

NOAA Data Report ERL AOML-30



**MEASUREMENTS OF UNDERWAY fCO_2 IN THE EASTERN EQUATORIAL PACIFIC
ON NOAA SHIPS *MALCOLM BALDRIGE* AND *DISCOVERER* FROM FEBRUARY TO
SEPTEMBER, 1994**

D.T. Ho
R. Wanninkhof
J. Masters
R.A. Feely
C.E. Cosca

Atlantic Oceanographic and Meteorological Laboratory
Miami, Florida
April 1997

noaa NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION

Environmental Research
Laboratories

NOAA Data Report ERL AOML-30

**MEASUREMENTS OF UNDERWAY fCO_2 IN THE EASTERN EQUATORIAL PACIFIC
ON NOAA SHIPS *MALCOLM BALDRIGE* AND *DISCOVERER* FROM FEBRUARY TO
SEPTEMBER, 1994**

David T. Ho
Rik Wanninkhof
Jason Masters

Ocean Chemistry Division
Atlantic Oceanographic and Meteorological Laboratory

Richard A. Feely
Cathy E. Cosca

Ocean Climate Research Division
Pacific Marine Environmental Laboratory

Atlantic Oceanographic and Meteorological Laboratory
Miami, Florida
April 1997



**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**

REMOTE ACCESS TO DATA LISTED IN THIS REPORT

The data described can be obtained via anonymous FTP from:

<<ftp://ftp.aoml.noaa.gov/pub/ocd/carbon/uweqpac94>>

or via the World Wide Web:

<<http://www.aoml.noaa.gov/ocd/oaces/>>

NOTICE

Mention of a commercial company or product does not constitute an endorsement by NOAA/ERL. Use of information from this publication concerning proprietary products or the tests of such products for publicity or advertising purposes is not authorized.

CONTENTS

ABSTRACT	1
1. INTRODUCTION	1
2. UNDERWAY fCO ₂ SYSTEM DESCRIPTIONS	2
2.1. Underway fCO ₂ System Version 1.0 Description	3
2.2. Underway fCO ₂ System Version 1.5 Description	3
2.2.1. Overview	3
2.2.2. Standard Gas Standardization/Conversion Polynomial	4
2.2.3. Sampling/Data Set	4
2.2.4. Screen Display	9
3. DATA REDUCTION	9
4. CALCULATIONS	10
5. ESTIMATES OF PRECISION	11
6. EXPLANATION OF COLUMNS IN THE DATA SET	19
7. SUPPORT MEASUREMENTS	20
7.1. DIC Determination	20
7.2. Oxygen Measurements	20
7.3. Nutrient Analysis Methods	26
7.3.1. Nitrate and Nitrite	26
7.3.2. Silicates	26
7.4. Chlorophyll Extraction and Analysis	26
8. NOAA SHIP DISCOVERER CRUISES	26
ACKNOWLEDGMENTS	27
REFERENCES	28
APPENDIX A: BASIC PROGRAM	31
APPENDIX B: EXAMPLE OF UNDERWAY DATA	40
APPENDIX C: PLOTS OF fCO _{2a} , fCO _{2w} , SST AND SAL VS. LATITUDE	41

MEASUREMENTS OF UNDERWAY $f\text{CO}_2$ IN THE EASTERN EQUATORIAL PACIFIC ON NOAA SHIPS MALCOLM BALDRIGE AND DISCOVERER FROM FEBRUARY TO SEPTEMBER, 1994

David T. Ho, Rik Wanninkhof, Jason Masters, Richard A. Feely, Cathy E. Cosca

ABSTRACT. From February through September, 1994 underway measurements of the fugacity (partial pressure) of carbon dioxide ($f\text{CO}_2$) were performed in the Eastern Equatorial Pacific as part of the Ocean Atmosphere Carbon Exchange Study (OACES) of the National Oceanographic and Atmospheric Administration (NOAA). The measurements were performed with semi-autonomous instruments which measured the fugacity in the air and in the headspace of an equilibrator drawing water from the bow of the ship, from which the $f\text{CO}_2$ of the surface water is calculated. From the difference in fugacity in air and water, the CO_2 flux from the Equatorial Pacific can be estimated. On the NOAA ship MALCOLM BALDRIGE the system measured three reference standards, three air values, and eight water values per hour. The system on the DISCOVERER measured three standards, one 19-minute average air sample and one 20-minute average water sample per hour. This report contains a description of the methodology and reduction of the $f\text{CO}_2$ and ancillary measurements. The results from the cruises of the MALCOLM BALDRIGE in the Equatorial Pacific in the (boreal) spring and fall of 1994, and from the DISCOVERER along nominally 110°W in the spring of 1994 are shown in a series of graphs with $f\text{CO}_2$ air and water versus latitude as top panel and temperature and salinity versus latitude as bottom panel. The full data sets and support measurements can be obtained either via anonymous FTP from: <ftp://ftp.aoml.noaa.gov/pub/ocd/carbon/uweqpac94> or via the World Wide Web: <http://www.aoml.noaa.gov/ocd/oaces/>.

1. INTRODUCTION

The underway component of the Ocean-Atmosphere Carbon Exchange Study (OACES) of NOAA's Climate and Global Change (C&GC) program performs surface water measurements to determine the oceanic source and sink regions for atmospheric CO_2 . The results are used to map air-water concentration differences to provide an estimate of the magnitude of the air-water CO_2 flux. Quasi-continuous measurements of the fugacity of CO_2 in air and surface water using an infrared analyzer have been performed on NOAA ships MALCOLM BALDRIGE and DISCOVERER from 1991 through 1996. The ships have performed yearly cruises to the Eastern Equatorial Pacific in support of the TOGA/TAO mooring array. This cruise schedule has facilitated a bi-annual record of CO_2 observations in this region. In addition to the Equatorial cruises, these ships have been used for the NOAA OACES/TRACERS long lines work with meridional sections in the Atlantic, Pacific and Indian Oceans. In this report we present the Equatorial observations and a long lines cruise along nominally 107°W from 67°S to 20°N for 1994.

The Equatorial Pacific is the largest natural CO_2 source to the atmosphere. It has become increasingly apparent from historical and from current measurements that the CO_2 source is also highly variable (Keeling, 1965; Feely et al., 1987; Feely et al., 1994; Feely et al., 1995a; Wanninkhof et al., 1996). As pointed out by Feely et al. (1995b) El Niño conditions cause depressed $f\text{CO}_2$ values in the mixed layer. Decreased upwelling during El Niño periods causes less water containing high dissolved inorganic carbon concentrations to reach the surface and

lowers the surface $f\text{CO}_2$ levels. The latest El Niño conditions started in 1991/92. The coverage of $f\text{CO}_2$ on the NOAA Ships MALCOLM BALDRIGE, and DISCOVERER, and now the KA'IMIMOANA in the Equatorial Pacific has offered the opportunity to determine the evolution of the surface water $f\text{CO}_2$ signal with unsurpassed resolution.

Previous results, as discussed in Dandonneau (1995) and Wanninkhof et al. (1995), show that the surface water $f\text{CO}_2$ are influenced by the rate of upwelling, with decreased upwelling causing lower $f\text{CO}_2$ levels. Recent work suggests that sea surface temperature is an important parameter determining $f\text{CO}_2$, as $f\text{CO}_2$ increases by about $4.2\% / ^\circ\text{C}$ (Takahashi et al., 1993) by a combination of decrease in solubility and repartitioning of the inorganic carbon pools favoring gaseous CO_2 at higher temperatures. For the Equatorial Pacific at the equator an opposite effect is observed with high $f\text{CO}_2$ corresponding with lower temperatures. This is caused by upwelling water containing high levels of dissolved inorganic carbon (DIC). The $f\text{CO}_2$ values in the Equatorial Pacific are thus controlled by a complex interplay of upwelling, mixing, biological drawdown, and water temperature. This can be illustrated with a simple example. A water parcel which rises to the surface the water will be cold, and contain high DIC and nutrients due to remineralization of organic tissue at depth. It thus reaches the surface with high $f\text{CO}_2$. Two competing processes takes place in the euphotic zone. Warming of the water will increase the $f\text{CO}_2$ while biological drawdown will decrease the $f\text{CO}_2$ level. Since the response time of heating is generally shorter than biological productivity, the initial effect will be further increases in $f\text{CO}_2$ which will be counteracted in time by net biological productivity. The strong zonal current structures, which are influenced by El Niño as well, will cause the upwelled water to move on the order of $1\text{ m}\cdot\text{s}^{-1}$ (or about 30 degrees longitude per month). Thus significant displacements of the water over time take place while the biological and physical processes influence $f\text{CO}_2$ in the water parcel. The large variability in physical, biological, and chemical processes which take place thus cause large interannual variability in $f\text{CO}_2$ levels in the Equatorial Pacific. The biannual coverage of the Equatorial Pacific region has enabled us to start quantifying and parameterizing the processes involved in controlling $f\text{CO}_2$.

The South Pacific cruise is part of the NOAA OACES/TRACERS long lines effort and was designated as a World Ocean Circulation Experiment/World Hydrographic Program, WOCE/WHP line (P18). The cruise transected the Equatorial region along $103/110^\circ\text{W}$ thereby giving additional coverage in the Eastern Equatorial Pacific during the (boreal) spring of 1994. The data from the cruise also confirmed the large Southeastern Pacific $f\text{CO}_2$ source region from 40°S to 20°S first observed in Murphy et al. (1991). This appears to be a robust feature and is unique to the Southeastern Pacific. The subtropical gyres in the Indian, Southwestern Pacific, and Atlantic Ocean are predominantly sink regions.

This data report presents the measurements from the MALCOLM BALDRIGE during the boreal spring and fall of 1994, and measurements taken on the DISCOVERER along $103/110^\circ\text{W}$ from 65°S to 20°N as part of the Climate and Global Change 1994 (CGC94) World Ocean Circulation Experiment (WOCE) P-18 cruise during March/April 1994. The cruise track in the spring included transects along 95°W between 5°N and 5°S , 110°W between 5°N and 8°S , 125°W between 8°N and 8°S , and 140°W between 9°N and 9°S . In the fall, coverage included transects from 8°N to 8°S along 95°W , 110°W , and 125°W . The DISCOVERER Cruise included a deadhead from San Francisco to Punta Arenas, and return along $103/110^\circ\text{W}$ (see Fig. 1).

2. UNDERWAY $f\text{CO}_2$ SYSTEM DESCRIPTIONS

Two slightly different underway $f\text{CO}_2$ measurement systems were used on the DISCOVERER and MALCOLM BALDRIGE. They are referred to as systems 1.0 and 1.5,

respectively. System 1.0 has been described in detail in Wanninkhof and Thoning (1993) and will only be briefly discussed here. System 1.5, which was a modification from the system 1.0 based on three years experience with the original system, was used for the first time during 1994 and will be discussed in greater detail below.

2.1. Underway $f\text{CO}_2$ System Version 1.0 Description

System 1.0 was built at NOAA/Climate Monitoring and Diagnostics Laboratory using a LI-COR Non-Dispersive Infrared (NDIR) analyzer (LI-COR model LI-6251, Lincoln, NE) (LI-COR, 1990) and is described in Wanninkhof and Thoning (1993). The system runs on hourly cycle in which the first 15 minutes are dedicated to analyzing compressed gas standards, the next 22 minutes are used to measure air, and an equilibrator headspace is measured for the last 23 minutes. Compressed gas standards bracket the air and water values. The air sample is drawn through multilaminate tubing (Dekoron, Furon, Aurora, OH) from the bow of the ship to the laboratory (OCEA lab). The headspace of a shower equilibrator is measured to determine the $f\text{CO}_2$ in the surface water. Water is drawn from the bow pump, through 2" PVC tubing to the OCEA lab where it enters the equilibrator. The droplets and severe turbulence in the equilibrator cause the gases in the water to equilibrate with the gases in the semi-closed headspace such that the $f\text{CO}_2$ in the headspace will be the same as the water. Based on our results in the South Atlantic, we believe we can routinely obtain air values with a precision of $0.3 \mu\text{atm}$ and water values with a precision of $2 \mu\text{atm}$.

2.2. Underway $f\text{CO}_2$ System Version 1.5 Description

2.2.1. Overview

For the MALCOLM BALDRIGE Equatorial Pacific cruises the underway $f\text{CO}_2$ system was slightly modified from system version 1.0 described above. The modified system is referred to as system 1.5. This system was used to determine the $f\text{CO}_2$ of surface water and overlaying air on a quasi-continuous basis. When in operation, seawater is drawn at a rate of $15 \text{ l}\cdot\text{min}^{-1}$ from the uncontaminated seawater intake on the ship's bow bubble at 5 m below the sea surface to a 24 l shower head equilibrator, where the 16 l headspace reaches equilibrium with seawater on a short time scale (Fig. 2). At specific times during an hourly cycle, the content of the headspace is measured by the LI-COR infrared CO_2 analyzer. Air from the marine boundary layer is drawn continuously from the bow mast to the underway $f\text{CO}_2$ system through Dekoron tubing at a rate of $6 \text{ l}\cdot\text{min}^{-1}$ and vented into the laboratory. At designated times, $100 \text{ ml}\cdot\text{min}^{-1}$ of air is teed off into the LI-COR infrared CO_2 analyzer.

The CO_2 measurement are made by a LI-COR model LI-6251 NDIR CO_2 analyzer (LI-COR, 1990), which is based on the difference in absorption of $4.26 \mu\text{m}$ (IR) radiation passing through two gas sampling cells. The lowest of the three reference gas standards is continuously flowed through the reference cell at a rate of $15 \text{ ml}\cdot\text{min}^{-1}$. The sample cell is flushed with either one of three reference gas standards (calibrated in the laboratory of Dr. P. Tans at NOAA/CMDL), marine air, or headspace gas from the equilibrator. The analyzer is operated in stopped flow mode in which the flow of sample gas is stopped during analysis. In the hourly cycle, the first 12 minutes of every hour are devoted to calibration of the LI-COR CO_2 analyzer. Next, the headspace gas of the equilibrator is sampled for a total of 18 minutes. This is followed by bow air sampling for 12 minutes. Finally, the equilibrator headspace is sampled again, concluding the last 18 minutes of the hour.

The analog output of the LI-COR CO₂ analyzer is converted to a digital signal with a 12-bit A/D converter board (DASCON-1, Keithley MetraByte, Taunton, MA) and the data is stored on a computer. The three other A/D channels are used to read the water flow meter (Cole Parmer, Vernon Hills, IL) and to convert the analog thermistor readings recording the temperature of the sample cell within the LI-COR and water temperature within the equilibrator (YSI, Yellow Springs, OH). The computer also logs the ship's position using a Global Positioning System (Magellan Systems, San Dimas, CA) and atmospheric pressure using a barometer (Model 370, Setra Systems, Boxborough, MA) with a RS-232 interface through the communication ports. All of these readings aid in simpler and more accurate data interpretation. The GW-BASIC program controlling the operation of the underway fCO₂ system is designed for easy timing sequence modifications and peripheral instrument elimination in the event of failure. (The program is listed in Appendix A).

A schematic diagram of the flow pathways is given in Fig. 3. The standards, ambient air, and equilibrator air gases are diverted to the NDIR sample cell by switching the appropriate 3-way solenoid valves (Skinner valves, Honeywell, New Britain, CT) in the valve switching box. The ambient air is drawn from the bow through 70 m of 0.95 cm OD (3/8") Dekoron tubing using a rubber bellows pump (Air Cadet, Cole Parmer, Vernon Hills, IL). The air is passed through a water trap held at 7 °C to lower the water vapor content and a 1 µm PTFE filter (Gelman Sciences, Ann Arbor, MI) to remove particulates and aerosols. The head space of the equilibrator is circulated with a small diaphragm pump (Spectrex, Redwood City, CA) at 100 ml·min⁻¹ through 0.31 cm OD (1/8") stainless steel tubing. Like the marine air samples, the water vapor pressure of the equilibrator air is also decreased by passing it through a water trap held at 7 °C. This trap contains a float with a magnet which will trip a breaker deactivating power to the pumps if the water level in the traps reaches a critical level. This mechanism prevents flooding of the valves and the NDIR if the traps are not emptied or if water inadvertently enters the air lines. In the Equatorial Pacific the traps are emptied daily. The air is completely dried using Mg(ClO₄)₂ (Magnesium perchlorate) downstream of the 3-way valves prior to entering the NDIR.

2.2.2. *Standard Gas Standardization/Conversion Polynomial*

The first 12 minutes of every hour are devoted to calibration of the LI-COR CO₂ analyzer. Three different standard gases of known concentrations, covering the CO₂ range that is encountered on the cruise, are passed through the IR cell at 50 ml·min⁻¹ for 3.5 minutes each. The flow is then stopped for 10 seconds to let the pressure and temperature of the cell equilibrate with stagnant flow conditions. Then, the analog output of the detector is sampled five times over three seconds. A second order polynomial is determined by curve fitting of the three standard voltage values. This polynomial is used to convert air or water LI-COR voltage readings for the subsequent hour, to a mixing ratio (ppm). During the post cruise data reduction (see below), the reference gas output values from the LI-COR are averaged with ones from the next hour and used to calculate a second order polynomial to "bracket" CO₂ marine air and equilibrator reading during the period.

2.2.3. *Sampling/Data Set*

After standards are measured, the headspace gas of the equilibrator is passed through the detector four times at 4.5 minutes each for a total of 18 minutes. The procedure is similar to that of reference gas analysis in which the sample gas flow is stopped at the end of each period after which 5 consecutive readings are taken. This is followed by three bow air samples at 4 minutes each, totaling 12 minutes, and finally the equilibrator headspace is sampled four more times at 4.5 minutes each, concluding the last 18 minutes of the hour.

