water mass being measured. Changes in pH are thus indicative of changes in the water mass being monitored. In sea surface temperature mode, the pH is inversely correlated with the sea surface pCO_2 and thus indicates changes in this parameter (note however, that it is probably better to measure pCO_2 directly if accurate measurements are needed).

The system is controlled by computer, and the software provides a near real-time display of sea surface temperature, salinity, and pH (plotted against time) as well as of parameters that are more directly related to instrument performance (which can thus be used to assess whether or not problems exist). Values for sea surface temperature and salinity were obtained from the SCS (Shipboard Computer System), time and position are obtained directly from a GPS (as well as being available from the SCS data stream). During this cruise, the system was operated predominantly in “constant temperature” mode, and despite a number of problem with the valve on the syringe pump — resulting from wear during the previous few months — the system operated for about 80% of the total time of the cruise, *i. e.* it made about 6,500 measurements. The latest update of the data can be obtained from Dr. Andrew Dickson at: adickson@ucsd.edu

3. ACKNOWLEDGMENTS

The dedication and assistance of the officers and crew of the NOAA Ship MALCOLM BALDRIGE is gratefully appreciated and hereby acknowledged. This research was supported by Ocean Atmospheric Carbon Exchange Study (OACES). We wish to acknowledge the OACES program managers Dr. James Todd and Lisa Dilling for supporting the field program.

4. REFERENCES

Armstrong, F.A.J., C.R. Stearns, and Strickland, J.D.H., 1967. The measurement of upwelling and subsequent biological processes by means of the Technicon Auto-Analyzer and associated equipment. *Deep-Sea Res*. **14**: 381-389.

Atlas, E. L., J.C. Callaway, R.D. Tomlinson, L.I. Gordon, L. Barstow, and Park, P.K., 1971. A practical manual for use of the Technicon Autoanalyzer for nutrient analysis, revised. Oregon State University, Technical Report 215, Reference No. 71-22.

Bradshaw, A. L. and Brewer, P. G., 1988. High precision measurements of alkalinity and total carbon dioxide in seawater by potentiometric titration-1. Presence of unknown protolyte(s)?, *Mar. Chem*., **23**, 69-86.

Bradshaw, A. L., Brewer, P. G., Shafer, D. K., and Williams, R. T., 1981. Measurements of total carbon dioxide and alkalinity by potentiometric titration in the GEOSECS program, *Earth and Planet. Sci*. *Lett*., **55**, 99-115.

Bullister, J.L. Anthropogenic Chlorofluoromethanes as Tracers of Ocean Circulation and Mixing Processes: Measurement and Calibration Techniques and Studies in the Greenland and Norwegian Seas, Ph.D. dissertation, Univ. Calif. San Diego, pp. 172

Bullister, J.L. and Weiss, R.F., 1988. Determination of CCl3F and CCl2F2 in seawater and air, *Deep-Sea Res.*, **35** (5), 839-853.

Clayton T. and Byrne, R. H., 1993. Calibration of m-cresol purple on the total hydrogen ion concentration scale and its application to CO_2-system characteristics in seawater, *Deep Sea Res.*, **40**, 2115-2129.

Cunnold, D.M., Fraser, P.J., Weiss, R.F., Prinn, R.G., Simmonds, P.G., Miller, B.R., Alyea, F.N., and Crawford, A.J., 1994. Global trends and annual releases of CCl3F and CCl2F2 estimated from ALE/GAGE and other measurements from July 1978 to June 1991, *J. Geophys. Res.*, **99**, 1107-1126.

Dickson, A.G., 1993. pH buffers for sea water media based on the total hydrogen ion concentration scale, *Deep Sea Res*., **40**, 107-118.

Dickson, A. G., 1990a. Thermodynamics of the dissociation of boric acid in synthetic seawater from 273.15 to 318.15 K. *Deep-Sea Res*., **37**: 755-766

Dickson, A. G., 1990b. Standard potential of the (AgCl + 1/2 H_2= Ag + HCl(aq)) cell and the dissociation of bisulfate ion in synthetic sea water from 273.15 to 318.15 K, *J. Chem. Thermody.*, **22**, 113-127.

Dickson, A. G. and Millero, F. J., 1987. A comparison of the equilibrium constants for The dissociation of carbonic acid in seawater media, *Deep-Sea Res.*, **34**, 1733-1743.

Dickson, A. G., 1984. pH scales and proton-transfer reactions in saline media such as seawater, *Geochim. Cosmochim. Acta*, **48**, 2299-2308.

Dickson, A.G., 1981. An exact definition of total alkalinity and a procedure for the estimation of alkalinity and total CO_2 from titration data. *Deep-Sea Res.*, **28**, 609–623.

Dickson, A. G. and Riley, J. P., 1979. The estimation of acid dissociation constants in sea water media from potentiometric titrations with strong base-I. The ionic production of water-K_w, *Mar. Chem.*, **78,** 89-99.

DOE, 1994. Handbook of methods for the analysis of the various parameters of the carbon dioxide system in sea water. *Version 2*. (A. Dickson and C. Goyet ed.) ORNL/CDIAC-74, 1991.

Ffield, A., Fleurant, C., Molinari, R., and Wilson, D. NOAA Ship MALCOLM BALDRIGE 1995 Cruises: MB95-02, MB95-04, MB95-07 hydrographic data. LDEO-98-1 technical report, 1998.

Fischer, J., and Visbeck, M., 1993. Deep Velocity Profiling with Self-contained ADCP'S, *Journal of Atmospheric and Oceanic Technology*, **10**, 764-773.

Friederich, G.E., Codispoti, L.A., and Sakamoto, C.M., 1991. An easy-to-construct automated Winkler titration system. MBARI Tech. Rep. 91-6.

Grasshoff, K., Ehrhardt, M. and Gremling, K. (eds), 1983. Methods of Seawater Analysis, 2nd edition. Verlag Chemie GmbH., Weinheim, pp.419.

Hacker, P., Firing, E., Wilson, W. D., and Molinari, R., 1996. Direct observations of the current structure east of the Bahamas, *Geophys. Res. Lett.*, **23**, 1127-1130.

Hansell, D.A, Carlson, C.A., Bates, N., and Poisson, A, 1997. Horizontal and vertical removal of organic carbon in the equatorial Pacific Ocean: a mass balance assessment. *Deep-Sea Res.II*, **44**, 2115-2130.

Hansson, I., 1973. A new set of acidity constants for carbonic acid and boric acid in sea water, *Deep Sea Res.*, **20**, 461-478.

Ho, D. T., Wanninkhof, R., Masters, J., Feely, R.A., Cosca, C., 1997. Measurements of Underway fCO, in the Eastern Equatorial Pacific on NOAA Ships MALCOLM BALDRIGE and DISCOVERER from February to September, 1994. NOAA Data Report ERL AOML-30, 52pp.

Johansson, O. and Wedborg, M., 1982. On the evaluation of potentiometric titrations of seawater with hydrochloric acid, *Oceanol. Acta*, **5**, 209-218.

Johnson K. M., Wills K. D., Butler D. B., Johnson W. K., and Wong C. S., 1993. Coulometric total carbon dioxide analysis for marine studies: maximizing the performance of an automated continuous gas extraction system and coulometric detector. *Mar. Chem.* **44,** 167-189.

Johnson K. M. and Wallace D. W. R., 1992. The single-operator multiparameter metabolic analyzer for total carbon dioxide with coulometric detection. DOE Research Summary, No. 19, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Keeling C. D., 1965. Carbon dioxide in surface waters of the Pacific Ocean 2. Calculation of the exchange with the atmosphere. *J. Geophys. Res.* **70,** 6099-6102.

Knap, A. H., Michaels, A.F., Dow, R.L., Johnson, R. J., Gundersen, K., Sorenson, J. C., Close, A. R., Howse, F. A., Hammer, M., Bates, N., Doyle, A., and Waterhouse, T., 1993. BATS Method Manual, U.S. JGOFS Planning Office, Woods Hole, MA.

Kroopnick, P., 1974. The dissolved O_2-CO_2-^{13}C system in the equatorial Pacific, *Deep-Sea Res.*, **21**, 211-227.

Lee, K. and Millero, F. J., 1995. The thermodynamic studies of the carbonate system in seawater. *Deep Sea-Res.*, **42**: 2035-2061.

LI-COR. 1990. LI-6262 C02/H20 Analyzer Operating and Service Manual. 9003-59, LICOR, Lincoln, NB.

Marinenko, G., and Taylor, J.K., 1968. Electrochemical equivalents of benzoic and oxalic acid. *Anal. Chem.*, **40**, 1645–1651.

Masters, J., Wanninkhof, R., Ho, D.T., Steckley, M., Feely, R., Cosca, C., 1997. Continuous air and surface seawater measurements of fCO_2 on board the NOAA Ship MALCOLM BALDRIGE around-the-world cruise during 1995. NOAA data report ERL AOML-31.

Millero, F.J., Lee, K., Roche, M., Goen, J., and Millero III, F.J., 1997. The Carbonate System Measurements in the Indian Ocean. Ocean Atmosphere Carbon Exchange Study, Leg I. University of Miami Technical Report, No. RSMAS 97-004.

Millero, F. J., 1995. Thermodynamics of the carbon dioxide system in the oceans. *Geochim. Cosmochim. Acta*, **59**, no. 4, 661-677

Millero, F. J., Zhang, J. Z., Fiol, S., Sotolongo, S., Roy, R., Lee, K., and Mane, S., 1993a. The use of buffers to measure the pH of seawater, *Mar. Chem.*, **44**, 143-152.

Millero, F. J., Zhang, J. Z., Lee, K., and Campbell, D. M., 1993b. Titration alkalinity of seawater, *Mar. Chem.*, **44**, 153-16.

Millero, F.J., and Poisson, A., 1981. International one-atmosphere equation of state of seawater. *Deep-Sea Res.*, **28**, 625–629.

Neill, C., Johnson, K.M., Lewis, E., and Wallace, D.W.R., 1997. Accurate headspace analysis of fCO_2 in discrete water samples using batch equilibration. *Limnol. Oceanogr.*, **42(8)**, 1774-1783

Quay P.D., Tilbrook, B., and Wong, C.S., 1992. Ocean uptake of fossil fuel CO_2: Carbon-13 evidence, *Science*, **256**, 74-79.

Ramette, R. W., Culberson, C. H., and Bates, R. G., 1977. Acid base properties of tris (hydroxymethyl) aminomethane (tris) buffers in seawater from 5 to 40^{o}C. *Anal. Chem.*, **49**, 867-870.

Taylor, J.K., and Smith S.W., 1959. Precise coulometric titration of acids and bases. *J. Res. Natl. Bur. Stds.*, **69A**, 153–159.

Walsh, T. W., 1989. Total dissolved nitrogen in seawater: a new-high-temperature combustion method and a comparison with photo-oxidation. *Marine Chemistry*, **26**, 295-311.

Wanninkhof R. and Thoning K., 1993. Measurement of fugacity Of C02 in surface water using continuous and discrete sampling methods. *Mar. Chem.*, **44,** 189-205.

Weiss R. F., Janke R. A., and Keeling C. D., 1982. Seasonal effects of temperature and salinity on the partial pressure Of C02 in seawater. *Nature,* **300,** 511-513.

Weiss R. F. 1974. Carbon dioxide in water and seawater: the solubility of a non-ideal gas. *Mar. Chem.* **2,** 203-215.

Weiss, R.F. 1970. The solubility of nitrogen, oxygen and argon in water and seawater. *Deep-Sea Res.*, **17**, 721-735.

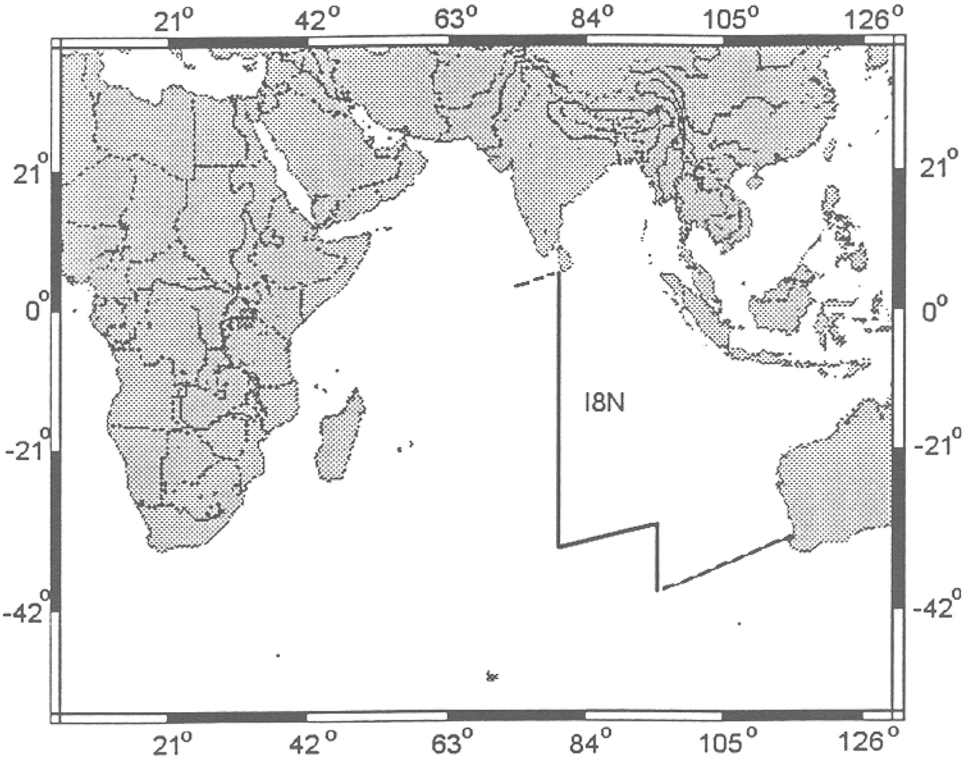

Figure 1. Cruise track for the Indian Ocean I8NR cruise in September-October 1995