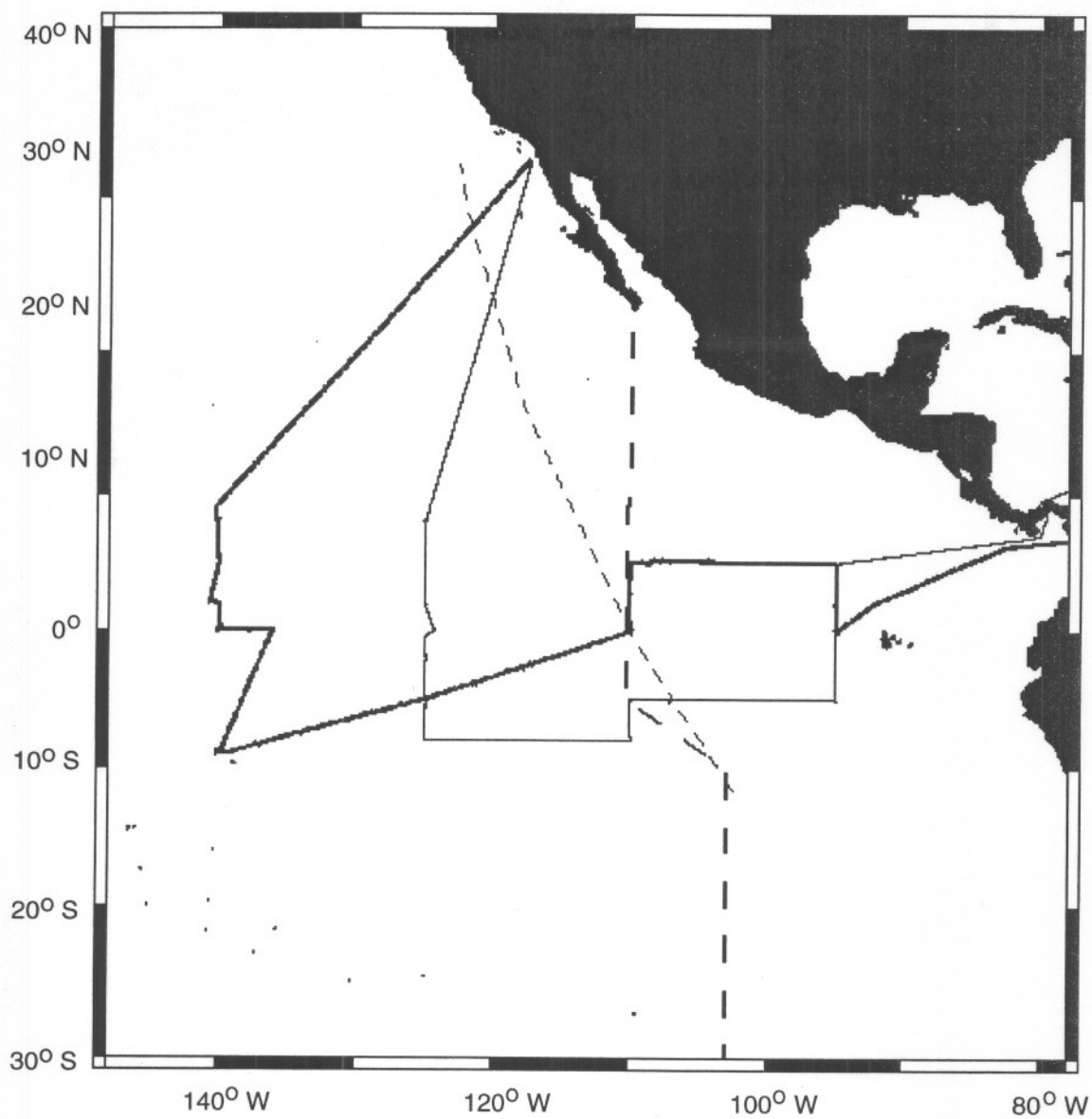


Fig. 1a. Cruise tracks for the Equatorial Pacific, spring 1994. Solid lines = MALCOLM BALDRIGE; Dotted lines = DISCOVERER.

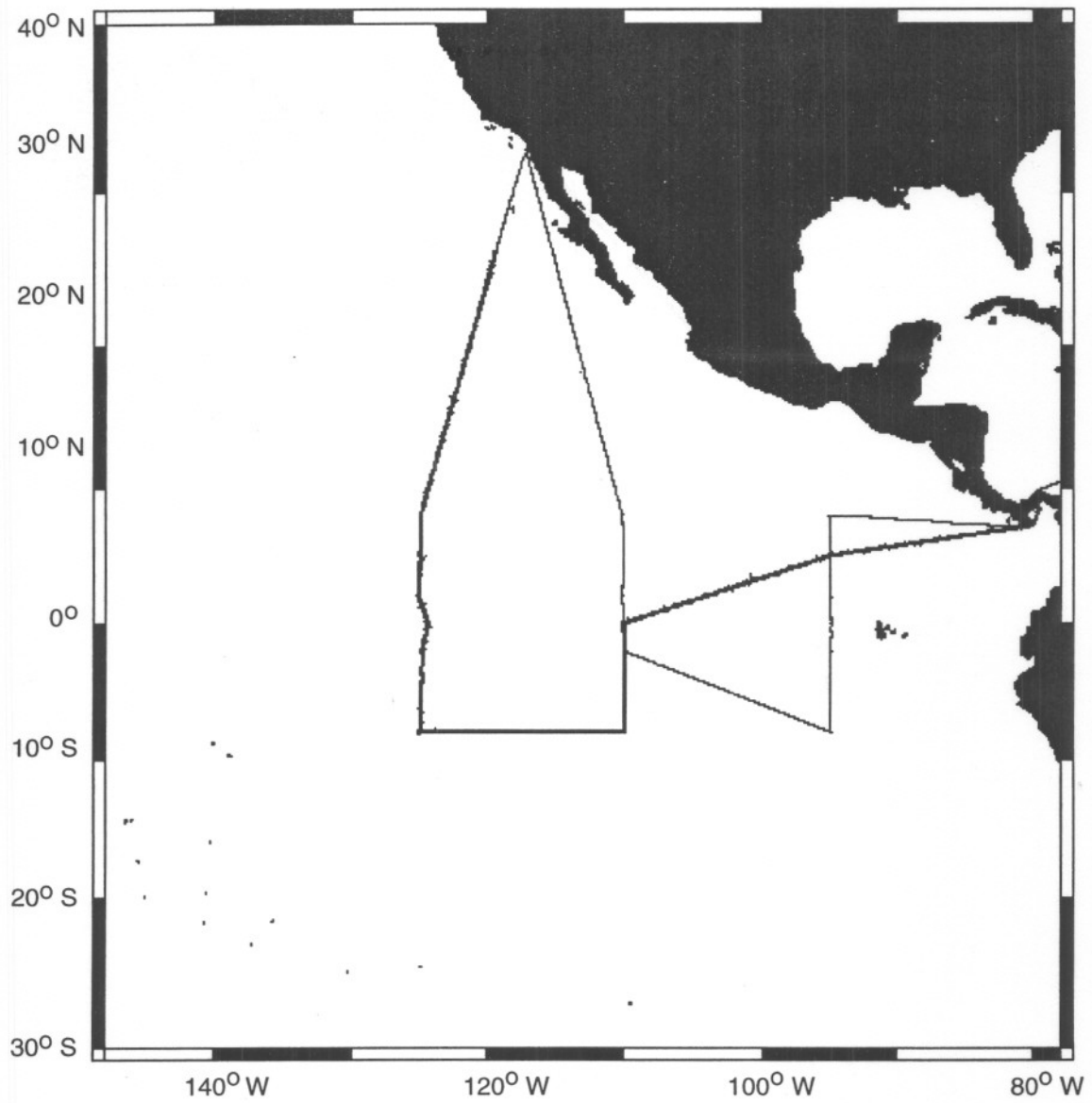


Fig. 1b. Cruise tracks for the MALCOLM BALDRIGE, Equatorial Pacific, fall 1994.

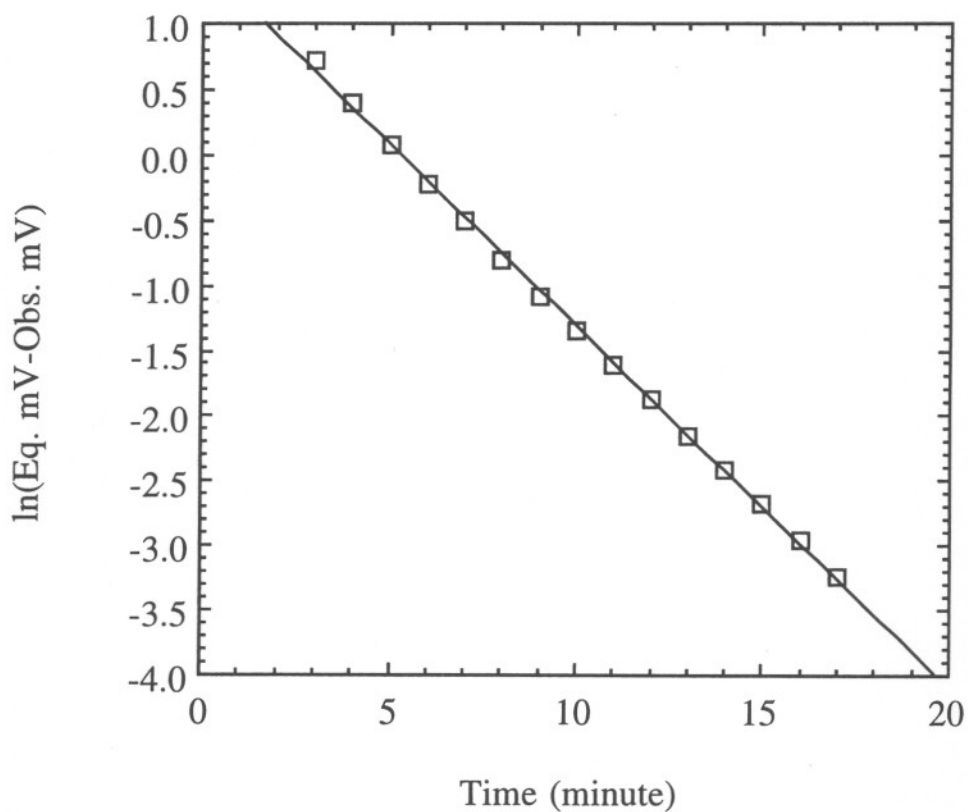


Fig. 2. Response of the IR after the headspace of the detector was flushed with nitrogen. The Y-axis gives the natural logarithm of the difference between the response of the detector at equilibrium conditions (Eq. mV) and the observed response (Obs. mV). The negative slope of the line is the equilibration time (3.6 minutes). From Wanninkhof and Thoning (1993).

NOAA/AOML Underway pCO₂ System Plumbing Block Diagram and Relay Schedule

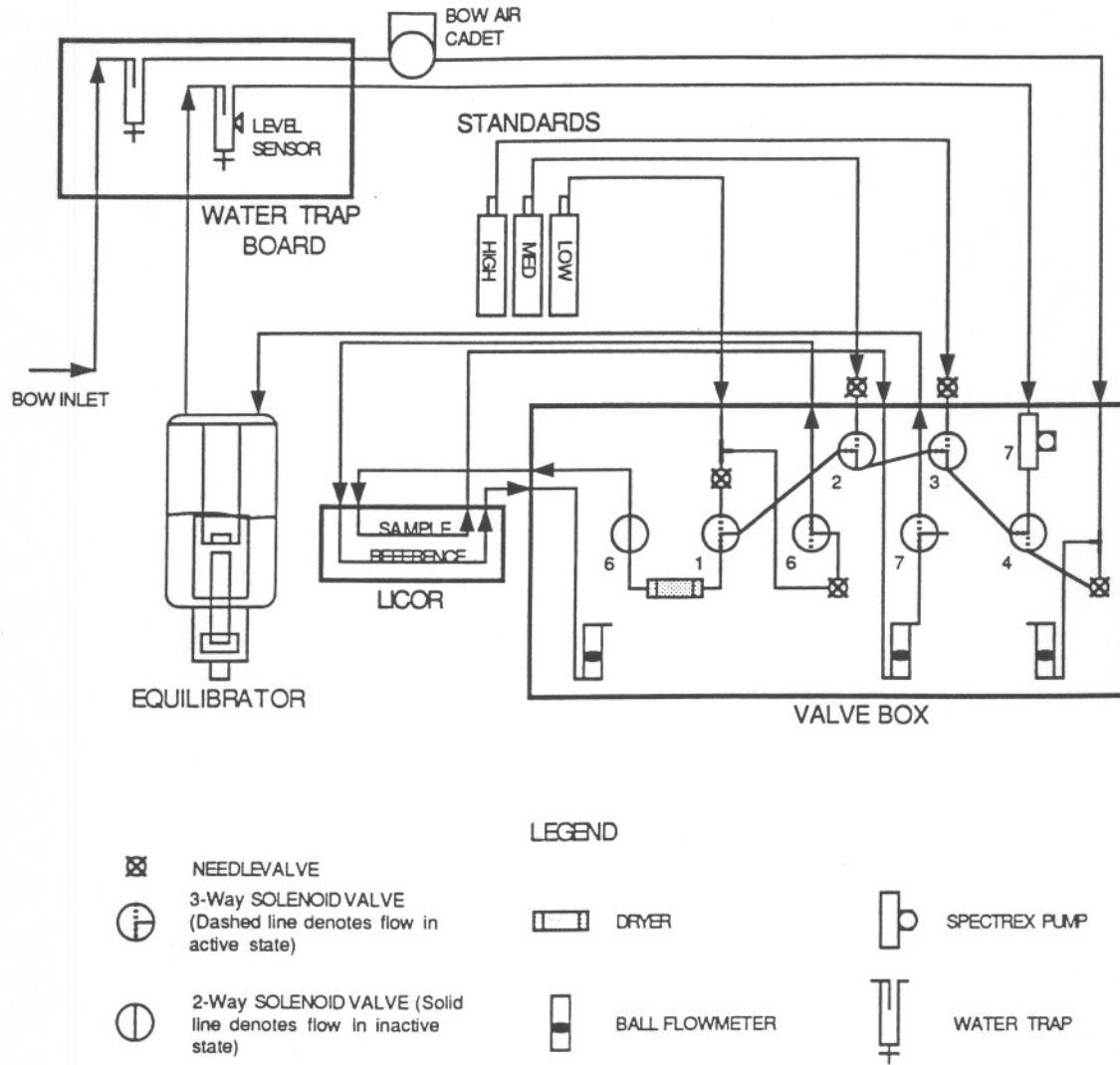


Fig. 3. Schematic of underway pCO₂ system used on the MALCOLM BALDRIGE Equatorial Pacific cruises in 1994.

Each sampling phase is done in the following manner: the sample is flushed through the system for 3.5 minutes (the equilibrator sample has a longer flushing time of 4 minutes to ensure complete flushing of new sample through the system). Then, flow stops and the system is vented to equilibrate with ambient pressure for 10 seconds. The four analog channels (LI-COR CO₂, LI-COR temp, equilibrator temp., equilibrator water flow meter) are then scanned five times, taking about 3 seconds total. An average of these scans is printed on the screen and logged to a data file. The Magellan GPS and Setra barometer are also read at this time. A brief waiting period follows and then the next sample is introduced. During post cruise data reduction, the thermosalinograph (TSG) temperature and salinity data are incorporated into the fCO₂ data file.

2.2.4. Screen Display

A comprehensive screen display facilitates on board quality control and error checking (Fig. 4). On the top line, the status of the system is displayed. The information includes: the current sample being measured (standard, "water" (= equilibrator headspace), or ambient air); whether the system is flushing the particular gas through the detector, waiting, or taking a reading; and a countdown (in seconds) of time remaining for the particular event. Displayed immediately below this status bar on the left hand corner are the mixing ratios of the standards (as calibrated by NOAA/CMDL) with the hourly updated detector response in millivolts (mV) listed below. To the right of this reading, the average mixing ratios of three air and eight equilibrator headspace readings of the previous hour along with their standard deviation are displayed. The main display contains the information taken during the current hourly cycle. It includes: the gas sampled; the time (in GMT); decimal latitude and longitude (from the GPS); the mixing ratio of CO₂ as determined from a polynomial through the standards measured the previous hour; the equilibrator temperature from the thermistor mounted in the bottom of the equilibrator; the LI-COR temperature from a plate thermistor mounted on the IR cell; and the ambient pressure measured with the Setra barometer; located immediately above the LI-COR, and the flow rate of water through the equilibrator. Inspection of the displayed readings along with knowledge of the default settings and atmospheric or oceanic CO₂ levels facilitates trouble shooting.

3. DATA REDUCTION

The final data reduction occurs on shore utilizing several spreadsheet macros (Excel 5.0 Visual BASIC, Microsoft, Redmond, WA) for merging and calculation. The raw data files with relevant information of each 4.5 minute sample event logged on a separate line are stored on the hard drive of the computer. They are listed by month and downloaded to floppy disks or removable cartridges (SyQuest Technology, Fremont, CA).