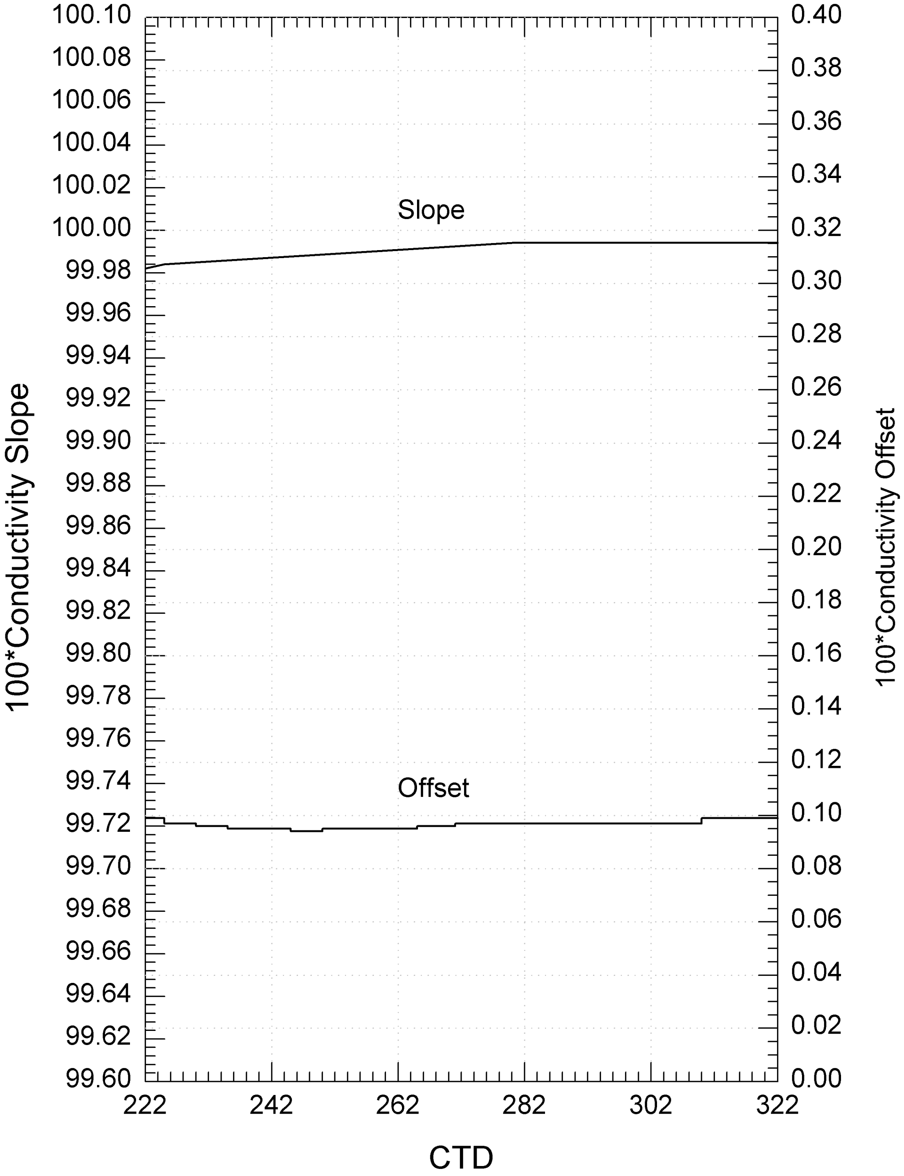

Figure 2. Conductivity slope and offset of sensors T_0 and C_0

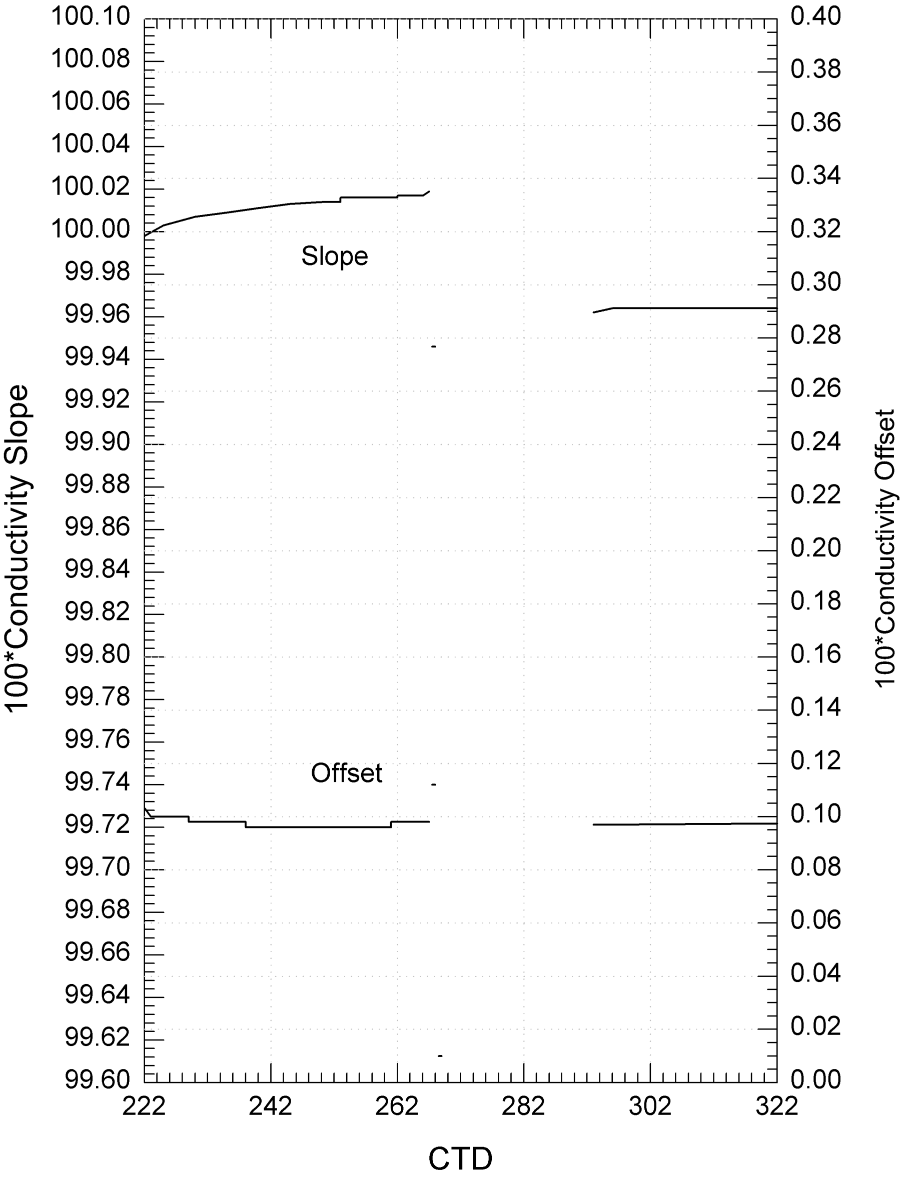

Figure 3. Conductivity slope and offset of sensors T_1 and C_1

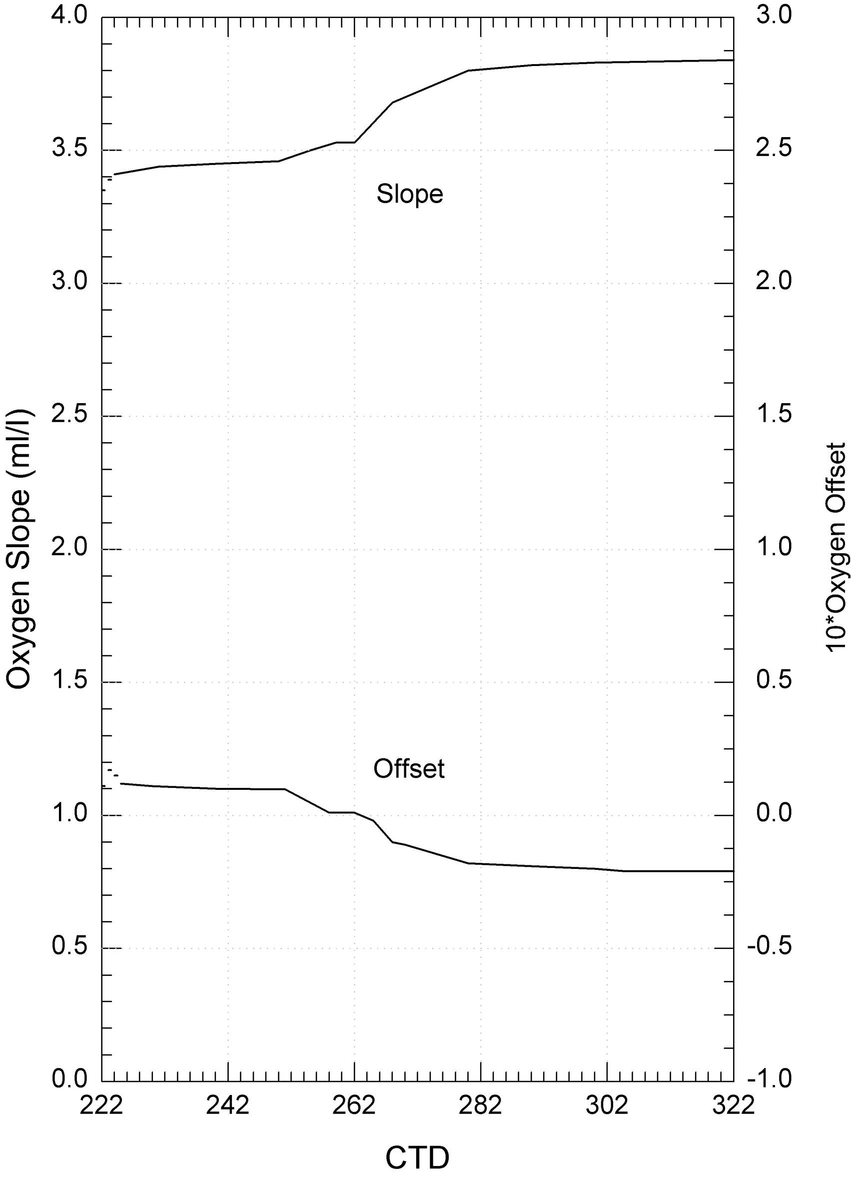

Figure 4. Oxygen slope and offset

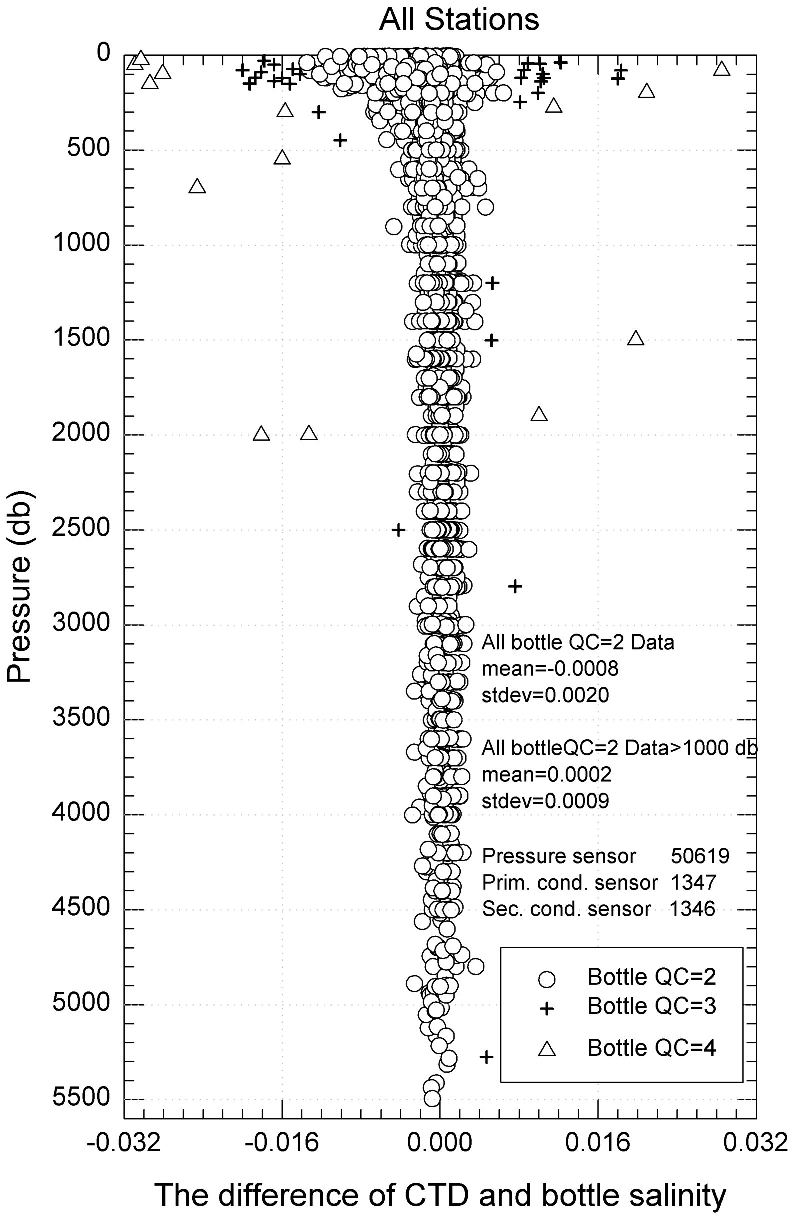

Figure 5. The difference of CTD and bottle salinity vs. pressure

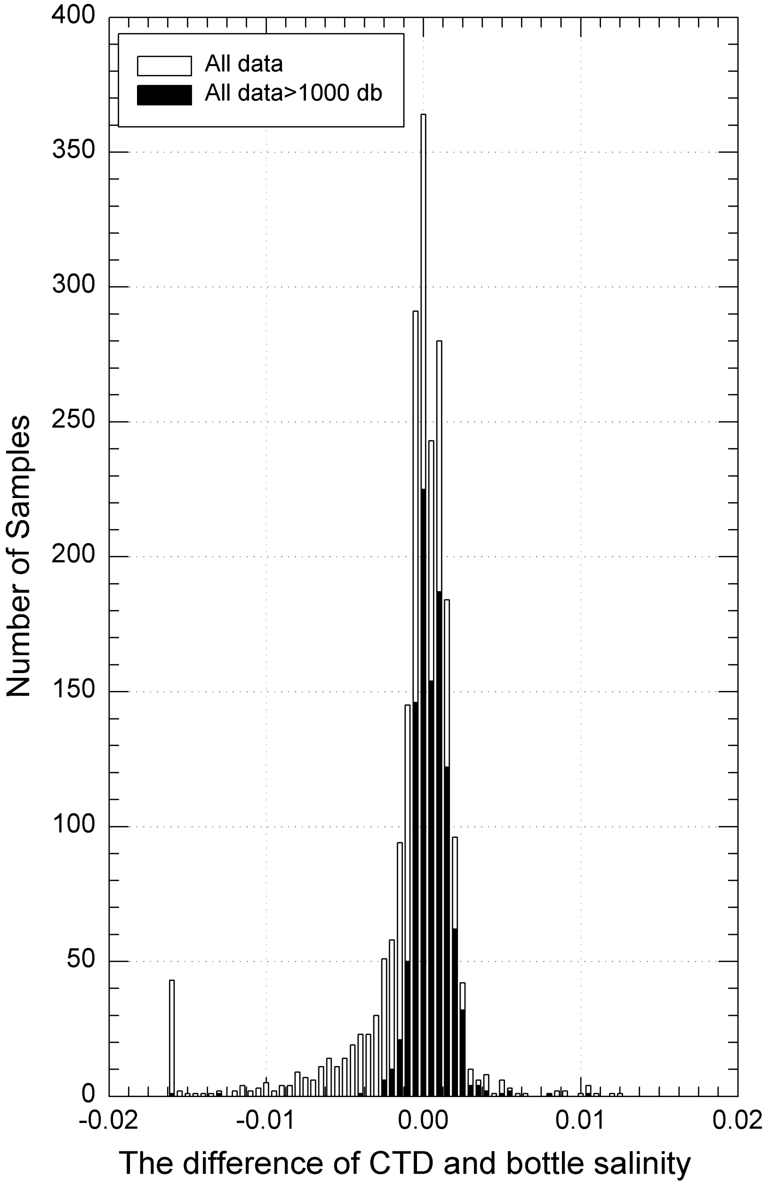

Figure 6. The difference of CTD and bottle salinity vs. number of samples

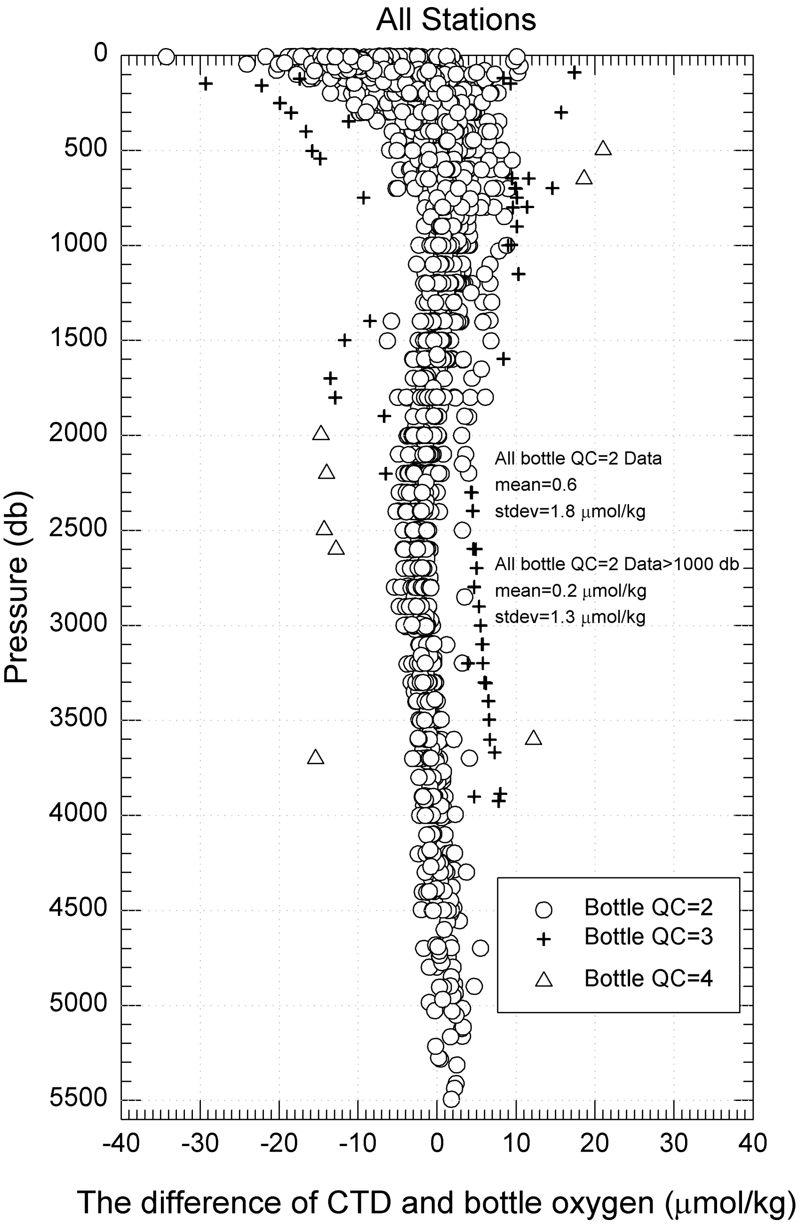

Figure 7. The difference of CTD and bottle oxygen vs. pressure

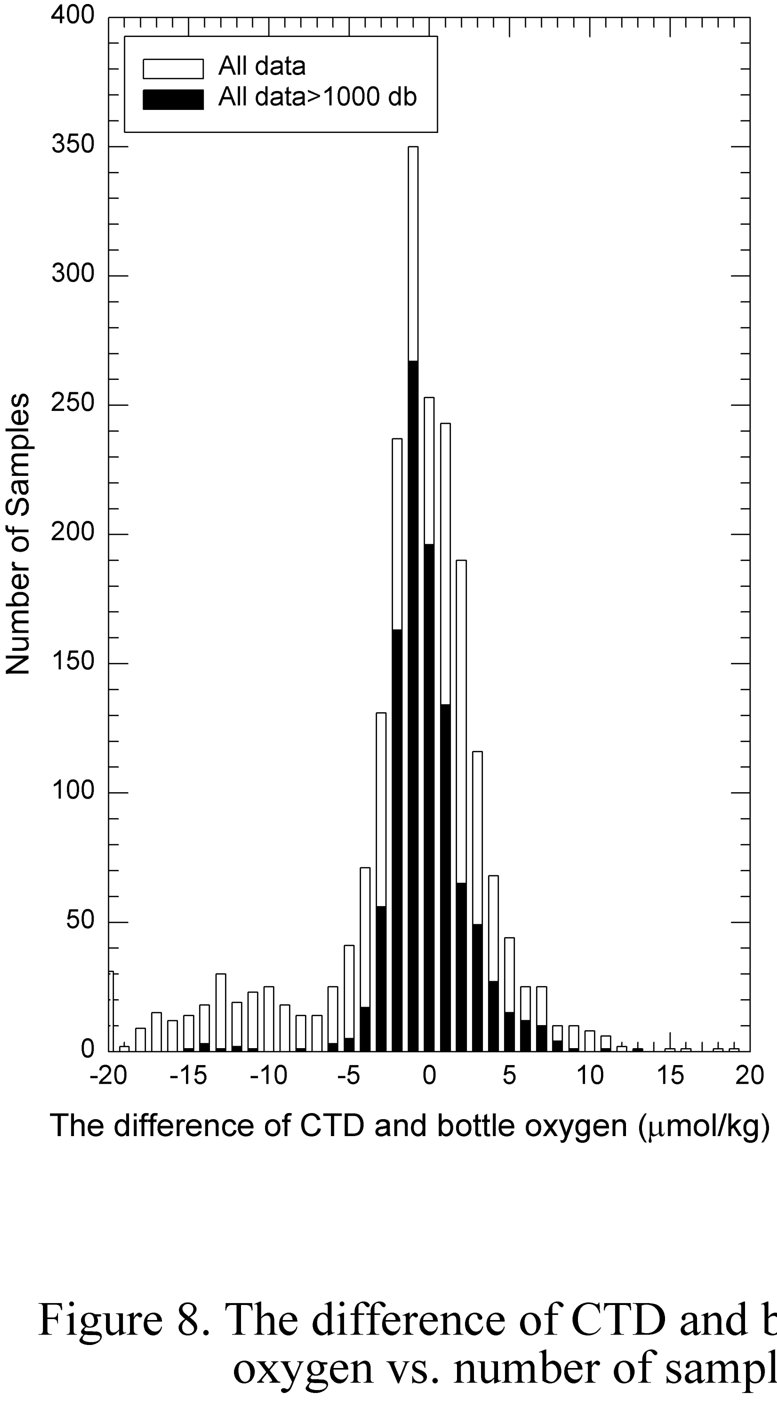

Figure 8. The difference of CTD and bottle oxygen vs. number of samples

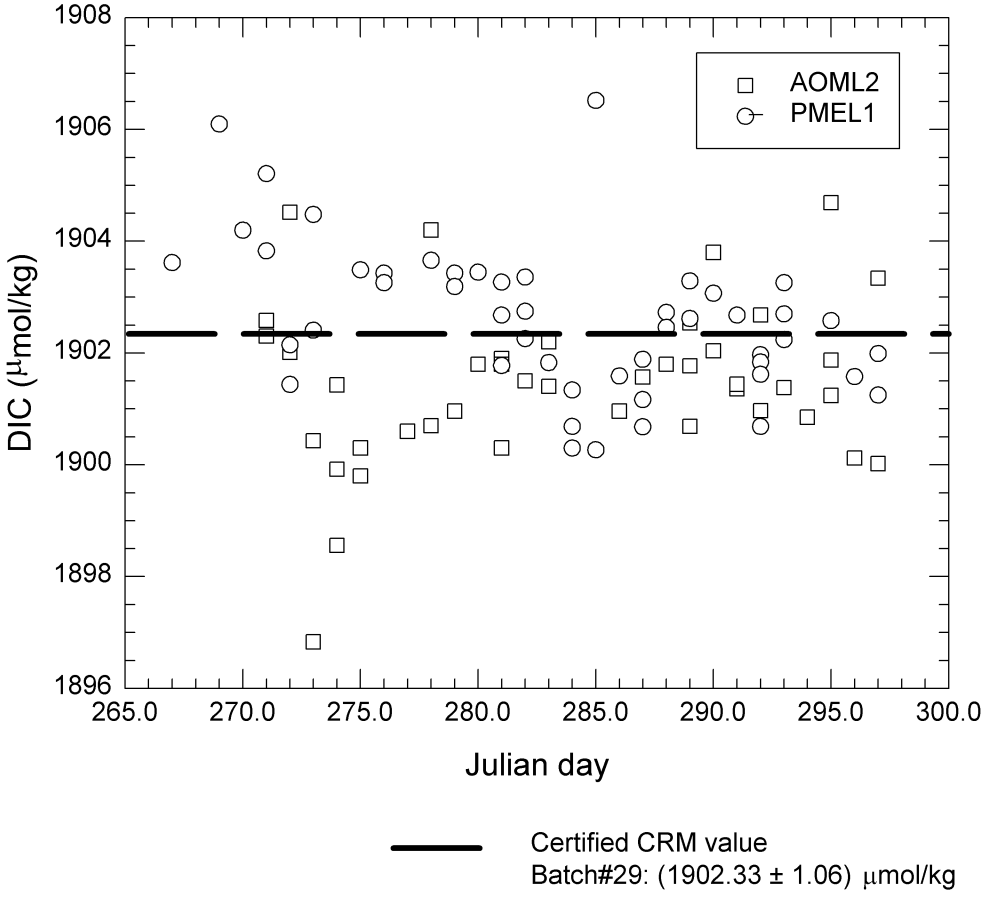

Figure 9. The results of the CRM measurements

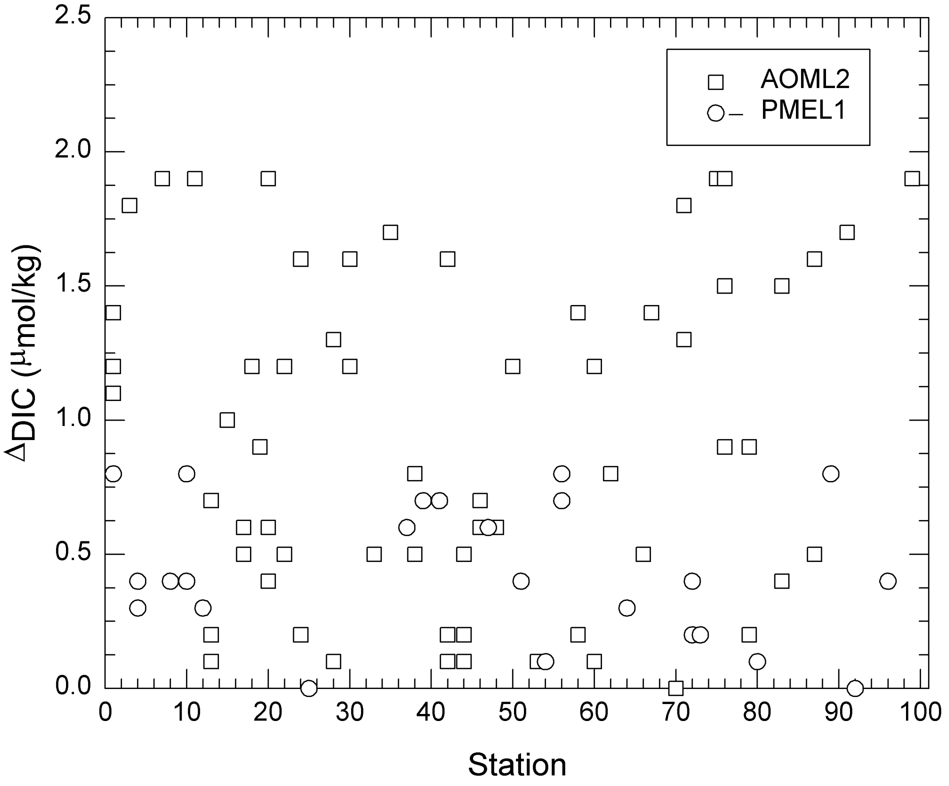

Figure 10. The difference of the DIC duplicates during the course of the cruise

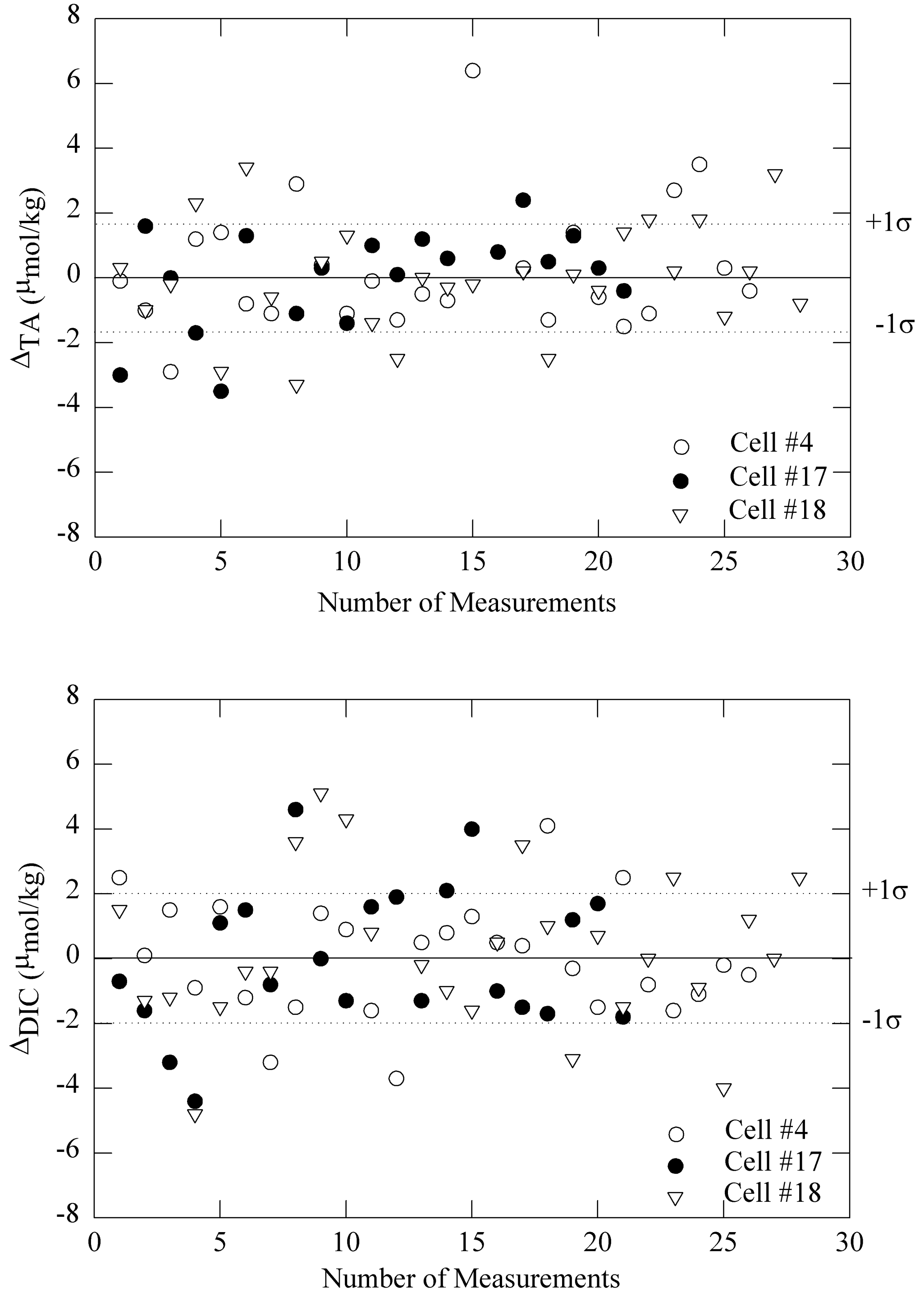

Figure 11. Potentiometric TA and DIC measurements on the Certified Reference Materials (CRMs) during the cruise.