The raw data files are in ASCII format and the columns are as follows:

- a) Phase
- b) Date
- c) Time
- d) Lat.
- e) Long.
- f) Standard Conc. (-99.99 for air and "water" samples)
- g) CO₂ mV

- h) CO₂ Concentration
- i) Li-COR Temperature (mV)
- j) Li-COR Temperature (°C)
- k) Equilibrator Temperature (mV)
- l) Equilibrator Temperature (°C)
- m) Equilibrator water flow rate (mA)
- n) Equilibrator water flow rate (L·min⁻¹)
- o) Setra Barometric Pressure

This data is merged by time with sea surface temperature (SST) and salinity data obtained from the thermosalinograph (TSG) situated in the bow bubble. The TSG data is logged at 30 second intervals on the MALCOLM BALDRIGE shipboard computing system (SCS). The TSG and raw pCO₂ data are merged using a macro called "prepare raw file". Subsequently macros called "make bracket files" and "check for data gaps" will delete columns not used in the calculations and assure that every hour has 14 data points. If less data points are obtained because of instrument malfunction or shut down, the appropriate number of blank rows are manually inserted. The next macro "average xCO₂ mV values" averages the mV response of the standards before and after the hourly series of 14 samples and calculates a second order polynomial fit through these points. This fit is used to recalculate xCO₂ for air and water. These new xCO₂ values are visually checked against the original ones determined on board from a single set of standards. If values differ by more than 2 ppm, the cause is investigated. Frequently, the discrepancy is caused by an erroneous standard reading because a standard tank was turned off or because of an instrument malfunction. The ship's location is checked at this point as well. Occasionally, the Magellan GPS gives a wrong value because of electronic interference or antenna blockage by the ship's superstructure. Any errors are corrected by linear extrapolation, or if a large block of values are incorrect, the correct data are obtained from the SCS data files. Values are hand deleted as well when the water flow to the equilibrator is turned off or when the drying traps are changed. The equilibrator temperature and SST are compared to assure that they track each other (generally to within 0.2 °C). Deviations are caused by stopped flow through the equilibrator or an inadvertent mismatch between TSG files and underway files during merging. Missing thermosalinograph data is interpolated. The fCO₂ values are then calculated following the procedure below. In the final file the average air value for a given hour is matched with the water values for the hour and the difference (ΔfCO₂) is calculated with positive values denoting a net flux from the water. The sequence of individual macros assures that data is scrutinized, and where necessary, corrected at every step of the merging process and calculations.

4. CALCULATIONS

The mixing ratios of ambient air and equilibrated headspace air are calculated by fitting a second-order polynomial through the hourly averaged response of the detector versus mixing ratios of the standards. Mixing ratios of dried equilibrated headspace and air are converted to fugacity of CO₂ in surface seawater and water saturated air in order to determine the ΔfCO₂. For ambient air and equilibrator headspace the fCO_{2a}, or fCO_{2eq} is calculated assuming 100 % water vapor content:

$$fCO_{2a/eq} = xCO_{2a/eq}(P - pH_2O)\exp(B_{11} + 2\delta_{12})P / RT \quad (2)$$

where $f\text{CO}_{2a/\text{eq}}$ is the fugacity in ambient air or equilibrator, $p\text{H}_2\text{O}$ is the water vapor pressure at the sea surface temperature, P is the atmospheric pressure (in atm), and T is the SST or equilibrator temperature (in K) and R is the ideal gas constant ($82.057 \text{ cm}^3 \cdot \text{atm} \cdot \text{deg}^{-1} \cdot \text{mol}^{-1}$). The exponential term is the fugacity correction where B_{11} is the second virial coefficient of pure CO_2 ($B_{11} = -1636.75 + 12.0408T - 0.0327957T^2 + 3.16528 \times 10^{-5}T^3$) and δ_{12} ($= 57.7 - 0.118 T$) is the correction for an air- CO_2 mixture in units of $\text{cm}^3 \text{mol}^{-1}$ (Weiss, 1974). The calculation for the fugacity at SST involves a temperature correction term for the increase of $f\text{CO}_2$ due to heating of the water from passing through the pump and through 5 cm ID PVC tubing within the ship. The water in the equilibrator is typically 0.2°C warmer than sea surface temperature. The empirical temperature correction from equilibrator temperature to SST is outlined in Weiss et al. (1982).

$$\Delta \ln(f\text{CO}_2) = (t_{\text{eq}} - \text{SST})(0.0317 - 2.78510 \times 10^{-4} t_{\text{eq}} - 1.83910 \times 10^{-3} \ln(f\text{CO}_{2\text{eq}})) \quad (3)$$

where $\Delta \ln(f\text{CO}_2)$ is the difference between the natural logarithm of the fugacity at t_{eq} and SST, and t_{eq} is the equilibrator temperature in $^\circ\text{C}$.

5. ESTIMATES OF PRECISION

Accuracy and precision are determined by instrument performance, gas calibration, and uncertainties in the calculations leading from instrument response to the $f\text{CO}_2$ value. Precision of the LI-COR infrared analyzer appears well within the factory specification of 0.2 ppm peak-to-peak deviation for instantaneous reading at 350 ppm. The CO_2 reference gases are believed to be accurate to 0.1 ppm for standards in the range of 300 to 400 ppm based on the WMO-X93 scale. The standard with nominal mixing ratio of 520 ppm is accurate to an estimated ± 1 ppm.

The accuracy and precision of the measurements will also depend on changes in temperature and pressure in the IR cell between analysis of samples and standards. For an estimate of this effect the average LI-COR cell temperature and pressure for the three gas standards and the equilibrator and air analyses are compared for the start of the spring cruise from 4/15/95 until 4/30/94. The average difference in the hourly reading of pressure between standards and samples is $-0.01 \text{ mB} \pm 0.28 \text{ mB}$ ($n=351$) while the difference in temperature is $-0.01^\circ\text{C} \pm 0.28^\circ\text{C}$ ($n=351$). The distribution of temperature differences, shown in Fig. 5, is close to a log normal distribution. Thus there is no bias in the readings and variations in temperature and pressure will degrade the overall precision but not cause biases in the $f\text{CO}_2$ calculations. The influence of temperature and pressure variations on the LI-COR reading is primarily caused by expansion/contraction of gas in the sample cell and thus can be approximated assuming ideal gas behavior. If the standard deviation of the differences are used as a guide, the pressure variations contribute about 0.1 ppm to the uncertainty of the mixing ratio ($0.28 \text{ mB} / 1013 \text{ mB} \times 400 \text{ ppm}$) and the temperature variation about 0.3 ppm ($0.21 \text{ K} / 300 \text{ K} \times 400 \text{ ppm}$). Since the response of the detector to standards before and after the hourly sample sequence is used, the uncertainty from pressure and temperature variations will decrease. Comparing the average temperature of the cell for the standard runs before and after the samples with the temperature during the sample run the average difference is $0.00^\circ\text{C} \pm 0.06^\circ\text{C}$ ($n=345$) which translates into an uncertainty of 0.1 ppm. Thus under typical operating conditions the variation of cell temperature and pressure does not degrade the precision appreciably.

Gas in IR: Water / Start at : 22:24:23 / Status : flush / sec. remaining : 40

GPS: 2544.08,N,08009.73,W

LAST 60 MIN AVG. AND STD. DEV

CO2 Standards Information

STD #	STD_1	STD_2	STD_3
STD ppm	296.53	347.87	524.87
STD mV	-18.1	312.1	1126

Sample	P.P.M	Std. Dev
WATER	350.53	0.15
AIR	356.64	2.52
WATER	350.34	0.34

GAS	TIME	D.LAT	D.LON	pCO2_PPM	IR_TEMP	EQ_TEMP	EQ_FLOW	PRESSURE
WAT	01:16:05	25.66	80.17	350.54	24.2	26.1	10	1014.53
WAT	01:20:05	25.66	80.17	350.49	24.2	26.2	10	1014.53
WAT	01:25:05	25.66	80.17	350.65	24.3	26.2	10	1014.53
WAT	01:29:05	25.66	80.17	350.51	24.2	26.3	10	1014.22
AIR	01:33:45	25.66	80.17	356.51	24.3	26.2	11	1014.89
AIR	01:37:45	25.66	80.17	356.99	24.3	26.4	11	1014.89
AIR	01:41:45	25.66	80.17	356.14	24.3	26.5	11	1014.89
WAT	01:46:45	25.66	80.17	349.88	24.2	26.2	10	1014.27
WAT	01:50:45	25.66	80.17	350.09	24.2	26.3	10	1014.82
WAT	01:55:45	25.66	80.17	350.77	24.3	26.4	10	1014.42
WAT	01:59:45	25.66	80.17	350.89	24.2	26.1	10	1014.22

10-14-1994 01:59:59

DOC/NOAA/AOML/OCD/CO2

Fig. 4. Screen display from the underway pCO2 system used on the MALCOLM BALDRIGE Equatorial Pacific cruises in 1994. (Description in the text).

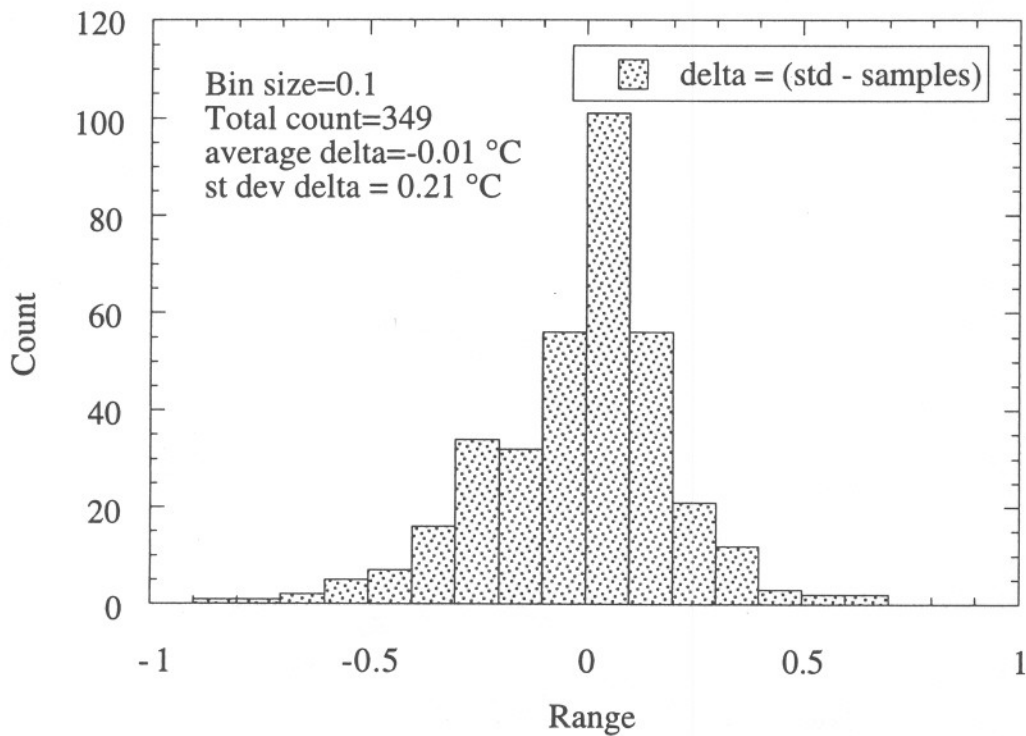


Fig. 5. Difference in the IR temperature during sampling of standards and air or water samples from 4/15 to 4/30/94. Since the response of the detector is dependent on the temperature, any systematic bias will influence the accuracy of the results, while the deviation will influence the precision. The influence of the IR temperature is roughly proportional to the absolute temperature. Thus the standard deviation of 0.21 °C is equivalent to 0.25 ppm in the CO₂ reading

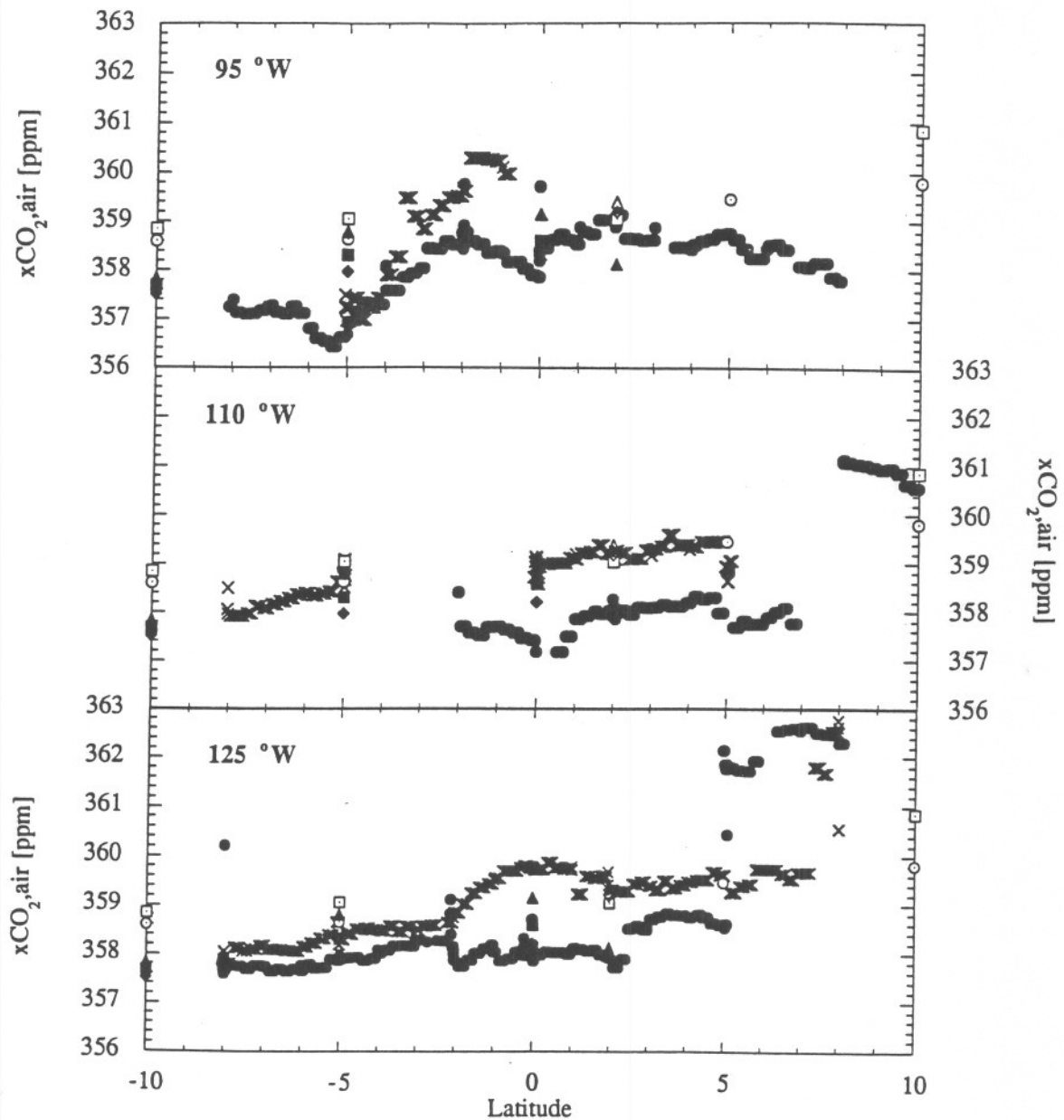


Fig. 6. Comparison of air values from the MALCOLM BALDRIGE cruise (\times = spring; \bullet = fall) with the monthly mean values obtained at the NOAA/CMDL flask network for 1994 (\odot = February; \square = March; \diamond = April; \triangle = May; \blacktriangle = July; \blacksquare = August; \blacklozenge = September; Conway and Tans, personal communication, see <http://www.cmdl.noaa.gov/>). The values at 2°N are from Christmas Island, while the other values are 5° averages from a commercial vessel en route from the West Coast of the United States to New Zealand with an equator crossing near the date line.

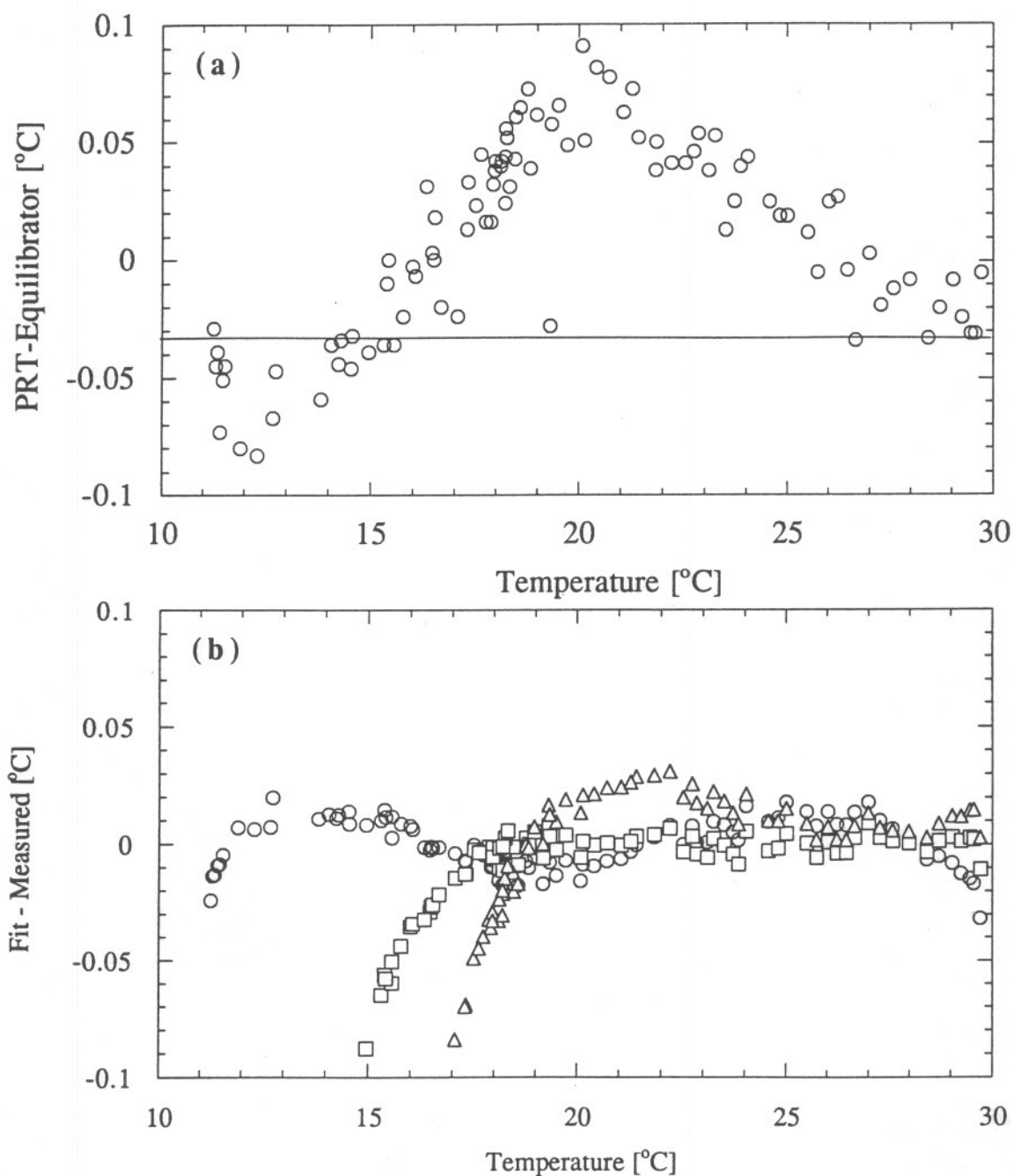


Fig. 7. (a) Comparison between the Guildline PRT with the thermometer mounted in the equilibrator and which was read every six-hours while the ship was underway. (b) Difference between the measured temperature with the Guildline PRT and the third order fit for three algorithms which were created from the calibrations (\circ = 1/94 11-30 °C; \square = 1/94 20-30 °C; \triangle = 7/94 20-30 °C). See text for details.