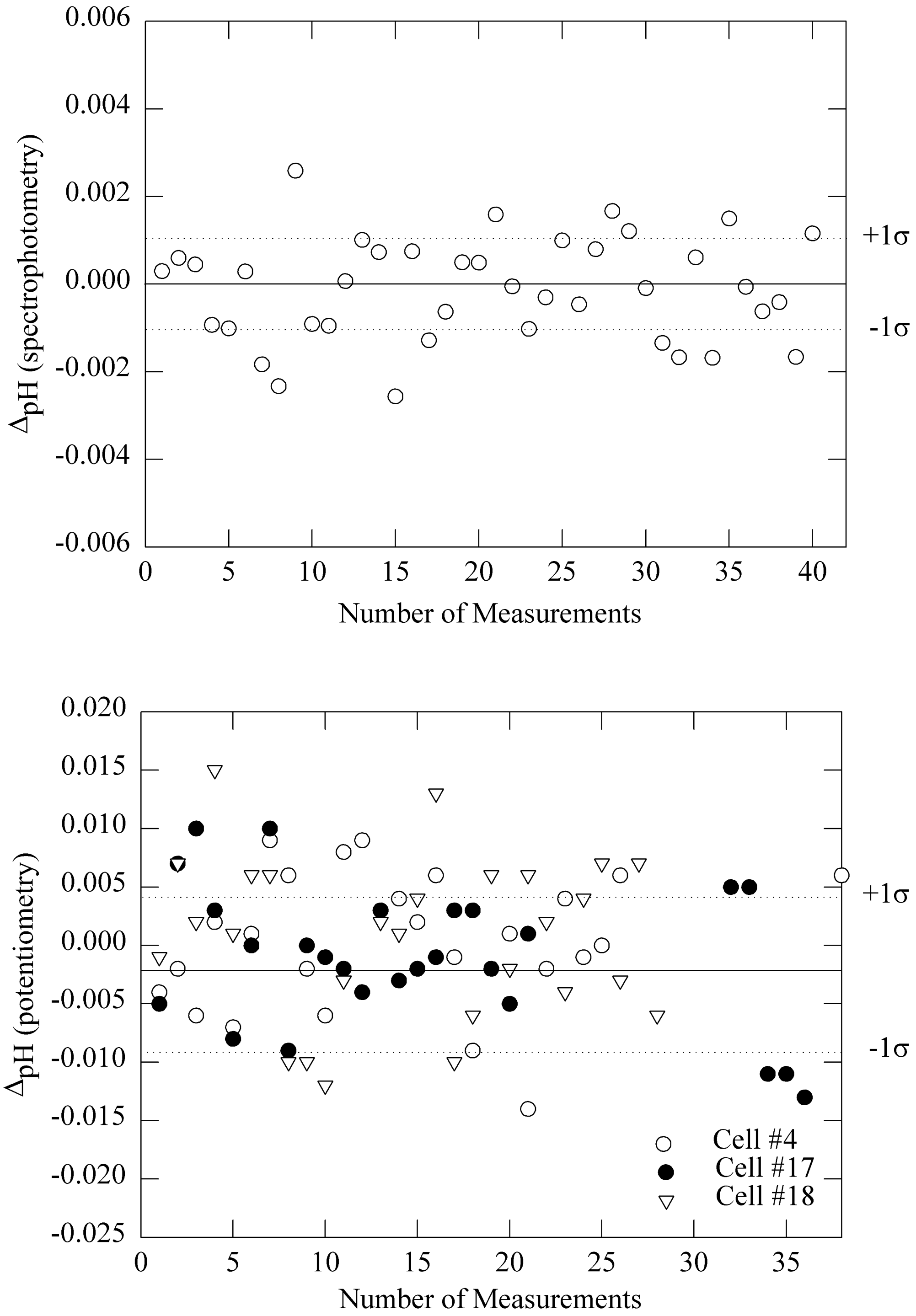

Figure 12. Spectrophotometric and potentiometric pH measurements on the Certified Reference Materials (CRMs) during the cruise.

Table 1. Station locations

Station	Cast	CTD cast	Latitude			Longitude			Date
1	2	222	36	1.40	'S	112	43.14	'E	9/23/1995
2	2	223	40	2.34	'S	109	21.2	'E	9/24/1995
3	2	224	43	0.00	'S	95	1.12	'E	9/28/1995
4	1	225	41	59.51	'S	95	1.03	'E	9/28/1995
5	1	226	40	59.95	'S	94	59.9	'E	9/28/1995
6	2	227	39	59.60	'S	95	0.91	'E	9/29/1995
7	1	228	39	0.39	'S	95	0.86	'E	9/29/1995
8	1	229	38	0.03	'S	95	0.15	'E	9/29/1995
9	2	230	36	59.95	'S	94	59.93	'E	9/30/1995
10	1	231	36	0.82	'S	95	1.24	'E	9/30/1995
11	1	232	34	59.92	'S	94	58.82	'E	9/30/1995
12	2	233	34	0.18	'S	94	58.68	'E	10/1/1995
13	1	234	33	0.41	'S	95	0.35	'E	10/1/1995
14	1	235	32	30.18	'S	94	59.81	'E	10/1/1995
15	1	236	32	0.31	'S	95	0.05	'E	10/1/1995
16	2	237	31	44.76	'S	94	59.72	'E	10/2/1995
17	1	238	31	39.14	'S	95	0.05	'E	10/2/1995
18	1	239	32	27.42	'S	92	35.84	'E	10/2/1995
19	2	240	33	10.26	'S	90	10.16	'E	10/3/1995
20	1	241	33	59.95	'S	87	46.04	'E	10/3/1995
21	2	242	34	10.06	'S	87	9.3	'E	10/4/1995
22	1	243	34	18.06	'S	86	37.55	'E	10/4/1995
23	1	244	34	27.17	'S	86	2.77	'E	10/4/1995
24	1	245	34	36.99	'S	85	28.12	'E	10/4/1995
25	1	246	34	45.71	'S	84	52.77	'E	10/4/1995
26	2	247	34	54.17	'S	84	17.42	'E	10/5/1995
27	1	248	35	3.09	'S	83	42.2	'E	10/5/1995
28	1	249	35	13.13	'S	83	8.62	'E	10/5/1995
29	1	250	35	21.56	'S	82	33.07	'E	10/5/1995
30	2	251	35	31.82	'S	81	58.18	'E	10/6/1995
31	1	252	35	27.37	'S	81	29.01	'E	10/6/1995
32	1	253	35	19.63	'S	80	49.1	'E	10/6/1995
33	1	254	35	0.13	'S	80	20.01	'E	10/6/1995
34	1	255	34	39.67	'S	79	49.6	'E	10/7/1995
35	2	256	34	20.14	'S	79	20.6	'E	10/7/1995
36	1	257	33	59.63	'S	80	0.01	'E	10/7/1995
37	1	258	33	0.01	'S	80	0.06	'E	10/7/1995
38	1	259	31	58.96	'S	80	0.29	'E	10/8/1995
39	1	260	30	59.85	'S	80	0.6	'E	10/8/1995
40	1	261	30	0.11	'S	79	59.77	'E	10/8/1995
41	1	262	28	59.94	'S	79	59.89	'E	10/9/1995
42	1	263	27	59.71	'S	80	0.22	'E	10/9/1995
43	1	264	26	59.84	'S	79	59.9	'E	10/9/1995
44	1	265	25	59.42	'S	79	59.59	'E	10/9/1995

Table 1. Station locations (continued)

Station	Cast	CTD cast	Latitude			Longitude			Date
45	2	266	25	0.38	'S	79	59.68	'E	10/10/1995
46	1	267	24	0.96	'S	79	59.13	'E	10/10/1995
47	1	268	22	59.23	'S	79	59.21	'E	10/11/1995
48	2	269	22	0.94	'S	80	0.11	'E	10/11/1995
49	1	270	20	59.48	'S	79	59.67	'E	10/11/1995
50	1	271	19	59.46	'S	80	0.53	'E	10/12/1995
51	1	272	19	0.00	'S	80	0.1	'E	10/12/1995
52	1	273	18	0.02	'S	80	0.31	'E	10/12/1995
53	2	274	16	58.85	'S	79	59.64	'E	10/13/1995
54	1	275	15	59.63	'S	80	0.01	'E	10/13/1995
55	1	276	14	59.17	'S	79	59.95	'E	10/13/1995
56	1	277	14	30.03	'S	79	59.98	'E	10/14/1995
57	2	278	13	59.58	'S	79	59.94	'E	10/14/1995
58	1	279	13	29.94	'S	80	0.01	'E	10/14/1995
59	1	280	13	0.24	'S	79	59.64	'E	10/14/1995
60	1	281	12	29.85	'S	80	0.04	'E	10/14/1995
61	2	282	11	59.60	'S	80	0.35	'E	10/15/1995
62	1	283	11	29.90	'S	79	59.75	'E	10/15/1995
63	1	284	10	59.46	'S	79	59.52	'E	10/15/1995
64	1	285	10	29.48	'S	80	0.22	'E	10/15/1995
65	2	286	9	59.46	'S	80	0.88	'E	10/16/1995
66	2	287	9	29.90	'S	80	0.29	'E	10/16/1995
67	1	288	9	0.01	'S	80	0.56	'E	10/16/1995
68	1	289	8	24.03	'S	80	0.19	'E	10/16/1995
69	2	290	7	59.88	'S	80	0.34	'E	10/17/1995
70	1	291	7	30.07	'S	79	59.72	'E	10/17/1995
71	1	292	7	0.00	'S	79	59.43	'E	10/17/1995
72	1	293	6	29.26	'S	79	59.3	'E	10/17/1995
73	1	294	5	59.72	'S	79	58.47	'E	10/18/1995
74	1	295	5	29.71	'S	79	59.1	'E	10/18/1995
75	1	296	4	59.75	'S	80	0.27	'E	10/18/1995
76	1	297	4	29.73	'S	80	0.22	'E	10/18/1995
77	1	298	3	59.39	'S	80	0.36	'E	10/19/1995
78	1	299	3	29.98	'S	80	0.35	'E	10/19/1995
79	1	300	2	59.54	'S	80	0.01	'E	10/19/1995
80	1	301	2	30.19	'S	80	0.27	'E	10/19/1995
81	1	302	2	0.34	'S	80	0.44	'E	10/20/1995
82	1	303	1	29.96	'S	80	0.4	'E	10/20/1995
83	1	304	1	0.26	'S	80	0.92	'E	10/20/1995
84	1	305	0	45.57	'N	79	59.98	'E	10/20/1995
85	1	306	0	30.35	'N	80	0.48	'E	10/20/1995
86	1	307	0	15.33	'N	80	0.35	'E	10/21/1995
87	1	308	0	0.46	'N	80	0.35	'E	10/21/1995
88	1	309	0	14.71	'N	80	0.35	'E	10/21/1995

Table 1. Station locations (continued)

Station	Cast	CTD cast	Latitude			Longitude			Date
89	1	310	0	29.77	'N	80	0.15	'E	10/21/1995
90	1	311	0	44.53	'N	80	0.06	'E	10/21/1995
91	1	312	0	59.63	'N	80	0.35	'E	10/21/1995
92	2	313	1	28.65	'N	80	0.14	'E	10/22/1995
93	1	314	1	59.79	'N	80	1.01	'E	10/22/1995
94	1	315	2	29.93	'N	79	59.81	'E	10/22/1995
95	1	316	2	59.47	'N	80	0.1	'E	10/22/1995
96	2	317	3	29.16	'N	79	59.8	'E	10/23/1995
97	1	318	3	59.35	'N	79	59.86	'E	10/23/1995
98	1	319	4	29.63	'N	80	0.09	'E	10/23/1995
99	1	320	4	59.61	'N	79	59.43	'E	10/23/1995
100	1	321	5	30.97	'N	79	59.43	'E	10/24/1995
101	2	322	5	47.22	'N	79	59.83	'E	10/24/1995

Table 2. Results of the certified reference material, CRM
(Assigned value by SIO Batch 29 = (1902.33 ± 1.06) μmol/kg
Coulometer: AOML-2

Date	Time	Julian Day	DIC (μmol/kg)
9/27/91	10:01:23	271	1902.3
9/27/91	23:15:45	271	1902.6
9/28/91	16:33:29	272	1904.5
9/28/91	19:54:06	272	1902.0
9/29/91	8:54:42	273	1900.4
9/29/91	17:47:02	273	1896.8
9/30/91	1:41:40	274	1901.4
9/30/91	12:43:34	274	1899.9
9/30/91	16:06:38	274	1898.6
10/1/91	2:12:11	275	1899.8
10/1/91	13:36:11	275	1900.3
10/3/91	1:47:30	277	1900.6
10/4/91	3:26:33	278	1900.7
10/4/91	17:42:19	278	1904.2
10/5/91	23:21:38	279	1901.0
10/6/91	15:25:35	280	1901.8
10/7/91	2:53:24	281	1901.9
10/7/91	13:40:38	281	1901.8
10/7/91	16:38:14	281	1900.3
10/8/91	9:46:52	282	1901.5
10/9/91	2:53:45	283	1902.2
10/9/91	14:28:37	283	1901.4
10/12/91	23:27:49	286	1901.0
10/13/91	15:00:19	287	1901.6
10/14/91	4:46:02	288	1901.8
10/15/91	6:58:01	289	1902.5
10/15/91	14:30:43	289	1900.7
10/15/91	19:21:40	289	1901.8
10/16/91	14:13:08	290	1903.8
10/16/91	20:12:56	290	1902.0
10/17/91	12:51:34	291	1901.4
10/17/91	20:08:23	291	1901.4
10/18/91	9:34:28	292	1902.7
10/18/91	23:16:50	292	1901.0
10/19/91	12:43:56	293	1901.4
10/20/91	4:21:52	294	1900.9
10/21/91	3:52:39	295	1901.9
10/21/91	15:55:30	295	1904.7
10/21/91	20:39:06	295	1901.2
10/22/91	11:46:41	296	1900.1
10/23/91	0:51:30	297	1903.3
10/23/91	3:07:16	297	1900.0

Table 2. Results of the certified reference material, CRM (continued)
(Assigned value by SIO Batch 29 = (1902.33 ± 1.06) µmol/kg
Coulometer: PMEL-1

Date	Time	Julian Day	DIC (µmol/kg)
9/23/91	19:00:19	267	1903.62
9/25/91	13:01:51	269	1906.10
9/26/91	13:36:04	270	1904.20
9/27/91	8:27:33	271	1905.21
9/27/91	15:09:44	271	1903.83
9/28/91	9:23:56	272	1902.15
9/28/91	15:49:32	272	1901.44
9/29/91	11:51:02	273	1904.48
9/29/91	22:39:20	273	1902.41
10/1/91	7:54:47	275	1903.49
10/2/91	8:47:21	276	1903.43
10/2/91	19:50:11	276	1903.26
10/4/91	9:37:11	278	1903.66
10/5/91	6:36:14	279	1903.43
10/5/91	21:44:11	279	1903.19
10/6/91	12:14:13	280	1903.45
10/7/91	2:26:36	281	1903.27
10/7/91	14:20:10	281	1901.78
10/7/91	17:05:47	281	1902.68
10/8/91	6:45:50	282	1902.26
10/8/91	15:22:36	282	1902.75
10/8/91	19:04:45	282	1903.36
10/9/91	10:25:59	283	1901.83
10/10/91	3:09:22	284	1900.69
10/10/91	13:05:28	284	1901.34
10/10/91	20:36:19	284	1900.30
10/11/91	13:42:00	285	1906.52
10/11/91	14:09:47	285	1900.27
10/12/91	12:07:59	286	1901.59
10/13/91	4:29:17	287	1900.68
10/13/91	16:32:57	287	1901.17
10/13/91	21:33:43	287	1901.89
10/14/91	7:11:08	288	1902.73
10/14/91	10:44:15	288	1902.46
10/15/91	4:08:42	289	1902.62
10/15/91	18:38:45	289	1903.29
10/16/91	10:13:52	290	1903.07
10/17/91	4:26:09	291	1902.68
10/18/91	5:03:11	292	1901.97
10/18/91	7:43:39	292	1901.84
10/18/91	18:49:56	292	1900.69
10/18/91	19:25:57	292	1901.62
10/19/91	4:44:58	293	1902.24
10/19/91	13:38:01	293	1903.26
10/19/91	17:00:08	293	1902.70

Table 2. Results of the certified reference material, CRM (continued)
(Assigned value by SIO Batch 29 = (1902.33 ± 1.06) µmol/kg
Coulometer: PMEL-1

Date	Time	Julian Day	DIC (µmol/kg)
10/21/91	8:17:04	295	1902.58
10/22/91	4:50:48	296	1901.58
10/23/91	3:55:10	297	1901.99
10/23/91	13:20:23	297	1901.25

Table 3. Dissolved inorganic carbon duplicates

Station#	Cast#	Bottle#	Pressure/db	DIC (µmol/kg)	Stdev	Coulometer
1	2	2	2000	2265.5	0.00	AOML2/PMEL1
2	2	1	4675	2263.9	1.88	AOML2
2	2	23	30	2087.3	1.59	AOML3
3	2	2	3200	2254.6	1.27	AOML4
3	2	22	50	2093.5	1.94	AOML5
4	1	1	3293	2258.1	0.31	PMEL1
4	1	23	50	2093.8	0.24	PMEL1
5	1	1	3487	2259.1	1.74	AOML2
5	1	22	100	2094.3	2.24	AOML2
6	2	23	50	2094.6	2.52	PMEL1
7	1	2	3400	2256.5	3.33	AOML2
7	1	23	50	2086.0	1.34	AOML2
8	1	1	4150	2268.5	0.27	PMEL1
8	1	24	8	2089.4	2.05	PMEL1
9	2	2	3900	2264.4	3.38	AOML2
9	2	9	2200	2260.4	4.71	AOML2
9	2	23	50	2081.2	3.34	AOML2
10	1	2	4000	2262.7	1.13	PMEL1
10	1	6	2500	2247.6	0.26	PMEL1
10	1	23	50	2082.0	2.52	PMEL1
11	1	1	4556	2266.2	3.10	AOML2
11	1	6	3000	2253.1	1.37	AOML2
11	1	24	10	2079.5	2.47	AOML2
12	2	2	4200	2266.4	1.66	PMEL1
12	2	15	1000	2138.6	0.24	PMEL1
13	1	2	3800	2265.2	0.04	AOML2
13	1	9	1700	2264.6	0.16	AOML2
13	1	23	50	2072.4	0.52	AOML2
14	1	24	7	2072.0	1.01	PMEL1
15	1	1	4244	2266.4	0.74	AOML2
16	2	1	3010	2256.9	1.21	PMEL1
17	1	2	1400	2257.4	1.45	AOML2
17	1	6	1000	2188.1	0.35	AOML2
17	1	22	7	2075.0	0.45	AOML2
18	1	2	4300	2267.4	2.65	AOML2
18	1	24	9	2064.1	0.83	AOML2
19	2	2	3600	2262.9	2.75	AOML2
19	2	5	2700	2251.2	2.28	AOML2
19	2	24	9	2073.9	0.65	AOML2
20	1	1	3643	2265.1	0.40	AOML2
20	1	4	2600	2250.8	1.36	AOML2
20	1	24	6	2078.1	0.30	AOML2
21	2	24	7	2076.4	0.24	PMEL1
22	1	1	3342	2260.2	0.32	AOML2
22	1	24	7	2077.5	0.01	AOML2

Table 3. Dissolved inorganic carbon duplicates (continued)

Station#	Cast#	Bottle#	Pressure/db	DIC (µmol/kg)	Stdev	Coulometer
23	1	1	3342	2262.4	0.67	PMEL1
23	1	23	40	2079.9	1.65	PMEL1
24	1	1	3541	2263.5	1.13	AOML2
24	1	10	1700	2258.8	0.11	AOML2
25	1	1	3711	2263.8	0.03	PMEL1
25	1	24	9	2080.2	1.15	PMEL1
26	2	1	3822	2264.3	1.88	AOML2
26	2	24	7	2080.2	1.77	AOML2
27	1	1	3804	2265.9	2.12	PMEL1
27	1	24	9	2078.0	2.99	PMEL1
28	1	1	3722	2262.7	0.10	AOML2
28	1	24	7	2076.4	0.95	AOML2
29	1	1	3770	2264.8	3.22	PMEL1
29	1	24	6	2075.8	0.45	PMEL1
30	2	1	4293	2262.2	0.87	AOML2
30	2	24	6	2077.5	1.12	AOML2
31	1	1	2976	2259.0	4.21	PMEL1
31	1	24	7	2077.0	2.14	PMEL1
32	1	1	2992	2252.3	3.02	PMEL1
32	1	24	7	2079.1	1.54	PMEL1
33	1	24	6	2078.2	0.36	AOML2
34	1	1	3200	2257.9	1.22	PMEL1
34	1	21	120	2081.6	2.30	PMEL1
34	1	23	40	2076.3	3.10	PMEL1
35	2	1	2973	2267.5	2.49	AOML2
35	2	24	9	2071.9	1.18	AOML2
36	1	1	3608	2255.3	3.39	AOML2
36	1	24	8	2073.1	2.75	AOML2
37	1	1	3300	2258.5	0.42	PMEL1
37	1	24	7	2071.0	0.91	PMEL1
38	2	1	3924	2265.6	0.38	AOML2
38	2	24	7	2066.4	0.55	AOML2
39	1	1	3888	2268.0	0.49	PMEL1
39	1	24	7	2063.9	2.02	PMEL1
40	1	1	3800	2268.8	2.36	AOML2
40	1	24	7	2062.7	1.42	AOML2
41	1	1	4011	2273.3	0.47	PMEL1
41	1	2	3650	2268.3	3.75	PMEL1
41	1	24	7	2056.9	0.85	PMEL1
42	1	1	4252	2275.9	0.04	AOML2
42	1	11	1250	2243.3	0.17	AOML2
42	1	24	8	2044.3	1.14	AOML2
43	1	1	4448	2277.3	1.59	PMEL1
43	1	24	7	2031.6	0.38	PMEL1
44	1	1	4336	2279.0	0.06	AOML2

Table 3. Dissolved inorganic carbon duplicates (continued)

Station#	Cast#	Bottle#	Pressure/db	DIC (µmol/kg)	Stdev	Coulometer
44	1	12	950	2183.2	0.14	AOML2
44	1	24	4	2006.1	0.36	AOML2
45	2	1	3673	2278.1	2.62	PMEL1
45	2	24	9	1993.6	1.22	PMEL1
46	1	1	4441	2288.5	0.46	AOML2
46	1	24	7	1994.3	0.42	AOML2
47	1	1	4561	2290.2	0.41	PMEL1
47	1	24	7	2003.8	0.13	PMEL1
48	2	1	4800	2294.3	0.45	AOML2
48	2	24	7	1982.5	1.75	AOML2
49	1	1	4745	2293.0	2.68	PMEL1
49	1	24	6	1967.9	0.17	PMEL1
50	1	1	4937	2295.8	1.46	AOML2
50	1	24	7	1973.1	0.83	AOML2
51	1	1	4889	2294.7	0.30	PMEL1
51	1	24	8	1950.5	0.34	PMEL1
52	1	1	5162	2292.7	0.77	PMEL1
52	1	4	3900	2290.3	3.90	PMEL1
52	1	24	7	1949.1	0.54	PMEL1
53	2	1	5204	2296.2	1.48	AOML2
53	2	24	6	1946.4	0.04	AOML2
54	1	1	5117	2298.1	0.07	PMEL1
54	1	24	9	1943.9	0.04	PMEL1
55	1	1	5053	2298.9	1.56	AOML2
55	1	24	8	1942.2	1.74	AOML2
56	1	1	3000	2290.6	0.53	PMEL1
56	1	15	50	1947.4	0.50	PMEL1
57	2	1	5032	2298.2	0.69	PMEL1
57	2	24	7	1942.3	0.10	PMEL1
58	1	1	3000	2292.9	0.16	AOML2
58	1	16	7	1952.5	0.99	AOML2
59	1	1	4949	2297.6	1.44	PMEL1
59	1	24	8	1950.7	1.14	PMEL1
60	1	1	3000	2295.6	0.85	AOML2
60	1	14	75	1998.2	0.04	AOML2
61	2	2	5163	2299.8	1.34	PMEL1
61	2	24	7	1959.2	2.01	PMEL1
62	1	1	3000	2297.1	1.66	AOML2
62	1	16	8	1949.6	0.53	AOML2
63	1	1	5411	2296.0	1.76	AOML2
64	1	1	3000	2296.4	0.20	PMEL1
64	1	16	7	1932.9	0.11	PMEL1
65	2	1	5436	2295.4	2.07	PMEL1
65	2	24	8	1924.1	1.06	PMEL1
66	1	9	3000	2301.6	1.61	AOML2