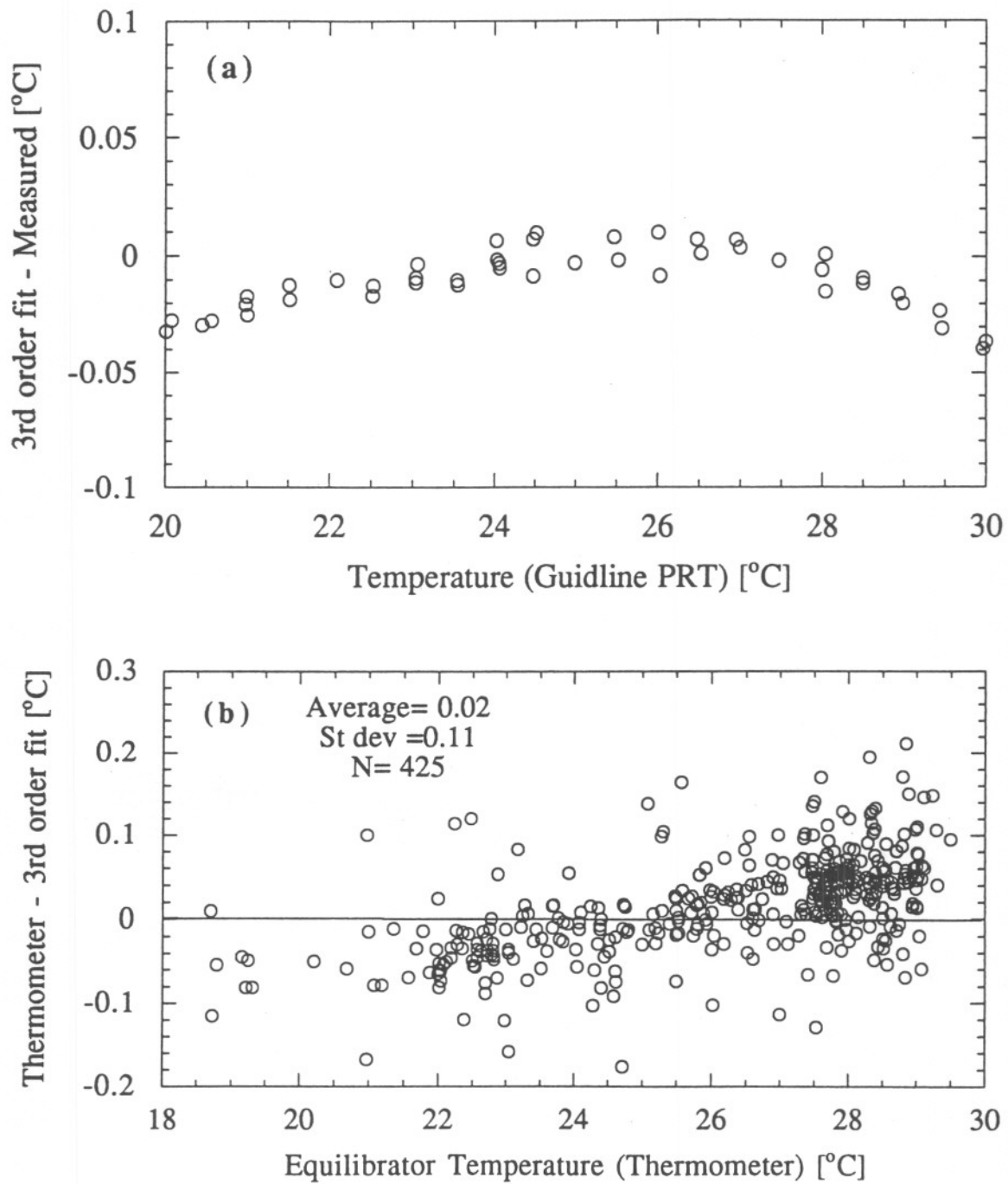


Fig. 8 (a) Comparison of the best fit algorithm and the calibration on 7/94 which shows that the thermistor did not drift appreciably during the Spring-94 cruise. (b) Comparison between the 6-hour thermometer reading in the equilibrator during the cruise and the thermistor temperature deduced from the algorithm listed in Eq 3.

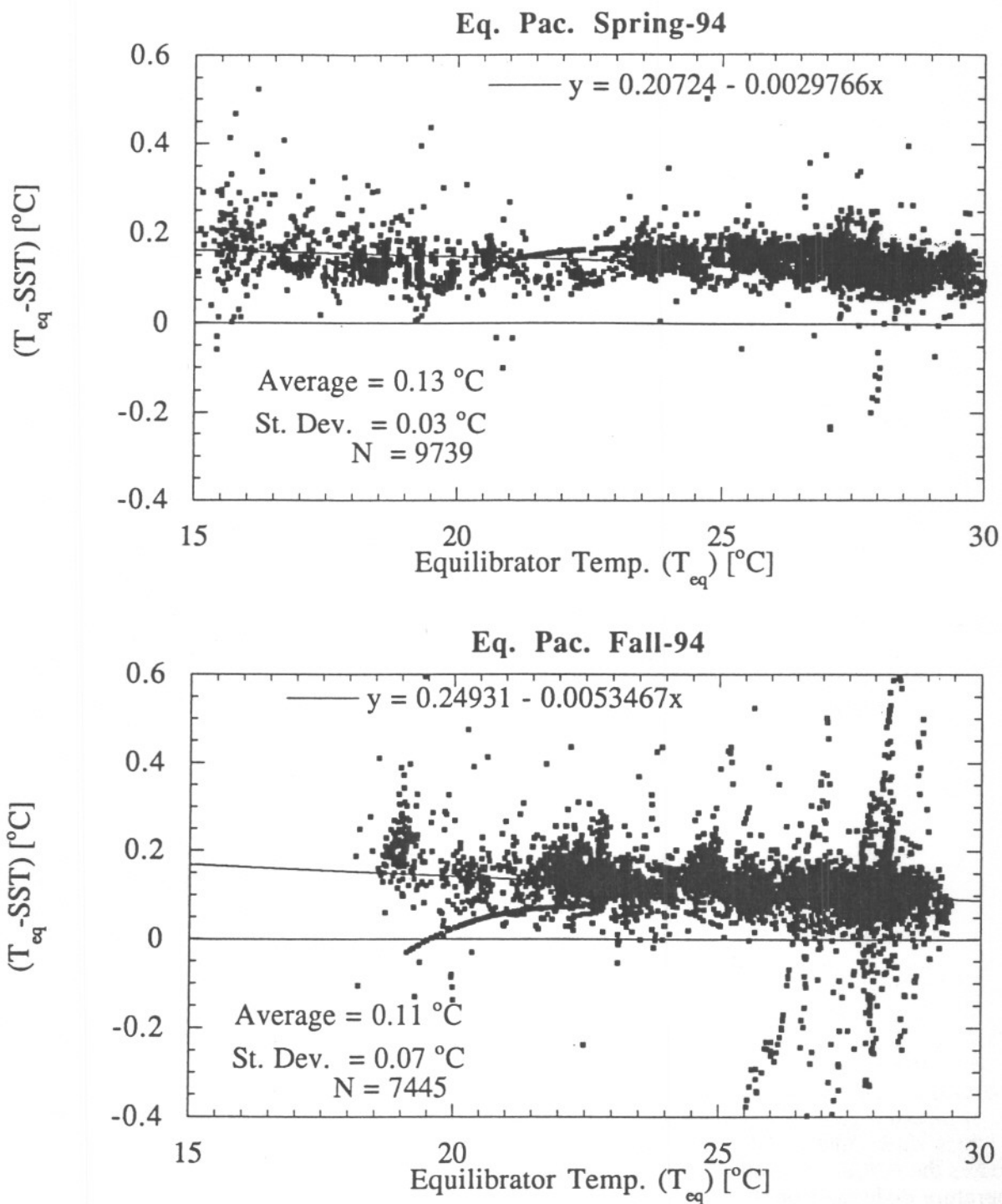


Fig. 9. Difference between the t_{eq} and SST for the spring and fall Equatorial Pacific cruises on the MALCOLM BALDRIGE. The temperature in the equilibrator is on average 0.2 °C warmer than the SST at the bow intake. High deviations occur when the flow is stopped.

The accuracy of the ambient air values for Equatorial Pacific cruises in 1992 and 1993 have been checked in Wanninkhof et al. (1996) by comparing 4 to 8° latitudinal band averages with values obtained from the NOAA/CMDL network suggesting that air values are accurate to within 1 ppm. Figures 6a-c show graphical comparisons of the air values obtained during Equatorial Pacific cruises in 1994 and monthly averaged values at Christmas Island (2°N, 157°W) and from flask samples taken on container vessels en route from San Francisco to Auckland, crossing the equator near the international date line. Although many flask sample values are missing and a zonal gradient in xCO₂ is likely, it appears that on average the air mixing ratios taken on the MALCOLM BALDRIGE are about 0.5 ppm lower than the NOAA/CMDL flask values.

The greatest source of uncertainty is the equilibration efficiency of the equilibrator and correction of the fCO_{2w} to SST. As shown in Chen et al. (1995) (pages 21-24) the equilibration efficiency is a function of water flow rate because of entrainment of bubbles through the water drain which is made up by introduction of marine air through the vents. During the Equatorial Pacific 1994 cruises the flow rate was nominally 15 l·min⁻¹ and based on previous test this would cause a maximum deviation towards ambient air values of 0.5 ppm.

The correction to SST is important because this is where biases, in addition to random error, can be introduced if the temperature probes are not adequately calibrated. The thermosalinograph was calibrated in October 1993 and November 1994 by Seabird Electronics and the two sets of calibration coefficients yielded a maximum deviation in salinity and temperature of 0.005 and of 0.005 °C, respectively (which is insignificant). The equilibrator temperature was measured with a YSI glass bead thermistor encapsulated in a 1/8" stainless steel probe. The resistance was converted to temperature using an empirical 3rd-order polynomial algorithm determined from calibrations before and after the spring cruise using a Guildline 9540 platinum resistance thermometer (PRT). The combination of the pre-cruise and post-cruise calibrations yielded a fit of:

$$t_{eq} = 73.6908 - 0.0383166R + 0.0000085113R^2 - 0.000000007868R^3 \quad (3)$$

where t_{eq} is in °C and R is the resistance in Ohm. The post cruise (new) calibration was only performed from 20 to 30 °C. Figures 7 and 8 show the results of laboratory calibrations. Fig. 7a compares the Guildline PRT with the thermometer mounted in the equilibrator and which was read every six hours while the ship was underway. The agreement is within 0.05 °C but there does appear to be a systematic trend with the thermometer reading up to 0.08 °C low from 18-23 °C and about 0.02 °C high at 30 °C. Fig. 7b shows the difference between the measured temperature with the PRT and the third order fit for three algorithms which were created from the calibrations. The one labeled 1/94 is the algorithm used to determine t_{eq} on the cruise. The other two are algorithms created in the range from 20 to 30 °C from calibration on 1/94 and 7/94. In the range of measurement all three algorithms show good agreement but deviation becomes large outside the range of measurement. Fig. 8a gives a comparison of the best fit algorithm and the calibration on 7/94 which shows that the thermistor did not drift appreciably during the Spring-94 cruise. Fig. 8b compares the 6-hour thermometer reading in the equilibrator during the cruise with the thermistor temperature deduced from the algorithm listed above. Twenty five data points which disagreed more than ± 0.25 °C are not plotted and presumed to be reading errors. The average difference of 0.02 °C, again indicating that the thermistor did not drift during the cruise, and the standard deviation of 0.11 °C is likely due to reading errors of the analog thermometer mounted in the equilibrator. The thermometer readings were not used because the measurements were only performed every six hours and probably have a reading error of at least 0.05 °C. The calibration comparisons suggest that biases in t_{eq} are less than 0.05 °C (or equivalent of 1 μ atm).

Figs. 9a,b shows the difference between the t_{eq} and SST for the cruises. The temperature in the equilibrator is on average 0.2 °C warmer than the SST at the bow intake. The larger deviations are during periods when the flow to the equilibrator was restricted, or when the air conditioning system in the laboratory malfunctioned. The slight trend in the data of smaller differences at higher temperatures is because heating in the lines is partly offset by temperatures in the laboratory being lower than SST.

6. EXPLANATION OF COLUMNS IN THE DATA SET

A sample of the underway fCO_2 data for the Spring and Fall 1994 Equatorial Pacific data are given in Appendix B. Here is an explanation of the column headers:

JD	Julian Day
Date	Date (month, day, year)
Time	Greenwich Mean Time
Lat	Latitude (decimal degrees)
Long	Longitude (decimal degrees)
$xCO_{2,w}$	mixing ratio of CO_2 (dry) in headspace of equilibrator. Water comes from a bow intake 5 m below the water line (in ppm)
$xCO_{2,a}$	mixing ratio of CO_2 (dry) from the bow of the ship (15 m above water)
Eq Temp	temperature in equilibrator measured with a calibrated thermistor (in °C)
Pressure	pressure in OCEA laboratory (in mB)
SST (TSG)	sea surface temperature measured at the water intake (5 m below water line) (in °C)
Sal (TSG)	salinity measured at the water intake (5 m below water line)
$fCO_{2w, eq}$	fugacity of water in equilibrator calculated according to DOE (1994) (in μatm)
$fCO_{2w, in situ}$	fugacity of water at SST calculated from algorithm of Weiss et al. (1982)
fCO_{2a}	fugacity of CO_2 in air
ΔfCO_2	water- air fugacity difference

Notes:

Columns have a default value of -999.99 in case of instrument malfunction or erroneous readings. Furthermore, if a suspicious xCO_2 value, pressure or temperature value is encountered which cannot be readily extrapolated, the fCO_2 is not calculated

For the spring cruise the air pump failed during the 140 °W transit. The xCO_2 values from 125°W at the appropriate latitude were used instead. The 125 °W transect occurred 2-weeks to a month earlier and air values show a seasonal cycle, particularly in the Northern hemisphere. To assess the possible error introduced by this extrapolation the air values at 125 °W were compared with the northern hemisphere values along 110 °W at the same latitude but occupied a month later, immediately after the 140 °W transect. The agreement from 0 to 5 °N is within 1 ppm. The correspondence between xCO_2 at 125 °W and at 140 °W when the air pump was working is good

as well. At 21 °N, the $x\text{CO}_2\text{a}$ value was 362.82 at 140 °W and 363.96 at 125 °W; at 8 °S the 140 °W value was 358.21 and at 125 °W it was 357.79. The *in situ* SST, salinity, and pressure values were used to calculate the corresponding $f\text{CO}_2\text{a}$ values along 140 °W.

7. SUPPORT MEASUREMENTS

Discrete samples were taken for DIC, O_2 , chlorophyll *a* and nutrients at nominally one degree spacing along the north-south transects. Near the equator the spacing was decreased to one half degree spacing between 1 °N and 1 °S, and 1/4 degree spacing from 0.5 °N and 0.5 °S. The samples were stored for shore based analyses, or in the case of oxygen and chlorophyll they were stored up to a week and analyzed aboard the ship. The storage and lack of expertise of the operators degraded the sample analysis compared to routine operation on dedicated long line cruises but because of the large natural variability in the Equatorial Pacific area, the analyses yield quantitative information of the chemical signals associated with upwelling. The results for the spring and fall cruises are given in Table 1 and 2. Upwelling near the equator is manifested by high DIC, AOU (apparent oxygen utilization), and nutrient values. Sea surface temperatures and oxygen values are low. Furthermore, an east-west trend is observed with higher DIC, and nutrient values towards the coast.

7.1. DIC Determination

Samples for dissolved inorganic CO_2 (DIC) analysis were drawn from 10-L Niskin bottles or from the underway line into 500 ml Pyrex bottles using Tygon tubing. Each sample had 0.2 ml of a saturated HgCl_2 solution added as preservative. The sample bottles were sealed with glass stoppers lightly covered with Apiezon grease (DOE, 1994). The samples were then stored in darkness at ambient (room) temperature for a maximum of two month prior to being analyzed on shore.

DIC analysis was performed by extracting the inorganic carbon from a 20 ml aliquot of sea water sample by acidification and subsequent displacement of the gaseous CO_2 into a coulometer cell using an automated SOMMA system. Details concerning this system and procedures are presented in Johnson (1992), and Johnson et al. (1993). Precision and accuracy based on replicates and analyses of certified reference materials is estimated at $3 \mu\text{mol}\cdot\text{kg}^{-1}$, or about twice as great as analysis under optimal conditions

7.2. Oxygen Measurements

The oxygen samples were collected, in 150 ml ground-glass stoppered sample bottles from the surface Niskin bottle or from the underway line. Reagents were added and the samples were stored in the dark with the stopper submerged under water. They were analyzed using the method described by Carpenter (1965), with computer-controlled colorimetric endpoint determination as described in Friederich et al. (1984) on a weekly basis. Oxygen samples that have been collected and analyzed using the above methodology with prolonged storage have a precision of about 2-3 percent.

Table 1. EQUATORIAL PACIFIC SPRING 1994 SUPPORT MEASUREMENTS

Date	Time (GMT)	Latitude	Longitude	Salinity	Temp. (°C)	O ₂ (μmol·l ⁻¹)	AOU (μmol·l ⁻¹)	NO ₂ (μmol·l ⁻¹)	NO ₃ (μmol·l ⁻¹)	SiO ₃ (μmol·l ⁻¹)	DIC (μmol·kg ⁻¹)	Chl <i>a</i> (μg·l ⁻¹)	phao (μg·l ⁻¹)	total Chl (μg·l ⁻¹)
4/19/94	20:10	5.03	94.99	32.04	28.67	200	2	0.0	0.0	0.0	1812	0.20	0.05	0.25
4/20/94	03:20	4.00	95.00	32.43	28.88	198	3	0.0	0.0	0.0	1826	0.13	0.04	0.17
4/20/94	09:22	3.00	95.00	32.69	28.50	197	5	0.0	0.0	0.0	1842	0.18	0.05	0.23
4/21/94	05:15	2.00	95.02	33.02	27.54	203	1	0.0	0.0	0.0	1869	0.20	0.04	0.25
4/21/94	12:31	1.01	94.98	35.00	23.99	197	18	1.9	7.4	4.2	2066	0.36	0.11	0.47
4/21/94	15:05	0.51	95.00	35.00	23.06	210	8					0.19	0.07	0.25
4/21/94	18:30	-0.03	94.94	35.18	23.39	186	31	2.5	7.6	3.3	2071	0.22	0.05	0.27
4/21/94	23:08	-0.55	94.97	35.15	22.43	206	15					0.23	0.07	0.30
4/22/94	02:00	-1.00	94.98	35.22	23.58	181	35	2.5	8.3	3.0	2079	0.21	0.05	0.26
4/22/94	08:02	-2.01	94.96	35.12	25.03	204	7	1.6	6.8	2.1	2063	0.24	0.10	0.34
4/22/94		-3.00	95.00									1.24	0.17	1.41
4/22/94		-4.00	95.00									0.39	0.10	0.49
4/23/94	04:38	-4.98	95.03	35.11	26.69	215	-10	2.0	1.8	0.0		0.27	0.08	0.35
4/26/94	23:15	-4.98	110.02	35.12	27.46	210	-7	1.0	5.0	0.8	2015			
4/27/94		-5.00	110.00									0.24	0.06	0.30
4/28/94	02:18	-8.00	109.97	34.85	27.64	203	-1	0.3	2.0	0.0	1971	0.24	0.10	0.34
4/30/94	21:38	-8.00	125.00	35.19	27.96	198	3	0.7	3.3	0.0	1921	0.17	0.02	0.19
5/1/94	21:35	-4.97	124.93	35.12	27.70	199	3	0.6	3.4	0.0		0.22	0.05	0.27
5/2/94	03:41	-3.98	125.02	35.16	27.78	199	3				2003	0.20	0.02	0.23
5/2/94	09:18	-3.00	125.00	35.14	27.68	196	5	0.6	3.5	0.8	2006	0.19	0.07	0.26
5/2/94	15:04	-2.02	124.90	35.19	27.22	210	-7	0.9	3.4	0.0	2017	0.16	0.07	0.23
5/2/94	19:56	-1.00	124.99	35.19	26.57	200	5	2.5	2.7	1.0	2027	0.31	0.12	0.43
5/2/94	23:30	-0.50	125.00		26.27	207	-1					0.17	0.07	0.24
5/3/94	04:30	0.02	124.32	35.11	25.98	201	6	2.7	2.4	0.9	2026	0.30	0.06	0.36
5/3/94	05:53	0.47	124.51	35.03	25.60	200	9					0.28	0.08	0.36
5/3/94	10:31	1.00	124.67			200	8				2013	0.12	0.11	0.23
5/4/94	05:38	1.96	125.08	34.74	26.64	198	7				2008	0.24	0.11	0.34
5/4/94	12:17	3.00	125.02	34.74	27.46	194	8				1984	0.20	0.04	0.25
5/4/94	18:15	4.00	125.01	34.71	27.64	199	4				2000	0.14	0.03	0.17
5/5/94	00:47	5.08	125.00	34.40	28.72	199	0				1932	0.29	0.09	0.38
5/6/94	03:15	8.15	124.93	34.13	28.23	195	6				1909	0.23	0.07	0.30
5/24/94		9.00	140.00									0.15	0.03	0.18
5/25/94	04:42	5.02	139.98	34.45	28.58	198	2				1929	0.12	0.05	0.17
5/25/94	10:36	4.00	140.22	34.72	28.52			0.0	0.8	0.0	1956	0.17	0.05	0.22
5/25/94	15:11	3.00	140.46	34.78	28.30							0.15	0.07	0.22
5/25/94		2.00	140.00									0.20	0.04	0.25
5/26/94	08:00	1.97	140.02	34.78	28.13			0.0	1.1	0.0	1960			
5/26/94	13:41	1.00	139.85	34.92	27.61			0.0	2.5	0.7	1983	0.20	0.06	0.26

Table 1. EQUATORIAL PACIFIC SPRING 1994 SUPPORT MEASUREMENTS

Date	Time (GMT)	Latitude	Longitude	Salinity	Temp. (°C)	O ₂ (μmol·l ⁻¹)	AOU (μmol·l ⁻¹)	NO ₂ (μmol·l ⁻¹)	NO ₃ (μmol·l ⁻¹)	SiO ₃ (μmol·l ⁻¹)	DIC (μmol·kg ⁻¹)	Chl <i>a</i> (μg·l ⁻¹)	phao (μg·l ⁻¹)	total Chl (μg·l ⁻¹)
5/26/94	15:50	0.49	139.97	35.06	26.67							0.31	0.09	0.40
5/27/94	11:20	0.01	139.94	35.05	26.85	192	13	0.2	4.6	1.3	2011			
5/28/94	05:04	0.02	139.98			196		0.2	4.6	1.3	2005	0.32	0.08	0.40
5/29/94	17:34	-4.02	137.75	35.07	28.06	167	33							
6/2/94		-6.00	130.00									0.18	0.05	0.23
6/3/94	06:03	-4.97	123.88	35.01	27.74	201	1	0.0	4.8	0.5	1994	0.20	0.08	0.28
6/4/94		-3.20	120.00									0.09	0.02	0.11
6/5/94	07:19	-1.67	115.01	35.07	25.61							0.18	0.08	0.26
6/7/94	09:04	0.00	110.02	35.08	25.15	192	19	0.1	7.3	3.5	2029	0.21	0.08	0.30
6/7/94	11:45	0.49	110.01	34.99	25.41	205	4					0.16	0.08	0.23
6/7/94	15:03	1.01	110.03	34.90	25.39	195	15	0.2	6.0	1.9	2016	0.23	0.10	0.33
6/7/94	22:30	2.07	110.13	34.14	27.23	204	0	0.0	1.6	0.0	1939	0.21	0.09	0.30
6/7/94		2.00	110.00	34.14	27.23							0.24	0.02	0.26
6/8/94	04:13	3.00	110.06	34.26	27.53	202	2	0.0	1.8	0.0	1941	0.17	0.05	0.21
6/8/94	10:00	4.01	110.01	33.86	28.19	195	6	0.0	0.5	0.0	1904	0.17	0.03	0.20
6/9/94	08:02	5.10	109.94	33.35	28.12	198	4		0.0	0.0	1879	0.19	0.05	0.24
6/12/94	12:34	5.05	95.00	33.76	27.88	199	2	0.0			1908	0.19	0.08	0.27
6/12/94	23:49	2.99	95.00	34.77	24.73	198	14					0.27	0.08	0.36
6/12/94		3.00	95.00	34.77	24.73							0.17	0.07	0.25
6/13/94	07:42	2.01	95.01	34.84	23.62	192	24	0.0	8.2	4.2	2044	0.20	0.06	0.26
6/13/94	17:35	1.00	94.97	35.00	23.44	186	31					0.22	0.05	0.27
6/13/94	20:17	0.48	94.96	35.00	23.59	186	30					0.25	0.04	0.28
6/14/94	06:52	0.01	94.90	35.12	23.73	184	32	0.2	8.7	3.4	2053	0.23	0.03	0.26

Table 2. EQUATORIAL PACIFIC FALL 1994 SUPPORT MEASUREMENTS

Date	Time (GMT)	Latitude	Longitude	Salinity	Temp. (°C)	O ₂ (μmol·l ⁻¹)	AOU (μmol·l ⁻¹)	NO ₂ (μmol·l ⁻¹)	NO ₃ (μmol·l ⁻¹)	SiO ₃ (μmol·l ⁻¹)	PO ₄ (μmol·l ⁻¹)	DIC (μmol·kg ⁻¹)
8/8/94	6:10	7.94	-94.95	33.76	26.14	191	17					
8/8/94	6:10	7.94	-94.95	33.76	26.14	191	17					1932
8/8/94	12:08	6.99	-94.98	33.74	26.95							1913
8/8/94	12:08	6.99	-94.98	33.74	26.95							1912
8/8/94	17:45	5.99	-94.99	33.73	27.12	197	8	0.0	0.1	0.0	0.35	1872
8/8/94	22:23	4.92	-94.99	33.73	26.75	205	2	0.0	0.1	0.0	0.37	1898
8/9/94	4:44	4.00	-95.00	33.98	26.93	199	6	0.0	0.1	0.0	0.47	1921
8/9/94	10:20	3.01	-95.01	33.92	26.42	198	10	0.0	0.1	0.0	0.46	1914
8/10/94	4:14	2.00	-94.00	33.93	25.39	204	7	0.0	0.5	0.0	0.45	1915
8/10/94	10:35	1.00	-94.98	34.64	21.43	199	25	0.2	8.4	3.4	0.98	2019
8/10/94	12:55	0.49	-94.94	34.95	19.80	197	34	0.3	14.2	7.1	1.24	2070
8/10/94	13:57	0.26	-94.93	35.06	19.54	190	42	0.3	18.4	9.2	1.45	2100
8/10/94	19:06	-0.02	-94.94	35.11	19.09	184	49	0.3	16.5	4.1	1.41	2092
8/10/94	19:06	-0.02	-94.94	35.11	19.09			0.3	18.0	4.4	1.45	2091
8/10/94	21:16	-0.26	-94.93	35.03	18.70			0.2	14.7	0.0	1.47	2076
8/10/94	22:25	-0.54	-94.93	34.89	18.87	198	37	0.3	15.8	2.2	1.33	2080
8/11/94	3:12	-1.00	-94.95	35.12	19.92	205	25	0.2	12.5	0.0	1.23	2080
8/11/94	11:00	-1.99	-95.03	35.06	18.92	206	29	0.2	10.5	1.8	0.95	2060
8/12/94	1:22	-1.97	-95.00	35.09	19.63							
8/12/94	7:20	-3.00	-95.00	35.14	20.13	200	29	0.1	11.3	6.6	0.90	2070
8/12/94	13:00	-4.00	-95.01	35.36	22.24	203	18	0.1	11.9	6.5	0.94	2064
8/12/94	18:57	-5.00	-95.03	35.46	22.82			0.2	12.1	7.7	1.09	2052
8/13/94	1:42	-6.00	-95.01	35.46	22.75	210	9	0.2	11.9	1.5	1.20	2056
8/13/94	7:30	-7.00	-95.00	35.55	22.75	207	11	0.2	11.7	1.6	1.24	2057
8/13/94	20:45	-7.96	-95.06	35.46	22.62	209	10	0.3	12.8	1.8	1.27	2077
8/13/94	20:45	-7.96	-95.06	35.46	22.62	209	11	0.3	11.7	0.9	1.18	2059
8/17/94	6:40	-1.99	-110.02	34.82	22.12	190	32	0.2	11.6	4.0	1.13	2038
8/17/94	12:30	-1.00	-110.03	34.81	21.98	184	38	0.1	10.2	3.2	1.01	2034
8/17/94	14:56	-0.50	-110.02	34.75	21.91	179	43	0.2	12.7	6.3	1.22	2033
8/17/94	15:44	-0.25	-110.02	34.81	21.87							
8/17/94	20:49	0.01	-110.02	34.76	21.90	183	39	0.1	10.2	5.3	0.93	2038
8/17/94	20:49	0.01	-110.02	34.76	21.90	185	37	0.2	10.3	4.8	0.98	2038
8/17/94	23:59	0.50	-110.06	34.69	22.74			0.0	11.5	7.1	0.99	2019
8/18/94	3:12	1.00	-110.08	34.54	24.45	198	15	0.0	4.9	0.4	0.69	1977

Table 2. EQUATORIAL PACIFIC FALL 1994 SUPPORT MEASUREMENTS

Date	Time (GMT)	Latitude	Longitude	Salinity	Temp. (°C)	O ₂ (μmol·l ⁻¹)	AOU (μmol·l ⁻¹)	NO ₂ (μmol·l ⁻¹)	NO ₃ (μmol·l ⁻¹)	SiO ₃ (μmol·l ⁻¹)	PO ₄ (μmol·l ⁻¹)	DIC (μmol·kg ⁻¹)
8/18/94	6:35	1.49	-110.11	34.01	25.37	199	12	0.0	2.5	3.2	0.43	1956
8/18/94	11:11	2.01	-110.15	34.32	25.73	198	11	0.0	2.6	0.4	0.57	1951
8/19/94	10:20	3.52	-110.05	34.04	26.32							
8/19/94	12:41	4.04	-110.02	33.48	27.47	193	11					1881
8/19/94	17:20	5.00	-109.97	33.35	27.70			0.0	0.1	2.1	0.37	1868
8/20/94	0:05	6.00	-110.00	33.24	28.09	195	8	0.0	0.1	0.0	0.35	1880
8/20/94	4:51	7.00	-110.00	32.48	27.81	195	9	0.0	0.1	0.0	0.37	1821
8/20/94	7:55	7.50	-110.10	32.92	27.94			0.0	0.2	0.0	0.35	1848
8/20/94	13:27	8.04	-110.13	32.89	27.98	211	-8	0.0	0.1	1.2	0.40	1842
9/4/94	18:20	8.15	-124.91	34.13	27.97	194	8	0.0	0.0	0.4	0.07	1912
9/4/94	18:20	8.15	-124.91	34.13	27.97	194	7	0.0	0.0	5.8	0.12	1912
9/5/94	6:36	6.00	-124.95	34.59	27.41	195	8	0.0	0.1	0.3	0.42	1935
9/5/94	12:00	5.08	-125.02	34.64	26.74			0.0	0.9	0.4	0.34	1948
9/6/94	10:08	4.00	-125.01	34.67	26.42	197	9	0.0	2.2	0.3	0.55	1957
9/6/94	16:15	3.00	-125.04	34.83	24.36	218	-4	0.0	9.7	2.3	0.94	2018
9/6/94	23:19	1.98	-125.10	34.72	24.70	210	2	0.0	8.8	2.5	0.85	2007
9/7/94	6:00	1.00	-124.73	34.64	24.78	216	-4	0.0	8.1	3.9	0.93	1998
9/7/94	8:56	0.47	-124.58	34.36	24.71			0.1	8.6	4.7	1.02	1998
9/7/94	10:05	0.26	-124.50	34.67	24.60			0.1	7.9	4.2	0.94	2000
9/7/94	12:51	0.00	-124.47	34.68	24.53			0.2	9.3	4.0	1.07	2003
9/7/94	12:51	0.00	-124.47	34.68	24.53			0.2	9.8	5.2	1.09	2001
9/8/94	8:12	-0.24	-124.47	34.69	24.25	204	10	0.2	10.0	5.3	1.07	2006
9/8/94	10:10	-0.50	-124.50	34.76	23.81			0.3	12.1	5.3	1.22	2024
9/8/94	13:37	-1.00	-124.63	34.86	23.51	181	35	0.2	11.9	8.2	0.93	2035
9/9/94	8:09	-2.08	-124.90	34.89	22.95	181	37	0.2	11.7	8.2	0.92	2038
9/9/94	14:10	-3.00	-124.88	34.89	23.35			0.2	10.3	4.9	0.84	2037
9/9/94	20:00	-4.00	-124.88	34.87	23.91	202	13	0.2	9.8	7.1	0.83	2034
9/10/94	2:35	-4.80	-124.91	35.19	24.66	205	7	0.1	9.0	4.6	0.74	2035
9/10/94	8:41	-5.99	-124.93	35.35	25.35			0.0	9.2	1.9	0.83	2033
9/10/94	14:55	-7.00	-124.98	35.47	25.78	204	3	0.0	5.7	3.8	0.58	2025
9/11/94	7:20	-7.99	-124.99	35.55	25.89	186	20	0.0	6.7	3.7	0.68	2022
9/11/94	7:20	-7.99	-124.99	35.55	25.89	210	-3	0.0	7.4	0.0	0.93	2026
9/11/94	20:50	-7.98	-125.02	35.52	25.99	205	2	0.1	6.5	6.2	0.69	2023
9/12/94	21:11	-7.97	-125.02	35.28	25.63			0.0	7.9	5.8	0.70	2026