Table 3. Dissolved inorganic carbon duplicates (continued)

Station#	Cast#	Bottle#	Pressure/db	DIC (μmol/kg)	Stdev	Coulometer
66	1	24	8	1908.2	0.38	AOML2
67	1	1	5286	2299.2	1.03	AOML2
67	1	24	7	1899.9	1.66	AOML2
68	1	16	6	1902.4	1.73	PMEL1
69	2	1	5493	2294.4	2.52	PMEL1
69	2	24	7	1900.3	0.58	PMEL1
70	1	16	8	1885.1	0.03	AOML2
71	1	1	4485	2294.2	0.92	AOML2
71	1	24	6	1882.1	1.26	AOML2
72	1	1	3000	2303.9	0.18	PMEL1
72	1	15	40	1909.5	0.26	PMEL1
73	2	1	5275	2293.1	0.16	PMEL1
73	2	24	9	1882.0	0.22	PMEL1
75	1	1	5213	2294.7	1.36	AOML2
75	1	24	7	1912.3	2.57	AOML2
76	1	1	3000	2307.3	0.66	AOML2
76	1	16	8	1913.4	1.05	AOML2
77	2	1	4861	2300.4	0.81	PMEL1
77	2	24	6	1920.5	0.66	PMEL1
79	1	1	5029	2299.7	0.66	AOML2
79	1	24	6	1923.9	0.14	AOML2
80	1	1	3000	2307.4	0.05	PMEL1
80	1	16	6	1937.2	1.39	PMEL1
81	1	24	6	1928.5	0.35	PMEL1
82	1	2	2500	2308.6	2.26	AOML2
83	2	1	4740	2305.4	1.09	AOML2
83	2	24	9	1932.9	0.28	AOML2
84	1	11	250	2201.6	0.99	PMEL1
85	1	1	4773	2305.2	3.35	PMEL1
85	1	24	6	1931.9	1.77	PMEL1
86	1	1	3000	2312.8	2.46	PMEL1
86	1	16	6	1944.9	0.21	PMEL1
87	2	1	4739	2304.5	0.35	AOML2
87	2	24	8	1946.2	1.13	AOML2
88	1	11	250	2203.5	0.48	PMEL1
89	1	1	4714	2305.2	0.55	PMEL1
90	1	1	3000	2314.4	0.82	PMEL1
90	1	16	6	1937.1	0.08	PMEL1
91	1	1	4691	2305.4	3.17	AOML2
91	1	24	7	1945.7	1.17	AOML2
92	2	1	3000	2314.8	0.00	PMEL1
93	1	24	7	1942.5	1.97	PMEL1
94	1	1	3160	2320.7	1.55	AOML2
96	2	11	350	2233.8	0.30	PMEL1
96	2	16	9	1949.3	0.51	PMEL1

Table 3. Dissolved inorganic carbon duplicates (continued)

Station#	Cast#	Bottle#	Pressure/db	DIC (μmol/kg)	Stdev	Coulometer
97	1	1	4402	2311.4	1.60	PMEL1
97	1	24	7	1947.9	1.35	PMEL1
98	1	1	3000	2327.6	1.50	AOML2
99	1	1	4210	2310.5	1.32	AOML2
99	1	24	7	1928.8	1.34	AOML2
100	1	17	400	2260.7	0.92	PMEL1

Table 4. Replicate dissolved CFC-11 Analyses

Station	Cast	Bottle	CFC-11 pmol/kg	CFC-11 Stdev
2	2	18	3.632	0.004
2	2	24	3.661	0.060
3	2	17	2.952	0.043
4	1	12	1.431	0.004
5	1	15	2.837	0.006
6	2	24	3.506	0.001
7	1	7	0.029	0.005
7	1	14	2.460	0.062
9	2	10	0.008	0.002
9	2	24	3.264	0.005
10	1	10	0.020	0.005
11	1	14	0.842	0.026
11	1	20	3.358	0.020
12	2	8	0.003	0.002
12	2	16	2.830	0.016
13	1	6	0.003	0.001
13	1	22	3.131	0.004
14	1	18	3.180	0.052
14	1	21	3.091	0.015
15	1	16	3.042	0.017
17	1	11	2.386	0.005
17	1	21	3.019	0.019
18	1	1	0.008	0.002
18	1	24	2.728	0.024
19	2	14	2.129	0.010
19	2	21	2.942	0.019
20	1	11	0.192	0.021
21	2	11	0.751	0.000
23	1	11	0.331	0.001
24	1	11	0.185	0.004
26	2	14	1.564	0.014
28	1	11	0.913	0.003
28	1	14	2.986	0.004
30	2	11	0.198	0.001
30	2	21	3.192	0.029
32	1	6	0.037	0.000
34	1	11	0.772	0.004
34	1	23	3.074	0.034
36	1	7	0.030	0.002
37	1	10	0.379	0.004
38	2	10	0.079	0.001
38	2	22	3.031	0.003
39	1	11	0.432	0.008
40	1	8	0.008	0.003
41	1	20	2.838	0.021
42	1	21	2.901	0.013
43	1	13	0.956	0.003

Table 4. Replicate dissolved CFC-11 Analyses
(continued)

Station	Niskin Bottle		CFC-11 pmol/kg	CFC-11 Stdev
44	1	21	2.316	0.024
45	2	14	1.553	0.008
46	1	7	0.000	0.000
47	1	14	0.017	0.002
48	2	16	2.713	0.014
49	1	14	0.071	0.000
50	1	17	0.319	0.004
51	1	18	2.758	0.002
52	1	12	0.000	0.000
53	2	18	2.238	0.011
54	1	15	0.159	0.002
55	1	20	1.899	0.035
57	2	14	0.026	0.002
59	1	20	1.333	0.000
61	2	18	0.754	0.011
63	1	19	0.794	0.000
65	2	18	0.885	0.002
67	1	14	0.012	0.001
69	2	17	0.484	0.003
71	1	18	0.319	0.007
73	2	18	0.191	0.003
75	1	20	0.778	0.004
79	1	22	1.626	0.007
81	1	20	0.884	0.000
83	2	18	0.446	0.003
85	1	21	1.596	0.004
87	2	17	0.643	0.006
89	1	16	0.126	0.004
91	1	15	0.056	0.002
93	1	17	0.213	0.000
95	1	18	0.474	0.001
97	1	18	0.130	0.002
99	1	16	0.040	0.002

Table 5. Replicate dissolved CFC-12 Analyses

Station	Cast	Bottle	CFC-12 pmol/kg	CFC-12 Stdev
2	2	18	1.854	0.007
2	2	24	1.855	0.019
3	2	17	1.456	0.012
4	1	12	0.654	0.002
5	1	15	1.371	0.001
6	2	24	1.770	0.001
7	1	7	0.006	0.001
7	1	14	1.158	0.024
9	2	10	-0.001	0.002
10	1	10	0.004	0.002
11	1	14	0.394	0.015
11	1	20	1.706	0.002
12	2	8	-0.002	0.000
12	2	16	1.367	0.006
13	1	6	-0.001	0.000
13	1	22	1.659	0.010
14	1	18	1.596	0.009
14	1	21	1.620	0.033
15	1	16	1.502	0.005
17	1	21	1.603	0.017
18	1	1	0.004	0.001
18	1	24	1.485	0.031
19	2	14	1.041	0.009
19	2	21	1.561	0.004
20	1	11	0.098	0.010
21	2	11	0.376	0.002
23	1	11	0.169	0.001
24	1	11	0.096	0.003
26	2	14	0.765	0.011
28	1	11	0.436	0.005
28	1	14	1.505	0.027
30	2	2	0.001	0.000
30	2	11	0.093	0.005
30	2	21	1.703	0.004
30	2	23	1.700	0.002
32	1	6	0.018	0.000
34	1	11	0.380	0.002
34	1	23	1.638	0.017
36	1	7	0.017	0.002
37	1	10	0.187	0.002
38	2	10	0.041	0.001
38	2	22	1.628	0.003
39	1	11	0.219	0.004
40	1	8	0.004	0.003
41	1	20	1.520	0.002
42	1	21	1.538	0.003
43	1	13	0.497	0.001

Table 5. Replicate dissolved CFC-12 Analyses (continued)

Station	Niskin Bottle		CFC-12 pmol/kg	CFC-12 Stdev
44	1	21	1.287	0.015
45	2	14	0.780	0.005
46	1	7	0.000	0.000
47	1	14	0.009	0.001
48	2	16	1.360	0.017
49	1	14	0.044	0.001
50	1	17	0.178	0.006
51	1	18	1.399	0.000
52	1	12	0.001	0.001
53	2	18	1.196	0.002
54	1	15	0.094	0.002
55	1	20	1.086	0.029
57	2	14	0.017	0.002
59	1	20	0.720	0.005
61	2	18	0.389	0.010
63	1	19	0.435	0.003
65	2	18	0.458	0.002
67	1	14	0.006	0.002
69	2	17	0.260	0.003
71	1	18	0.175	0.001
73	2	18	0.111	0.001
75	1	20	0.425	0.002
79	1	22	0.926	0.005
81	1	20	0.495	0.007
83	2	18	0.257	0.003
85	1	21	0.934	0.002
87	2	17	0.363	0.000
89	1	16	0.074	0.002
91	1	15	0.038	0.003
93	1	17	0.128	0.001
95	1	18	0.272	0.002
97	1	18	0.080	0.000
99	1	16	0.025	0.003

Table 6. CFC Air Measurements
(Local time = GMT + 5 h)

Date	GMT (hhmm)	Latitude	Longitude	CFC-11 ppt	CFC-12 ppt
24-Sep-95	947	40 01.5 S	109 58.7 E	259.6	522.4
24-Sep-95	959	40 01.5 S	109 58.7 E	260.4	520.8
24-Sep-95	1011	40 01.5 S	109 58.7 E	260.0	523.4
24-Sep-95	1023	40 01.5 S	109 58.7 E	261.5	524.2
25-Sep-95	1125	40 41.5 S	107 10.6 E	261.5	516.5
25-Sep-95	1137	40 41.5 S	107 10.6 E	261.5	518.7
26-Sep-95	422	41 16.8 S	103 48.6 E	259.7	519.5
26-Sep-95	434	41 16.8 S	103 48.6 E	261.0	516.7
26-Sep-95	446	41 16.8 S	103 48.6 E	260.7	516.3
26-Sep-95	458	41 16.8 S	103 48.6 E	261.7	514.0
27-Sep-95	935	42 39.4 S	096 46.1 E	260.2	522.5
27-Sep-95	947	42 39.4 S	096 46.1 E	260.6	521.7
27-Sep-95	959	42 39.4 S	096 46.1 E	260.7	522.9
27-Sep-95	1011	42 39.4 S	096 46.1 E	260.1	521.4
28-Sep-95	713	43 00.0 S	095 00.0 E	261.6	520.6
28-Sep-95	725	43 00.0 S	095 00.0 E	260.8	520.5
28-Sep-95	737	43 00.0 S	095 00.0 E	262.1	521.0
28-Sep-95	749	43 00.0 S	095 00.0 E	260.9	519.8
1-Oct-95	800	34 00.0 S	095 00.0 E	261.5	516.8
1-Oct-95	812	34 00.0 S	095 00.0 E	261.1	520.5
1-Oct-95	824	34 00.0 S	095 00.0 E	261.2	522.1
1-Oct-95	836	34 00.0 S	095 00.0 E	260.7	519.2
3-Oct-95	855	33 10.5 S	090 10.5 E	260.8	505.3
3-Oct-95	908	33 10.5 S	090 10.5 E	260.8	512.6
3-Oct-95	921	33 10.5 S	090 10.5 E	261.0	510.2
3-Oct-95	934	33 10.5 S	090 10.5 E	261.0	505.3
6-Oct-95	1711	35 19.3 S	080 49.5 E	263.2	523.7
6-Oct-95	1724	35 19.3 S	080 49.5 E	263.8	526.0
6-Oct-95	1737	35 19.3 S	080 49.5 E	262.3	521.1
6-Oct-95	1750	35 19.3 S	080 49.5 E	-9.0	-9.0
8-Oct-95	443	32 00.0 S	080 00.0 E	260.3	517.7
8-Oct-95	456	32 00.0 S	080 00.0 E	261.0	518.5
8-Oct-95	509	32 00.0 S	080 00.0 E	260.9	520.4
8-Oct-95	522	32 00.0 S	080 00.0 E	261.1	521.8
10-Oct-95	1033	25 00.0 S	080 00.0 E	261.5	522.9
10-Oct-95	1045	25 00.0 S	080 00.0 E	262.0	522.0
10-Oct-95	1056	25 00.0 S	080 00.0 E	261.5	522.4
10-Oct-95	1108	25 00.0 S	080 00.0 E	261.5	521.6
13-Oct-95	2254	15 00.0 S	080 00.0 E	261.0	524.9
13-Oct-95	2306	15 00.0 S	080 00.0 E	262.2	522.5
13-Oct-95	2318	15 00.0 S	080 00.0 E	261.2	521.5
13-Oct-95	2330	15 00.0 S	080 00.0 E	261.7	531.4
15-Oct-95	1837	11 30.0 S	080 00.0 E	261.6	525.7
15-Oct-95	1849	11 30.0 S	080 00.0 E	261.3	522.1
15-Oct-95	1901	11 30.0 S	080 00.0 E	261.4	522.7