Table 2. EQUATORIAL PACIFIC FALL 1994 SUPPORT MEASUREMENTS

Date	Time (GMT)	Latitude	Longitude	Salinity	Temp. (°C)	O ₂ (μmol·l ⁻¹)	AOU (μmol·l ⁻¹)	NO ₂ (μmol·l ⁻¹)	NO ₃ (μmol·l ⁻¹)	SiO ₃ (μmol·l ⁻¹)	PO ₄ (μmol·l ⁻¹)	DIC (μmol·kg ⁻¹)
9/16/94	3:40	-8.00	-109.97	35.25	23.27	217	0	0.0	15.6	9.6	1.23	2064
9/16/94	3:40	-8.00	-109.97	35.25	23.27	215	2	0.2	11.5	0.9	1.00	
9/16/94	9:36	-8.00	-109.98	35.21	23.10	212	5	0.2	15.3	2.1	1.31	2066
9/16/94	15:25	-6.00	-109.98	35.17	23.28	209	8	0.1	12.1	1.9	1.09	2060
9/16/94	21:47	-4.97	-110.00	35.34	23.77	216	-1	0.0	12.9	8.2	1.01	2063
9/17/94	3:06	-3.98	-109.98	35.53	23.98	209	5	0.2	8.9	0.0	1.03	2047
9/17/94	8:45	-3.01	-109.97	34.90	22.76	190	16	0.3	12.1	3.6	1.16	2038
9/17/94	14:33	-2.01	-109.99	34.87	22.27	196	25	0.0	11.4	11.2	0.89	2046
9/17/94	20:32	-0.99	-110.00	34.91	21.52			0.5	14.0	4.7	1.22	2062
9/17/94	22:35	-0.48	-110.01	34.90	21.89	186	36	0.5	15.5	6.5	1.36	2062
9/17/94	23:45	-0.25	-110.02	34.89	21.93	184	38	0.0	15.6	16.2	1.15	2064
9/18/94	7:13	0.02	-109.98	34.87	22.02	190	32					2057
9/18/94	7:13	0.02	-109.98	34.87	22.02							2060
9/19/94	6:44	0.31	-109.14	34.96	21.88	182	40					2064

7.3. Nutrient Analysis Methods

Nutrient samples were collected from 10-L Niskin bottles or from the underway line in aged 60 ml linear polyethylene bottles after three complete seawater rinses. They were flash frozen by submerging the bottle in a salt/ice mixture and stored in the dark at -10 °C until analysis, several months after collection. Concentrations of dissolved inorganic nitrite (NO₂), dissolved inorganic nitrate (NO₃), and silicate (SiO₄), reported in $\mu\text{mol}\cdot\text{l}^{-1}$, were determined using an AlpKem RFA/2 Auto-Analyzer on shore.

7.3.1. Nitrate and Nitrite

The automated colorimetric procedures and methodologies used in the analysis of nitrite and nitrate are similar to those described by Armstrong et al. (1967), with modifications described in Atlas et al. (1971). Standardizations were performed prior to each sample run with working solutions from pre-weighed "Baker Analyzed" reagent-grade standards. Nitrite was determined by diazotizing with sulfanilamide and coupling with N-1 naphylethelendiamine dihydrochloride to form an azo dye. The color produced is proportional to the nitrite concentration. Samples for nitrate analysis were passed through a copperized cadmium column, which reduces nitrate to nitrite and the resulting nitrite concentration was then determined as described above. The detection limits for nitrite and nitrate were 0.1 $\mu\text{mol}\cdot\text{l}^{-1}$ and 0.4 $\mu\text{mol}\cdot\text{l}^{-1}$, respectively. The precision of duplicate standards measurements was $\pm 4\%$ at 8 $\mu\text{mol}\cdot\text{l}^{-1}$ for nitrite and $\pm 4\%$ at 40 $\mu\text{mol}\cdot\text{l}^{-1}$ for nitrate. The accuracy for both analyses was assumed to be $\pm 10\%$ since no absolute standards are available.

7.3.2. Silicates

The analytical procedures and methodologies used in the analysis of silicate are similar to those described by Armstrong et al. (1967), with modifications described in Atlas et al. (1971). Silicate was determined from the reduction of silicomolybdate in acidic solution to molybdenum blue by ascorbic acid. The color produced is proportional to the concentration of silicate in the sample, with a detection limit of 0.4 $\mu\text{mol}\cdot\text{l}^{-1}$.

7.4. Chlorophyll Extraction and Analysis

Chlorophyll *a* and phaeopigments were determined by the fluorometric technique using a Turner Designs Model 10-AU-005 R fluorometer that was calibrated with commercial chlorophyll *a* (Sigma). Samples for determination of plant pigments were filtered onto 25 mm Whatman GF/F glass fiber filters and extracted in 90% acetone in a freezer for between 24 and 30 hours (Venrick and Hayward, 1984). Other than the modification of the extraction procedure, the method used is the conventional fluorometric procedure of Holm-Hansen et al. (1965) and Lorenzen (1966).

8. NOAA SHIP DISCOVERER CRUISES

The first leg of the Discoverer CGC94 cruise departed Seattle, WA on January 26, 1994 to begin the transit to Punta Arenas, Chile. Underway measurements were conducted for pH, pCO₂, nitrous oxide, methyl bromide, salinity and temperature from the ship's underway sea water system. The second leg (Leg 2) departed Punta Areas on February 22, 1994. The ship steamed from the entrance of the Strait of Magellan to the first station at 67 °S, 103 °W. Seventy-eight stations were occupied along 103 °W, following WOCE Hydrographic Program (WHP) protocol.

The last station occupied on Leg 2 was at 26 °S, 103 °W, and the ship docked in Isla de Pascua, Chile on March 24. The third leg (Leg 3) departed Isla de Pascua on March 29, 1994 and proceeded to 25°30' S, 103°W, where 30 nautical mile spacing was resumed along 103 °W to 10 °S. Stations were occupied along a dog-leg from 10 °S, 103 °W to 5 °S, 110°20' W over the East Pacific Rise. The 30-nautical mile spacing was resumed from 5 °S to 3 °S along 110°20' W; from 3 °N to 22 °30' N stations were occupied at 30 nautical mile intervals, except from 12 °N to 16 °N, where spacing was increased to 40 nautical mile. A gradual shift in longitude from 110°20' W to 110 °W was made between 8 °N and 10 °N. North of 22°30' N, station spacing was reduced to as little as 3 nautical mile over the rapidly shoaling bathymetry approaching Cabo San Lucas. The last station occupied was at 22°51' N, 110 °W, and the cruise ended in San Diego on April 27, 1994.

Underway pCO₂ measurements were made using the non-dispersive infrared method discussed in detail in Wanninkhof and Thoning (1993). Temperature and pressure corrections were made using the methods described by Murphy et al. (1993; 1994). The precision of the method is $\pm 1.0 \mu\text{atm}$. The thermistors used on the CGC94 cruise were calibrated against a NIST-traceable mercury thermometer (Brooklyn Thermometers Co, Farmingdale, NY). The thermistors were calibrated from 18 to 30 °C in 1° increments during the cruise on April 29, 1994.

ACKNOWLEDGMENTS

This work would not have been possible without the support of the crew and officers of NOAA ships MALCOLM BALDRIGE and DISCOVERER. In particular, we wish to acknowledge the commanding officers of the MALCOLM BALDRIGE and DISCOVERER, Captains C. Nelson, and D. MacAllister. The survey department of the MALCOLM BALDRIGE, chief survey technician Dennis Sweeney, Julian Saragoza, and Roger Lemire, maintained the underway system during the entire campaign, and dutifully took samples and logged data as required. They deserve much credit for the quality of the data set obtained at sea. Matt Steckley and Hua Chen, former employees of the AOML CO₂ group, built the underway system 1.5. This is PMEL contribution number 1850.

REFERENCES

- Armstrong F. A. J., Stearns C. R., 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., Callaway J. C., Tomlinson R. D., Gordon L. I., Barstow L., 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. .
- Carpenter J. H. 1965. The Chesapeake Bay Institute technique for the Winkler Dissolved Oxygen method. *Limnol. Oceanogr.* **10**, 141-143.
- Chen H., Wanninkhof R., Feely R. A., and Greeley D. 1995. Measurement of fugacity of carbon dioxide in sub-surface water: an evaluation of a method based on infrared analysis. Technical Memorandum ERL-AOML 85, NOAA/AOML, Miami, FL, pp. 49.
- Dandonneau Y. 1995. Sea-surface partial pressure of carbon dioxide in the Eastern Equatorial Pacific (August 1991 to October 1992): A multivariate analysis of physical and biological factors. *Deep-Sea Res.* **42**, 349-364.
- DOE. 1994. *Handbook of methods for the analysis of the various parameters of the carbon dioxide system in sea water. Version 2.* ORNL/CDIAC-74.
- Feely R. A., Gammon R. H., Taft B. A., Pullen P. E., Waterman L. S., Conway T. J., Gendron J. F., and Wisegarver D. P. 1987. Distribution of chemical tracers in the Eastern Equatorial Pacific during and after the 1982-1983 El Niño/southern oscillation event. *J. Geophys. Res.* **92**, 6545-6558.
- Feely R. A., Wanninkhof R., Cosca C. E., McPhaden M. J., Byrne R. H., Millero F. J., Chavez F. P., Clayton T., Campbell D. M., and Murphy P. P. 1994. The effect of tropical instability waves on CO₂ species distribution along the Equator in the Eastern Equatorial Pacific during the 1992 ENSO event. *Geophys. Res. Lett.* **21**, 277-280.
- Feely R. A., Wanninkhof R., Cosca C. E., Murphy P. P., Lamb M. F., and Steckley M. D. 1995a. CO₂ distributions in the Equatorial Pacific during the 1991-92 ENSO Event. *Deep-Sea Res.* **42**, 365-386.
- Feely R. A., Wanninkhof R., Cosca C. E., Murphy P. P., Lamb M. F., and Steckley M. D. 1995b. fCO₂ distributions in the Eastern Equatorial Pacific during and after the 1992-93 El Niño. In *Global fluxes of carbon and its related substances in the coastal sea-ocean-atmosphere system* (ed. J. c. f. t. IGBP). Hokkaido, Sapporo Hokkaido, Japan, 361-367.
- Friederich G. E., Sherman P., and Codispoti L. A. 1984. A high precision automated Winkler titration system based on an HP-85 computer, a simple colorimeter and an inexpensive electromechanical burette. Tech. Report 42, Bigelow Lab. for Ocean Sciences.

- Holm-Hansen O., Lorenzen C. J., Holmes R. W., and Strickland J. D. H. 1965. Fluorometric determination of chlorophyll. *J. Cons. Int. Explor. Mer* **30**, 3-15.
- 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.
- 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.
- 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.
- LI-COR. 1990. LI-6262 CO₂/H₂O Analyzer Operating and Service Manual. 9003-59, LI-COR, Lincoln, NB.
- Lorenzen C. J. 1966. A method for the continuous measurement of in vivo chlorophyll concentration. *Deep-Sea Res.* **13**, 223-227.
- Murphy P. P., Cosca C., Lee D. C., and Feely R. A. 1993. Temperature calibration and correction report for PMEL trace gas cruises 1986-1989. NOAA Technical Memorandum, NOAA/PMEL, Seattle, pp. 192 + 1 diskette.
- Murphy P. P., Feely R. A., Gammon R. H., Kelly K. C., and Waterman L. S. 1991. Autumn air-sea disequilibrium of CO₂ in the South Pacific Ocean. *Mar. Chem.* **35**, 77-84.
- Murphy P. P., Kelly K. C., Feely R. A., and Gammon R. H. 1994. Carbon dioxide concentrations in surface water and the atmosphere: PMEL cruises 1986-1989. NOAA Technical Memorandum, NOAA/PMEL, Seattle pp. 185.
- Takahashi T., Olafsson J., Goddard J. G., Chipman D. W., and Sutherland S. C. 1993. Seasonal variation of CO₂ and nutrients in the high-latitude surface oceans: a comparative study. *Global Biogeochem. Cycles* **7**, 843-878.
- Venrick E. L. and Hayward T. L. 1984. Determining chlorophyll on the 1984 CalCOFI surveys, California Coop. Oceanic Fish. Invest. Report 24. .
- Wanninkhof R., Feely R. A., Atwood D. K., Berberian G. A., Wilson W. D., Murphy P. P., and Lamb M. F. 1995. Seasonal and lateral variations in carbon chemistry of surface water in the Eastern Equatorial Pacific during 1992. *Deep-Sea Res.* **42**, 387-410.
- Wanninkhof R., Feely R. A., Chen H., Cosca C., and Murphy P. 1996. Surface water fCO₂ in the Eastern Equatorial Pacific during the 1992-93 El Niño. *J. Geophys. Res.* **101**, 16333-16343.
- Wanninkhof R. and Thoning K. 1993. Measurement of fugacity of CO₂ in surface water using continuous and discrete sampling methods. *Mar. Chem.* **44**, 189-205.

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., Janke R. A., and Keeling C. D. 1982. Seasonal effects of temperature and salinity on the partial pressure of CO₂ in seawater. *Nature* **300**, 511-513.

**A: BASIC PROGRAM FOR OPERATION OF UNDERWAY
SYSTEM VERSION 1.5'**

```

10 '*****
11 '*
12 '*          WELCOME TO NOAA\AOML UNDERWAY pCO2 GROUP
13 '*
14 '*****
15 '
16 '
17 'THIS PROGRAM IS MADE FOR AOML UNDERWAY pCO2 SYSTEM.
18 '
19 'NAME OF PROGRAM: UWPCO2.BAS
20 '
21 'VERSION: 1.5, MARCH, 1994
22 '
100 '
110 '-----
120 ' SECTION 1.  INITIALIZATION
130 '-----
140 '
150 KEY OFF:CLS
160 'Contract BASIC working space to 64k
170 CLEAR, 60000!
180 DEF SEG =0
190 'Find start of BASIC's segment
200 SG=256*PEEK(&H511)+PEEK(&H510)
210 DEF SEG
220 'Initialize offset variable (DASCON1) into CALL routine to zero
230 DASCON1=0
240 'Work out segment to load DASCON1.BIN at end of working place
250 SG=(32768!/16)+SG
260 'Initialize call parameters and declare DIO%, AD% and other arrays
270 DIM DIO%(8), AD%(8)
280 DIM STD(3), STDNU(3)
290 DIM SAMP(4), TIR(4), TMS1(4), TMS2(4), PRES(4)
300 'Fetch base address from DASCON1.ADR file
310 OPEN "I", #1,"DASCON1.ADR":INPUT#1,BASADR%:CLOSE #1
320 'Load DASCON1.BIN
330 SG=&H5000
340 DEF SEG =SG
350 BLOAD "DASCON1.BIN",0
400 '
410 '-----
420 'SECTION 2.  MAIN CONTROL LOOP OF PROGRAM
430 '-----
440 '
450 LOPFRT=11 : ' STARTLINE FOR PRINT ON SCREEN
460 STD(1)=296.53 : STD(2)=347.87: STD(3)=524.87 : 'Standard CO2 in ppm, when
replacing standard tank, please change relative CO2 ppm value on this
line!
470 X1%=0 : GOSUB 7190 : 'reset system
480 GOSUB 5290
490 CN=CN+1
500 ' TIME CONTROL LOOP

```

```

510   TP0$=TIME$
520   TP1$=MID$(TP0$,4,2)
530   TP2$=RIGHT$(TP0$,2)
540   TP=VAL(TP1$)+VAL(TP2$)/60
550   IF CN<=1 GOTO 580
560   IF TP>=RT GOTO 710
570   LOCATE 1,1 : PRINT "START TIME IS";RT;"," , PRESENT TIME IS ";
      RIGHT$(TIME$,5): LOCATE 1,51 : PRINT "PLEASE WAIT." : GOTO 510
580   '
590   RT=12      : NW=4 : IF TP<RT GOTO 490
600   RT=16.5   : NW=3 : IF TP<RT GOTO 490
610   RT=21     : NW=2 : IF TP<RT GOTO 490
620   RT=25.5   : NW=1 : IF TP<RT GOTO 490
630   RT=30     : NA=3 : IF TP<RT GOTO 490
640   RT=34     : NA=2 : IF TP<RT GOTO 490
650   RT=38     : NA=1 : IF TP<RT GOTO 490
660   RT=42     : NW=4 : IF TP<RT GOTO 490
670   RT=46.5   : NW=3 : IF TP<RT GOTO 490
680   RT=51     : NW=2 : IF TP<RT GOTO 490
690   RT=55.5   : NW=1 : IF TP<RT GOTO 490
700   RT=59.97 : GOTO 490
710   '
720   IF RT=59.97 GOTO 770
730   IF RT<=25.5 GOTO 790
740   IF RT>=30 AND RT<=38 GOTO 810
750   IF RT>=42 AND RT<=55.5 GOTO 830
760   '
770   GOSUB 1000 :           'starting standard measurement section
780   NW=4      :           'NW is total measurements in one water section
790   GOSUB 2000 :           'Starting water sample measurement section
800   NA=3     :           'NA is total measurements in one air section
810   GOSUB 3000 :           'Starting air sample measurement section
820   NW=4     :           'NW is total measurements in one water section
830   SN=1 : GOSUB 2000 :   'SN is the # of finished water section in this hour
840   ' TIME RESET LOOP
850   TP0$=TIME$
860   TP1$=MID$(TP0$,4,2)
870   TP2$=RIGHT$(TP0$,2)
880   TP=VAL(TP1$)+VAL(TP2$)/60
890   IF TP<=55.5 GOTO 770
900   GOTO 850
910   '
920   '-----
930   'SECTION 3. SUBROUTINES
940   '-----
950   '
960   '
970   ' SECTION 3-1. SUBROUTINES FOR MEASUREMENTS OF STANDARDS, WATER, AND AIR
980   '-----
990   '
1000  'SECTION 3-1-1. SUBROUTINE FOR STANDARD MEASUREMENTS
1010  '.....
1020  SN=0 :           'SN is the # of finished water section in this hour
1030  CLS : GOSUB 5290
1040  LOFPRT=11 : ' STARTLINE FOR PRINT ON SCREEN
1050  SAMPNAM$="STD "
1060  FOR I=1 TO 3
1070  STDSUM=0 : TIRSUM=0 : TMS1SUM=0 : TMS2SUM=0

```

```

1080 X=1+2^I
1090 XI%=X : GOSUB 7190
1100 TIMPOINT$=TIME$
1110 RTIME1$=MID$(TIMPOINT$,4,2)
1120 RTIME2$=RIGHT$(TIMPOINT$,2)
1130 INTVAL=210 : STATUS$="FLUSH"
1140 RTIME=VAL(RTIME1$)*60+VAL(RTIME2$)
1150 GOSUB 6120
1160 XI%=0 : GOSUB 7190
1170 INTVAL=220 : STATUS$="PR_EQ" : GOSUB 6120
1172 XI%=65 : GOSUB 7190
1180 LOCATE 1,49 : PRINT "SCAN "
1190 GOSUB 7030
1200 FOR J=1 TO 3
1210 TI=2 : GOSUB 6030
1220 GOSUB 7110
1230 STDSUM=STDSUM+AD%(0) : TIRSUM=TIRSUM+AD%(1)
1240 TMS1SUM=TMS1SUM+AD%(2) : TMS2SUM=TMS2SUM+AD%(3)
1250 NEXT J
1260 XI%=0 : GOSUB 7190
1270 J=J-1
1280 MUAUE=STDSUM/J : TIRAVE=TIRSUM/J
1290 TMS1AUE=TMS1SUM/J : TMS2AUE=TMS2SUM/J
1300 STDMU(I)=MUAUE
1310 GOSUB 4030
1320 GOSUB 4230
1330 GOSUB 4510
1340 X=STD(I) : CHL0=STD(I) : CHL1=TIR : CHL2=TMS1 : CHL3=TMS2
1350 GOSUB 5030
1360 LOCATE 8,11
1370 PRINT USING "*****.** *****.** *****.**"; STDMU(1);STDMU(2);STDMU(3)
1380 INTVAL=236 : STATUS$="SAVE " : GOSUB 6120
1390 NEXT I
1400 RETURN
1410 '
1420 '
2000 'SECTION 3-1-2. SUBROUTINE FOR WATER MEASUREMENT
2010 '.....
2020 SAMPNAM$="WAT "
2030 TSAMP=0 : TTIR=0 : TTMS1=0 : TTMS2=0 : TPRES=0
2040 DSAMP=0 : DTIR=0 : DTMS1=0 : DTMS2=0 : DPRES=0
2050 '
2060 FOR M=1 TO NW
2070 N=4-NW+M
2080 TEND=12+30*SN+4.5*N
2090 XI%=129 : GOSUB 7190
2100 TIMPOINT$=TIME$
2110 RTIME1$=MID$(TIMPOINT$,4,2)
2120 RTIME2$=RIGHT$(TIMPOINT$,2)
2130 INTVAL=240 : STATUS$="FLUSH"
2140 RTIME=VAL(RTIME1$)*60+VAL(RTIME2$) : GOSUB 6120
2150 XI%=0 : GOSUB 7190
2160 INTVAL=250 : STATUS$="PR_EQ" : GOSUB 6120
2162 XI%=65 : GOSUB 7190
2170 LOCATE 1,49 : PRINT "SCAN "
2180 GOSUB 7030
2190 SAMPSUM=0 : TIRSUM=0 : TMS1SUM=0 : TMS2SUM=0
2200 'SCANNING

```

```

2210 FOR J=1 TO 3
2220 TI=2 : GOSUB 6030
2230 GOSUB 7110
2240 SAMP SUM=SAMP SUM+AD%(0) : TIR SUM=TIR SUM+AD%(1) : TMS1 SUM=TMS1 SUM+AD%(2) :
      TMS2 SUM=TMS2 SUM+AD%(3)
2250 NEXT J
2252 X1%=0 : GOSUB 7190
2260 J=J-1
2270 MUAVE=SAMP SUM/J : TIRAVE=TIR SUM/J : TMS1AVE=TMS1 SUM/J : TMS2AVE=TMS2 SUM/J
2280 GOSUB 4030
2290 GOSUB 4120
2300 GOSUB 4230
2310 GOSUB 4510
2320 X=-99.99 : CHL0=SAMP : CHL1=TIR : CHL2=TMS1 : CHL3=TMS2
2330 GOSUB 5030
2340 SAMP(M)=SAMP : TIR(M)=TIR : TMS1(M)=TMS1 : TMS2(M)=TMS2 : PRES(M)=PRES
2350 TSAMP=TSAMP+SAMP : TTIR=TTIR+TIR : TTMS1=TTMS1+TMS1 : TTMS2=TTMS2+TMS2 :
      TPRES=TPRES+PRES
2360 STATUS$="SAVE "
2370 GOSUB 5210
2380 TP0$=TIME$ : TP1$=MID$(TP0$,4,2) : TP2$=RIGHT$(TP0$,2):
      TP=VAL(TP1$)+VAL(TP2$)/60
2390 DIFF=(TEND-TP)*60 : IF TEND>55.5 AND DIFF<=4 GOTO 2440
2400 IF DIFF<=0 THEN 2440 ELSE 2410
2410 LOCATE 1,1 : PRINT "GAS IN IR: ";SAMPNAM$;"/ START AT: ";TIMPOINT$; "/
      STATUS: ";STATUS$;"/ SEC. REMAINING: ";FIX(DIFF)
2420 COLOR 0,7 : LOCATE 23,1 : PRINT " ";DATE$;" ";TIME$;" " : COLOR 7,0
2430 GOTO 2380
2440 NEXT M
2450 '
2460 M=M-1
2470 MSAMP=TSAMP/M : WMSAMP=MSAMP : AMSAMP=-99.99 : MTIR=TTIR/M :
      MTMS1=TTMS1/M : MTMS2=TTMS2/M : MPRES=TPRES/M
2480 FOR I=1 TO M
2490 DSAMP=DSAMP+(SAMP(I)-MSAMP)^2 : DTIR=DTIR+(TIR(I)-MTIR)^2 :
      DTMS1=DTMS1+(TMS1(I)-MTMS1)^2 : DTMS2=DTMS2+(TMS2(I)-MTMS2)^2 :
      DPRES=DPRES+(PRES(I)-MPRES)^2
2500 NEXT I
2510 IF M=1 THEN M=2 ELSE M=M
2520 STSAMP=SQR(DSAMP/(M-1)) : WSTSAMP=STSAMP : ASTSAMP=-99.99 :
      STTIR=SQR(DTIR/(M-1)) : STTMS1=SQR(DTMS1/(M-1)) : STTMS2=SQR(DTMS2/(M-
      1)):STPRES=SQR(DPRES/(M-1))
2530 GOSUB 5100
2540 IF SN>=1 THEN 2580 ELSE 2550
2550 LOCATE 6,58 : PRINT USING " ***,**" ***,**"; MSAMP; STSAMP
2560 WATPPM1=MSAMP : WATSTD1=STSAMP
2570 GOTO 2600
2580 LOCATE 8,58 : PRINT USING " ***,**" ***,**"; MSAMP; STSAMP
2590 WATPPM2=MSAMP : WATSTD2=STSAMP
2600 RETURN
2610 '
2620 '
3000 'SECTION 3-1-3. SUBROUTINE FOR AIR MEASUREMENT
3010 '.....
3020 SAMPNAM$="AIR "
3030 TSAMP=0 : TTIR=0 : TTMS1=0 : TTMS2=0 : TPRES=0
3040 DSAMP=0 : DTIR=0 : DTMS1=0 : DTMS2=0 : DPRES=0
3050 '

```



```

3060 FOR M=1 TO NA
3070 N=3-NA+M
3080 TEND=30+4*N
3090 X1%=17 : GOSUB 7190
3100 TIMPOINT$=TIME$
3110 RTIME1$=MID$(TIMPOINT$,4,2)
3120 RTIME2$=RIGHT$(TIMPOINT$,2)
3130 INTVAL=210 : STATUS$="FLUSH"
3140 RTIME=VAL(RTIME1$)*60+VAL(RTIME2$) : GOSUB 6120
3150 X1%=0 : GOSUB 7190
3160 INTVAL=220 : STATUS$="PR_EQ" : GOSUB 6120
3162 X1%=65 : GOSUB 7190
3170 LOCATE 1,49 : PRINT "SCAN "
3180 GOSUB 7030
3190 SAMPSUM=0 : TIRSUM=0 : TMS1SUM=0 : TMS2SUM=0
3200 'SCANNING
3210 FOR J=1 TO 3
3220 TI=2 : GOSUB 6030
3230 GOSUB 7110
3240 SAMPSUM=SAMPSUM+AD$(0) : TIRSUM=TIRSUM+AD$(1) : TMS1SUM=TMS1SUM+AD$(2)
: TMS2SUM=TMS2SUM+AD$(3)
3250 NEXT J
3252 X1%=0 : GOSUB 7190
3260 J=J-1
3270 MUAUE=SAMPSUM/J : TIRAVE=TIRSUM/J : TMS1AVE=TMS1SUM/J : TMS2AVE=TMS2SUM/J
3280 GOSUB 4030
3290 GOSUB 4120
3300 GOSUB 4230
3310 GOSUB 4510
3320 X=-99.99 : CHL0=SAMP : CHL1=TIR : CHL2=TMS1 : CHL3=TMS2
3330 GOSUB 5030
3340 SAMP(M)=SAMP : TIR(M)=TIR : TMS1(M)=TMS1 : TMS2(M)=TMS2 : PRES(M)=PRES
3350 TSAMP=TSAMP+SAMP : TTIR=TTIR+TIR : TTMS1=TTMS1+TMS1 : TTMS2=TTMS2+TMS2 :
TPRES=TPRES+PRES
3360 STATUS$="SAVE "
3370 GOSUB 5210
3380 TP0$=TIME$ : TP1$=MID$(TP0$,4,2) : TP2$=RIGHT$(TP0$,2) :
TP=VAL(TP1$)+VAL(TP2$)/60
3390 DIFF=(TEND-TP)*60 : IF DIFF<=0 THEN 3430 ELSE 3400
3400 LOCATE 1,1 : PRINT "GAS IN IR: ";SAMPNAM$;"/ START AT: ";TIMPOINT$; "/
STATUS: ";STATUS$;"/ SEC. REMAINING: ";FIX(DIFF)
3410 COLOR 0,7 : LOCATE 23,1 : PRINT " ";DATE$;" " ;TIME$;" " : COLOR 7,0
3420 GOTO 3380
3430 NEXT M
3440 '
3450 M=M-1
3460 MSAMP=TSAMP/M : AMSAMP=MSAMP : WMSAMP=-99.99 : MTIR=TTIR/M :
MTMS1=TTMS1/M : MTMS2=TTMS2/M : MPRES=TPRES/M
3470 FOR I=1 TO M
3480 DSAMP=DSAMP+(SAMP(I)-MSAMP)^2 : DTIR=DTIR+(TIR(I)-MTIR)^2 :
DTMS1=DTMS1+(TMS1(I)-MTMS1)^2 : DTMS2=DTMS2+(TMS2(I)-MTMS2)^2 :
DPRES=DPRES+(PRES(I)-MPRES)^2
3490 NEXT I
3500 IF M=1 THEN M=2 ELSE M=M
3510 STSAMP=SQR(DSAMP/(M-1)) : ASTSAMP=STSAMP : WSTSAMP=-99.99 :
STTIR=SQR(DTIR/(M-1)) : STTMS1=SQR(DTMS1/(M-1)) : STTMS2=SQR(DTMS2/(M-1))
: STPRES=SQR(DPRES/(M-1))
3520 GOSUB 5100

```

```

3530 LOCATE 7,58 : PRINT USING " ***,**      ***,**"; MSAMP; STSAMP
3540 AIRPPM=MSAMP : AIRSTD=STSAMP
3550 RETURN
3560 '
3570 '
4000 'SECTION 3-2. INTERFACE BETWEEN THERMISTERS, GPS AND BAROMETER
4010 '-----
4020 '
4030 'SECTION 3-2-1. THERMISTERS mV--CENTIGRADE CONVERSION
4040 '.....
4050 'Temperature of IR cell
4060 TIR=-.058558+.05057*TIRAVE+1.5527E-07*(TIRAVE)^2
4070 'Temperature of Equilibrator
4072 '
4073 '
4074 '
4075 ' THIS IS THE EQUATION TO CHANGE UPON COMPLETING A NEW
4076 '      TEMPERATURE CALIBRATION
4077 '
4080 TMS1=73.6908-.0.0383166*TMS1AVE+8.5113E-06*TMS1AVE^2-7.868E-10*TMS1AVE^3
4090 'Flow rate of equilibrator
4100 TMS2=30/(4260-852)*(TMS2AVE-852)
4110 RETURN
4120 '
4130 '
4140 'SECTION 3-2-2. CONVERT SAMPLE mV TO PPM BY INTERCEPTION
4150 '.....
4160 IF STD MU(1)=0 THEN 4170 ELSE 4180
4170 STD MU(1)=38 : STD MU(2)=460 : STD MU(3)=950
4180 A=((STD MU(1)-STD MU(2))/(STD MU(1)-STD MU(3))*(STD(3)-STD(1))-(STD(2)-
STD(1)))/((STD MU(1)-STD MU(2))*(STD MU(2)-STD MU(3)))
4190 B=((STD(1)-STD(2))-A*(STD MU(1)^2-STD MU(2)^2))/(STD MU(1)-STD MU(2))
4200 C=STD(1)-B*STD MU(1)-A*STD MU(1)^2
4210 SAMP=A*MUAVE^2+B*MUAVE+C
4220 RETURN
4230 '
4240 '
4250 'SECTION 3-2-3. LATITUDE AND LONGITUDE FROM GPS
4260 '.....
4270 'IN CASE OF GPS FAILURE, REMOVE SIGN ('), GOTO LINE "RETURN".
4280 'PRINT CHR$(10)
4290 OPEN "COM2:9600,n,8,1,RS,CS,DS,CD" AS #2
4300 B$=CHR$(36)+CHR$(80)+CHR$(77)+CHR$(71)+CHR$(76)+CHR$(73)+CHR$(44)+
CHR$(48)+CHR$(48)+CHR$(44)+CHR$(66)+CHR$(48)+CHR$(48)+CHR$(44)+CHR$(49)+
CHR$(44)+CHR$(65)+CHR$(44)+CHR$(48)+CHR$(48)+CHR$(13)+CHR$(10)
4310 PRINT #2,B$
4320 G$=INPUT$(34,#2)
4330 GPS$=MID$(G$,15,20)
4340 'PRINT GPS$
4350 'PRINT CHR$(10)
4360 CLOSE #2
4370 OPEN "COM2:9600,n,8,1,RS,CS,DS,CD" AS #2
4380 LOCATE 3,1 : PRINT "GPS: ";GPS$
4390 CLOSE #2
4400 LATD$=LEFT$(GPS$,2) : LATM$=MID$(GPS$,3,2)
4410 LATSS$=MID$(GPS$,6,2) : LATI$=MID$(GPS$,9,1)
4420 IF LATI$="N" THEN LATI=1 ELSE LATI=-1
4430 LAT=LATI*(VAL(LATD$)+VAL(LATM$)/60+VAL(LATSS$)/3600)

```

```

4440 LOGD$=MID$(GPS$,11,3) : LOGM$=MID$(GPS$,14,2)
4450 LOGS$=MID$(GPS$,17,2) : LOGI$=RIGHT$(GPS$,1)
4460 IF LOGI$="E" THEN LOGI=1 ELSE LOGI=-1
4470 LONG=LOGI*(VAL(LOGD$)+VAL(LOGM$)/60+VAL(LOGS$)/3600)
4480 RETURN
4490 '
4500 '
4510 'SECTION 3-2-4. PRESSURE (mB) FROM BAROMETER
4520 '.....
4530 'GOTO 4610 : 'IN CASE OF BARO. FAILURE, REMOVE SIGN ', GOTO LINE "RETURN"
4540 OPEN "com1:2400,n,8,1,RS" AS #3
4550 C$=CHR$(80)
4560 PRINT #3,C$
4570 P$=INPUT$(20,#3)
4580 PP$=MID$(P$,2,7)
4590 PRES=VAL(PP$)
4600 CLOSE #3
4610 RETURN
4620 '
4630 '
4640 '
5000 'SECTION 3-3. OUTPUT DATA TO DATAFILES IN DISK AND SHOW DATA ON SCREEN
5010 '-----
5020 '
5030 'SECTION 3-3-1. SAVE LATEST DATA TO DATAFILE "UWMMVY" (e.g. UW0394)
5040 '.....
5050 FILENAME$="UW"+LEFT$(DATE$,2)+"94"
5060 OPEN FILENAME$ FOR APPEND AS #3
5070 PRINT #3, SAMPNAM$; DATE$;" "; TIME$;" "; LAT; LONG;" "; X; MUAVE;
CHL0; TIRAVE;CHL1; TMS1AVE;CHL2; TMS2AVE; CHL3; PRES
5080 CLOSE #3
5090 RETURN
5100 '
5110 '
5120 'SECTION 3-3-2. SAVE AVG. & STDEV. TO DATAFILE "UWMMYAUG" (e.g. UW034AUG)
5130 '.....
5140 FILENAME$="UW"+LEFT$(DATE$,2)+"5"+"AUG"
5150 OPEN FILENAME$ FOR APPEND AS #3
5160 PRINT #3, SAMPNAM$; DATE$;" "; TIME$;" "; LAT; LONG; MTIR; STIR;
MTMS1; STMS1; MTMS2; STMS2; MPRES;STPRES; WMSAMP; WSTSAMP; AMSAMP;
STSAMP
5170 CLOSE #3
5180 RETURN
5190 '
5200 '
5210 'SECTION 3-3-3. SHOW LATEST DATA ON SCREEN
5220 '.....
5230 LOFPRT=LOFPRT+1
5240 LOCATE LOFPRT,1 :PRINT SAMPNAM$;TIME$;
5250 PRINT USING " ***.## ****.## ***.## ***.## **.*## *****.##";
AT;LONG;CHL0;CHL1;CHL2;CHL3;PRES
5260 RETURN
5270 '
5280 '
5290 'SECTION 3-3-4. SHOW STANDARD INFORMATION ON SCREEN
5300 '.....
5310 COLOR 0,7 : LOCATE 5,1
5320 PRINT " CO2 STANDARDS INFORMATION " : COLOR 7,0