Table 6. CFC Air Measurements (continued)
(Local time = GMT + 5 h)

Date	GMT (hhmm)	Latitude	Longitude	CFC-11 ppt	CFC-12 ppt
15-Oct-95	1912	11 30.0 S	080 00.0 E	261.5	523.2
16-Oct-95	1936	09 30.0 S	080 00.0 E	262.8	523.3
16-Oct-95	1948	09 30.0 S	080 00.0 E	263.0	521.5
16-Oct-95	1959	09 30.0 S	080 00.0 E	261.6	522.6
16-Oct-95	2011	09 30.0 S	080 00.0 E	261.7	520.2
19-Oct-95	613	04 00.0 S	080 00.0 E	262.3	519.8
19-Oct-95	625	04 00.0 S	080 00.0 E	261.9	520.9
19-Oct-95	636	04 00.0 S	080 00.0 E	261.1	527.0
19-Oct-95	648	04 00.0 S	080 00.0 E	262.3	520.4
23-Oct-95	809	04 00.0 N	080 00.0 E	263.5	519.7
23-Oct-95	820	04 00.0 N	080 00.0 E	263.0	522.6
23-Oct-95	832	04 00.0 N	080 00.0 E	262.4	521.1
23-Oct-95	844	04 00.0 N	080 00.0 E	262.1	525.9

Table 7. CFC Air values (interpolated to station locations)
(Local time = GMT + 5 h)

Station	GMT (hhmm)	Latitude	Longitude	CFC-11 ppt	CFC-12 ppt
2	40 02.2 S	109 58.6 E	24-Sep-95	260.8	521.0
3	42 59.7 S	095 00.4 E	28-Sep-95	260.9	521.3
4	41 59.6 S	095 00.9 E	28-Sep-95	260.9	521.3
5	40 59.8 S	095 00.0 E	28-Sep-95	260.9	521.3
6	39 59.7 S	095 00.7 E	29-Sep-95	260.9	521.3
7	39 00.1 S	095 00.0 E	29-Sep-95	260.9	521.3
8	38 00.1 S	095 00.0 E	29-Sep-95	261.0	520.8
9	37 00.0 S	094 59.6 E	30-Sep-95	261.0	517.6
10	36 00.9 S	095 01.2 E	30-Sep-95	261.0	514.0
11	34 60.0 S	094 58.7 E	30-Sep-95	261.0	514.0
12	34 00.2 S	094 58.6 E	1-Oct-95	261.0	514.0
13	33 00.5 S	095 00.3 E	1-Oct-95	261.0	514.0
14	32 30.2 S	094 59.7 E	1-Oct-95	261.0	514.0
15	32 00.4 S	094 60.0 E	1-Oct-95	261.0	514.0
16	31 44.7 S	094 59.8 E	2-Oct-95	261.0	514.0
17	31 39.1 S	095 00.0 E	2-Oct-95	261.0	514.0
18	32 27.4 S	092 35.9 E	2-Oct-95	261.0	514.0
19	33 10.3 S	090 10.1 E	3-Oct-95	261.0	514.0
20	33 59.9 S	087 46.0 E	3-Oct-95	261.6	516.6
21	34 10.2 S	087 09.3 E	4-Oct-95	261.9	514.9
22	34 17.9 S	086 37.5 E	4-Oct-95	261.9	514.9
23	34 27.2 S	086 02.8 E	4-Oct-95	261.9	514.9
24	34 37.0 S	085 28.1 E	4-Oct-95	261.9	514.9
25	34 45.7 S	084 52.7 E	5-Oct-95	261.5	516.6
26	34 54.2 S	084 17.4 E	5-Oct-95	261.8	521.3
27	35 03.1 S	083 43.0 E	5-Oct-95	261.8	521.3
28	35 13.1 S	083 08.6 E	5-Oct-95	261.8	521.3
29	35 21.6 S	082 33.1 E	5-Oct-95	261.8	521.3
30	35 31.8 S	081 58.2 E	6-Oct-95	261.8	521.3
31	35 27.4 S	081 29.0 E	6-Oct-95	261.8	521.3
32	35 19.6 S	080 49.1 E	6-Oct-95	261.8	521.3
33	35 00.1 S	080 19.5 E	8-Oct-95	261.8	521.3
34	34 39.7 S	079 49.2 E	7-Oct-95	261.8	521.3
35	34 20.2 S	079 20.6 E	7-Oct-95	261.8	521.3
36	33 59.6 S	080 00.5 E	7-Oct-95	261.8	521.3
37	33 00.0 S	080 00.1 E	7-Oct-95	261.8	521.3
38	31 59.0 S	080 00.3 E	8-Oct-95	261.8	521.3
39	30 59.9 S	080 00.6 E	8-Oct-95	261.8	521.3
40	30 00.1 S	079 59.8 E	8-Oct-95	261.7	521.7
41	28 60.0 S	079 59.9 E	9-Oct-95	261.2	520.9
42	27 59.7 S	080 00.2 E	9-Oct-95	261.2	520.9
43	26 59.8 S	079 59.9 E	9-Oct-95	261.2	520.9
44	25 59.4 S	079 59.6 E	9-Oct-95	261.2	520.9
45	25 00.4 S	079 59.7 E	10-Oct-95	261.2	520.9
46	24 00.9 S	079 59.1 E	10-Oct-95	261.2	520.9

Table 7. CFC Air values (interpolated to station locations, continued)
(Local time = GMT + 5 h)

Station	GMT (hhmm)	Latitude	Longitude	CFC-11 ppt	CFC-12 ppt
47	22 59.2 S	079 59.2 E	11-Oct-95	261.6	523.6
48	22 00.9 S	080 00.1 E	11-Oct-95	261.6	523.6
49	20 59.8 S	079 59.3 E	11-Oct-95	261.6	523.6
50	19 59.5 S	080 00.5 E	12-Oct-95	261.6	523.6
51	18 59.4 S	080 00.1 E	12-Oct-95	261.6	523.6
52	18 00.0 S	080 00.3 E	12-Oct-95	261.5	523.6
53	16 58.9 S	079 59.6 E	13-Oct-95	261.5	524.3
54	15 59.6 S	080 00.0 E	13-Oct-95	261.5	524.3
55	14 59.5 S	079 60.0 E	13-Oct-95	261.5	524.3
56	14 29.9 S	079 60.0 E	14-Oct-95	261.5	524.3
57	13 59.9 S	079 59.9 E	14-Oct-95	261.5	524.3
58	13 30.1 S	079 60.0 E	14-Oct-95	261.5	524.3
59	13 00.7 S	079 59.6 E	14-Oct-95	261.5	524.3
60	12 29.8 S	080 00.0 E	14-Oct-95	261.8	523.5
61	11 59.6 S	080 00.1 E	15-Oct-95	261.9	522.7
62	11 29.9 S	079 59.8 E	15-Oct-95	261.9	522.7
63	10 59.4 S	079 59.5 E	15-Oct-95	261.9	522.7
64	10 29.5 S	080 00.2 E	15-Oct-95	261.9	522.7
65	09 59.4 S	080 00.9 E	16-Oct-95	261.9	522.7
66	09 29.9 S	080 00.3 E	16-Oct-95	261.9	522.7
67	08 60.0 S	080 00.6 E	16-Oct-95	261.9	522.7
68	08 29.7 S	080 00.2 E	16-Oct-95	261.9	522.7
69	07 59.9 S	080 00.3 E	17-Oct-95	261.9	522.5
70	07 30.1 S	079 59.7 E	17-Oct-95	261.9	522.5
71	07 00.0 S	079 59.4 E	17-Oct-95	262.1	522.0
72	06 29.9 S	079 59.3 E	17-Oct-95	262.1	522.0
73	05 59.7 S	079 58.4 E	18-Oct-95	262.1	522.0
74	05 30.0 S	079 59.1 E	18-Oct-95	262.1	522.0
75	04 59.8 S	080 00.3 E	18-Oct-95	262.1	522.0
76	04 29.7 S	080 00.2 E	18-Oct-95	262.1	522.0
77	03 59.5 S	080 00.2 E	19-Oct-95	262.1	522.0
78	03 29.9 S	080 00.4 E	19-Oct-95	262.1	522.0
79	02 59.5 S	080 00.0 E	19-Oct-95	262.3	522.1
80	02 30.2 S	080 00.3 E	19-Oct-95	262.3	522.1
81	02 00.3 S	080 00.4 E	20-Oct-95	262.3	522.2
82	01 30.0 S	080 00.4 E	20-Oct-95	262.3	522.2
83	01 00.3 S	080 00.9 E	20-Oct-95	262.3	522.2
84	00 45.6 S	079 60.0 E	20-Oct-95	262.3	522.2
85	00 30.4 S	080 00.4 E	20-Oct-95	262.3	522.2
86	00 15.3 S	080 00.4 E	21-Oct-95	262.3	522.2
87	00 00.4 S	080 01.3 E	21-Oct-95	262.3	522.2
88	00 14.7 N	080 00.4 E	21-Oct-95	262.3	522.2
89	00 29.7 N	080 00.2 E	21-Oct-95	262.3	522.2
90	00 44.5 N	080 00.1 E	21-Oct-95	262.3	522.2
91	00 59.6 N	080 00.3 E	21-Oct-95	262.3	522.2

Table 7. CFC Air values (interpolated to station locations, continued)
(Local time = GMT + 5)

Station	GMT (hhmm)	Latitude	Longitude	CFC-11 ppt	CFC-12 ppt
92	01 28.6 N	080 00.2 E	22-Oct-95	262.3	522.2
93	01 59.8 N	080 00.0 E	22-Oct-95	262.3	522.2
94	02 29.9 N	079 59.8 E	22-Oct-95	262.3	522.2
95	02 59.5 N	080 00.1 E	22-Oct-95	262.3	522.2
96	03 29.2 N	079 59.8 E	23-Oct-95	262.3	522.2
97	03 60.0 N	079 59.9 E	23-Oct-95	262.3	522.2
98	04 29.6 N	080 00.1 E	23-Oct-95	262.3	522.2
99	04 59.6 N	079 59.4 E	23-Oct-95	262.3	522.2
100	05 31.0 N	079 59.4 E	24-Oct-95	262.3	522.2
101	05 47.2 N	079 59.8 E	24-Oct-95	262.3	522.2