```

```

5330 LOCATE 7,1 : PRINT "STD ppm" : LOCATE 8,1 : PRINT "STD mU"
5340 LOCATE 6,1 : PRINT "STD #          STD_1   STD_2   STD_3"
5350 LOCATE 7,11
5360 PRINT USING "****.## ****.## ****.##"; STD(1);STD(2);STD(3)
5370 LOCATE 8,11
5380 PRINT USING "****.## ****.## ****.##"; STDMU(1);STDMU(2);STDMU(3)
5390 COLOR 0,7 : LOCATE 11,1 : PRINT "GAS  TIME          "
5400 LOCATE 11,15
5410 PRINT "D. LAT      D. LON      pCO2_PPM  IR_TEMP  EQ_TEMP  EQ_FLOW  PRESSURE  "
5420 COLOR 7,0
5430 '
5440 '
5450 'SECTION 3-3-5. SHOW LAST 60 MIN. AVG. AND STD DEV. ON SCREEN
5460 '.....
5470 LOCATE 3,48: PRINT "LAST 60 MIN AVG. AND STD. DEV"
5480 COLOR 0,7 : LOCATE 5,49 : PRINT " SAMPLE      P.P.M      STD. DEV " : COLOR
7,0
5490 LOCATE 6,50 : PRINT " WATER"
5500 LOCATE 6,58 : PRINT USING "   .##          .##.##"; WATPPM1; WATSTD1
5510 LOCATE 7,50 : PRINT "   AIR"
5520 LOCATE 7,58 : PRINT USING "   .##          .##.##"; AIRPPM; AIRSTD
5530 LOCATE 8,50 : PRINT " WATER"
5540 LOCATE 8,58 : PRINT USING "   .##          .##.##"; WATPPM2; WATSTD2
5550 COLOR 0,7 : LOCATE 23,54 : PRINT " DOC/NOAA/AOML/OCD/CO2 " : COLOR 7,0
5560 RETURN
5570 '
5580 '
5590 '
6000 'SECTION 3-4. TIME CONTROL AND TIME ALLOCATION
6010 '-----
6020 '
6030 'SECTION 3-4-1. ABSOLUT TIME INTERVAL CONTROL
6040 '.....
6050 U=TIMER
6060 T=TIMER
6070 IF T-U < 0 THEN U=-1*(86400!-U)
6080 IF T-U < TI THEN 6060
6090 RETURN
6100 '
6110 '
6120 'SECTION 3-4-2. TIME ALLOCATION BY CLOCK
6130 '.....
6140 TPOINT$=TIME$
6150 FACTOR1$=MID$(TPOINT$,4,2)
6160 FACTOR2$=RIGHT$(TPOINT$,2)
6170 FACTOR=VAL(FACTOR1$)*60+VAL(FACTOR2$)
6180 IF FACTOR=RTIME GOTO 6140
6190 IF FACTOR<RTIME THEN 6200 ELSE 6210
6200 FACTOR=FACTOR+3600
6210 LOCATE 1,1
6220 PRINT "GAS IN IR: ";SAMPNAM$;"/  START AT: ";TIMPOINT$;"/  STATUS: ";
STATUS$;"/  SEC. REMAINING: ";INTVAL-(FACTOR-RTIME)
6230 COLOR 0,7 : LOCATE 23,1 : PRINT " ";DATE$;" ";TIME$;" " : COLOR 7,0
6240 IF FACTOR-RTIME<INTVAL GOTO 6140
6250 RETURN
6260 '
6270 '
6280 '

```

```

7000 'SECTION 3-5. SUBROUTINES FOR RELAYBOARD AND SCANNING CONTRAL
7010 '-----
7020 '
7030 'SECTION 3-5-1. SUBROUTINE FOR A/D FREE RUN TO COLLECT DATA ON INTERRUPT
7040 '.....
7050 'test5
7060 CH2%=5 : MD2%=5
7070 CALL DASCON1 (MD2%, CH2%, AD%(0), AD%(1), BASADR%)
7080 RETURN
7090 '
7100 '
7110 'SECTION 3-5-2. SUBROUTINE FOR COLLECTING DATA FROM INTERRUPT
7120 '.....
7130 'test6
7140 CH2%=0 : MD2%=6
7150 CALL DASCON1 (MD2%, CH2%, AD%(0), AD%(1), BASADR%)
7160 RETURN
7170 '
7180 '
7190 'SECTION 3-5-3. SUBROUTINE FOR RELAYBOARD CONTROL
7200 '.....
7210 'test9----- Select desired configuration -----
-
7220 A$="1" : 'INPUT Desired configuration number <0-5>
7230 IF A$="" THEN CH%=0:GOTO 7250
7240 CH%=VAL(A$)
7245 DEF SEG=&H5000
7248 BLOAD "dascon1.bin",0
7250 IF CH%<0 OR CH%>5 THEN GOTO 7410
7260 ON (CH%+1) GOTO 7270,7290,7320,7330,7340,7380
7270 DIO%(0)=X1% : 'INPUT"PB output data <0-255>"
7280 GOTO 7410
7290 DIO%(0)=X1% : 'INPUT"PB output data <0-255>"
7300 DIO%(1)=0 : 'INPUT"PC output data <0-15>"
7310 GOTO 7410
7320 GOTO 7410
7330 DIO%(1)=0 : 'INPUT"PC output data <0-15>"
7340 CLS:'LOCATE 25,1:PRINT"D/A mode 9 - Digital output mode"
7350 LOCATE 1,1:PRINT:PRINT:PRINT"In strobed output mode PC0-3 function as
follows:-"
7360 DIO%(0)=X1% : 'INPUT"PB output data <0 - 255>"
7370 GOTO 7410
7380 CLS:LOCATE 25,1:PRINT"D/A mode 9 - Digital output mode"
7390 LOCATE 1,1:PRINT:PRINT:PRINT"In strobed input mode PC0-3 function as
follows:-"
7400 GOTO 7410
7410 MD%=9
7420 DEF SEG=&H5000
7430 '----- Enter call routine -----
-
7440 CALL DASCON1 (MD%, CH%, DIO%(0),DIO%(1), BASADR%)
7450 'CLS: LOCATE 25,1:PRINT"D/A mode 9 - Digital output mode":LOCATE 2,1
7460 IF DIO%(8) <> 0 THEN PRINT:PRINT"!!!!!!!!!! ERROR!!!!!!!!!!":GOTO 7470
7470 'LOCATE 23,1
7480 RETURN
7490 END

```


APPENDIX B: EXAMPLE OF UNDERWAY fCO₂ DATA FILE

JD	Date	Time	Lat	Long	xCO _{2,w}	xCO _{2,a}	Eq Temp	Pressure	SST (TSG)	Sal (TSG)	fCO _{2w, eq}	fCO _{2w, in situ}	fCO _{2a}	ΔfCO ₂
213.011	8/1/94	0:16:05	11.81	-74.59	395.36	358.41	27.09	1010.48	26.92	36.29	379.56	377.21	344.15	33.06
213.014	8/1/94	0:20:47	11.79	-74.61	395.20	358.41	27.09	1010.44	26.94	36.30	379.38	377.21	344.15	33.06
213.018	8/1/94	0:25:17	11.78	-74.62	395.42	358.41	27.10	1010.62	26.96	36.32	379.65	377.56	344.15	33.41
213.021	8/1/94	0:29:47	11.79	-74.63	395.52	358.41	27.12	1010.45	26.99	36.34	379.65	377.79	344.15	33.64
213.032	8/1/94	0:46:17	11.76	-74.69	395.75	358.41	27.22	1010.88	27.12	36.43	379.94	378.47	344.15	34.32
213.035	8/1/94	0:50:47	11.76	-74.70	395.85	358.41	27.24	1010.91	27.08	36.43	380.07	377.77	344.15	33.62
213.038	8/1/94	0:55:17	11.75	-74.72	395.95	358.41	27.21	1011.06	27.06	36.40	380.23	378.16	344.15	34.01
213.042	8/1/94	0:59:47	11.74	-74.74	395.88	358.41	27.21	1011.20	27.06	36.34	380.22	378.12	344.15	33.97
213.053	8/1/94	1:16:05	11.72	-74.79	393.84	357.34	27.07	1011.31	26.92	36.17	378.41	376.23	343.54	32.70
213.056	8/1/94	1:20:47	11.71	-74.80	393.58	357.34	27.07	1011.35	26.91	36.15	378.19	375.89	343.54	32.35
213.059	8/1/94	1:25:17	11.70	-74.83	393.87	357.34	27.03	1011.40	26.87	36.14	378.52	376.16	343.54	32.62
213.062	8/1/94	1:29:47	11.70	-74.84	394.46	357.34	27.00	1011.47	26.84	36.12	379.13	376.88	343.54	33.34
213.074	8/1/94	1:46:17	11.68	-74.89	393.94	357.34	26.97	1011.68	26.81	36.10	378.73	376.42	343.54	32.88
213.077	8/1/94	1:50:47	11.67	-74.90	393.55	357.34	26.94	1011.76	26.78	36.07	378.41	376.06	343.54	32.53
213.080	8/1/94	1:55:17	11.67	-74.93	393.35	357.34	26.90	1011.77	26.72	36.04	378.27	375.73	343.54	32.19
213.083	8/1/94	1:59:46	11.66	-74.94	393.16	357.34	26.86	1011.82	26.70	36.00	378.12	375.81	343.54	32.27
213.095	8/1/94	2:16:05	11.64	-74.99	393.70	357.23	26.92	1011.90	26.81	35.99	378.58	376.93	343.45	33.48
213.098	8/1/94	2:20:47	11.64	-75.00	393.31	357.23	26.94	1011.93	26.81	35.96	378.22	376.34	343.45	32.89
213.101	8/1/94	2:25:17	11.64	-75.02	392.52	357.23	26.97	1011.93	26.88	35.93	377.41	376.08	343.45	32.62
213.104	8/1/94	2:29:47	11.63	-75.04	391.61	357.23	27.04	1011.99	26.95	35.93	376.50	375.21	343.45	31.75
213.115	8/1/94	2:46:17	11.60	-75.09	390.41	357.23	27.09	1012.11	26.96	35.78	375.38	373.58	343.45	30.13
213.119	8/1/94	2:50:47	11.60	-75.10	390.15	357.23	27.10	1012.13	26.97	35.75	375.13	373.19	343.45	29.74
213.122	8/1/94	2:55:17	11.59	-75.12	389.89	357.23	27.10	1012.01	26.96	35.74	374.84	372.87	343.45	29.41
213.125	8/1/94	2:59:47	11.59	-75.14	389.66	357.23	27.09	1012.12	26.95	35.75	374.68	372.67	343.45	29.21
213.136	8/1/94	3:16:05	11.58	-75.19	388.87	357.28	27.01	1012.25	26.84	35.70	374.04	371.62	343.16	28.46
213.139	8/1/94	3:20:47	11.57	-75.20	388.22	357.28	26.97	1012.15	26.87	35.54	373.36	371.95	343.16	28.79
213.143	8/1/94	3:25:17	11.56	-75.22	388.06	357.28	27.09	1012.20	27.04	35.47	373.09	372.40	343.16	29.24
213.146	8/1/94	3:29:47	11.56	-75.24	388.16	357.28	27.19	1012.09	27.19	35.55	373.03	373.07	343.16	29.91
213.157	8/1/94	3:46:17	11.53	-75.30	391.11	357.28	27.59	1012.00	27.54	36.16	375.56	374.85	343.16	31.69
213.160	8/1/94	3:50:47	11.53	-75.31	390.62	357.28	27.65	1011.96	27.57	36.29	375.05	373.91	343.16	30.75
213.163	8/1/94	3:55:17	11.53	-75.33	389.62	357.28	27.69	1012.00	27.62	36.29	374.06	373.01	343.16	29.85
213.167	8/1/94	3:59:47	11.52	-75.34	388.55	357.28	27.76	1011.93	27.66	36.29	372.97	371.66	343.16	28.50
213.178	8/1/94	4:16:05	11.49	-75.40	387.23	357.24	27.85	1011.89	27.78	36.25	371.60	370.63	342.49	28.14
213.181	8/1/94	4:20:47	11.49	-75.41	386.97	357.24	27.89	1011.82	27.82	36.24	371.30	370.22	342.49	27.72
213.184	8/1/94	4:25:17	11.48	-75.43	387.10	357.24	27.92	1011.79	27.85	36.24	371.38	370.33	342.49	27.83

APPENDIX C: PLOTS OF $f\text{CO}_2\text{a}$, $f\text{CO}_2\text{w}$, SST AND SAL VS. LATITUDE

This section contains results from the cruises of the NOAA ship MALCOLM BALDRIGE in the Equatorial Pacific in the (boreal) spring and fall of 1994; and from the DISCOVERER along nominally 110 °W in the spring of 1994 in a series of plots with $f\text{CO}_2$ air and water versus latitude as top panel (● = $f\text{CO}_2\text{w}$; □ = $f\text{CO}_2\text{a}$) and temperature and salinity versus latitude as bottom panel (× = SST; ○ = Salinity).

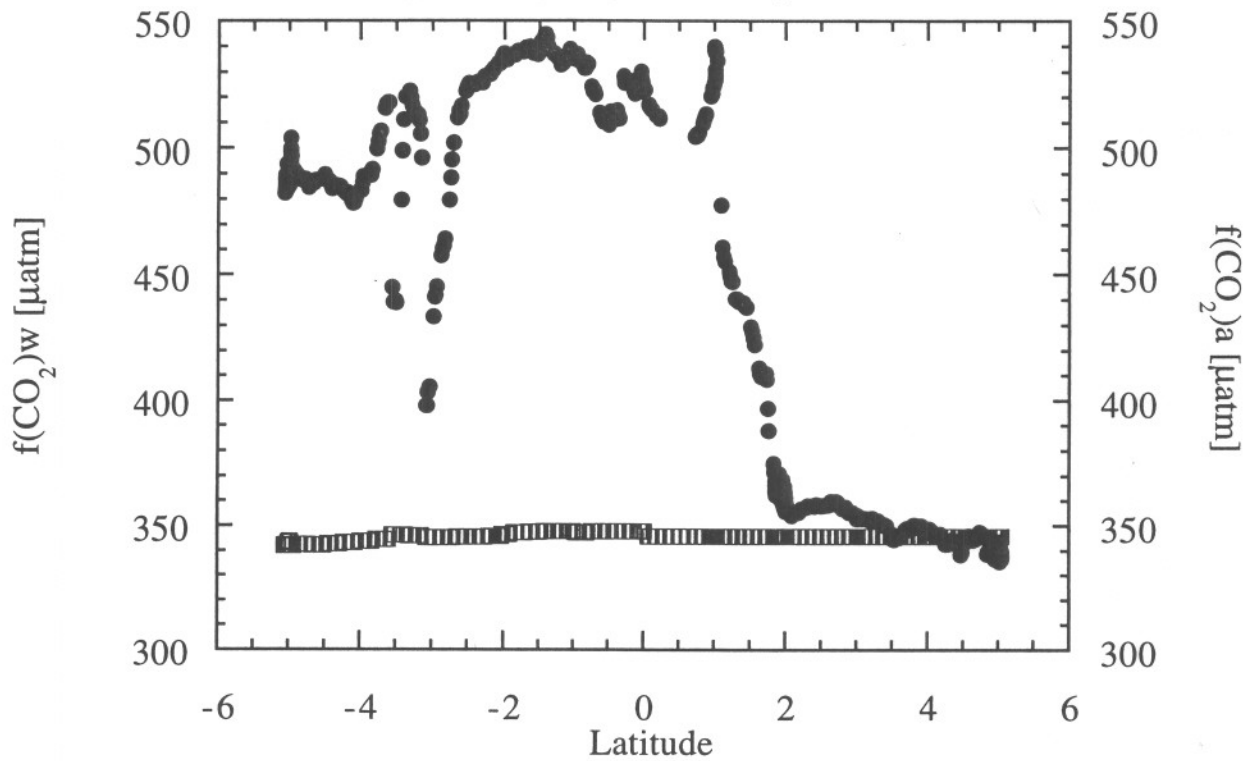
The full data set can be obtained via anonymous FTP from:

<<ftp://ftp.aoml.noaa.gov/pub/ocd/carbon/uweqpac94>>

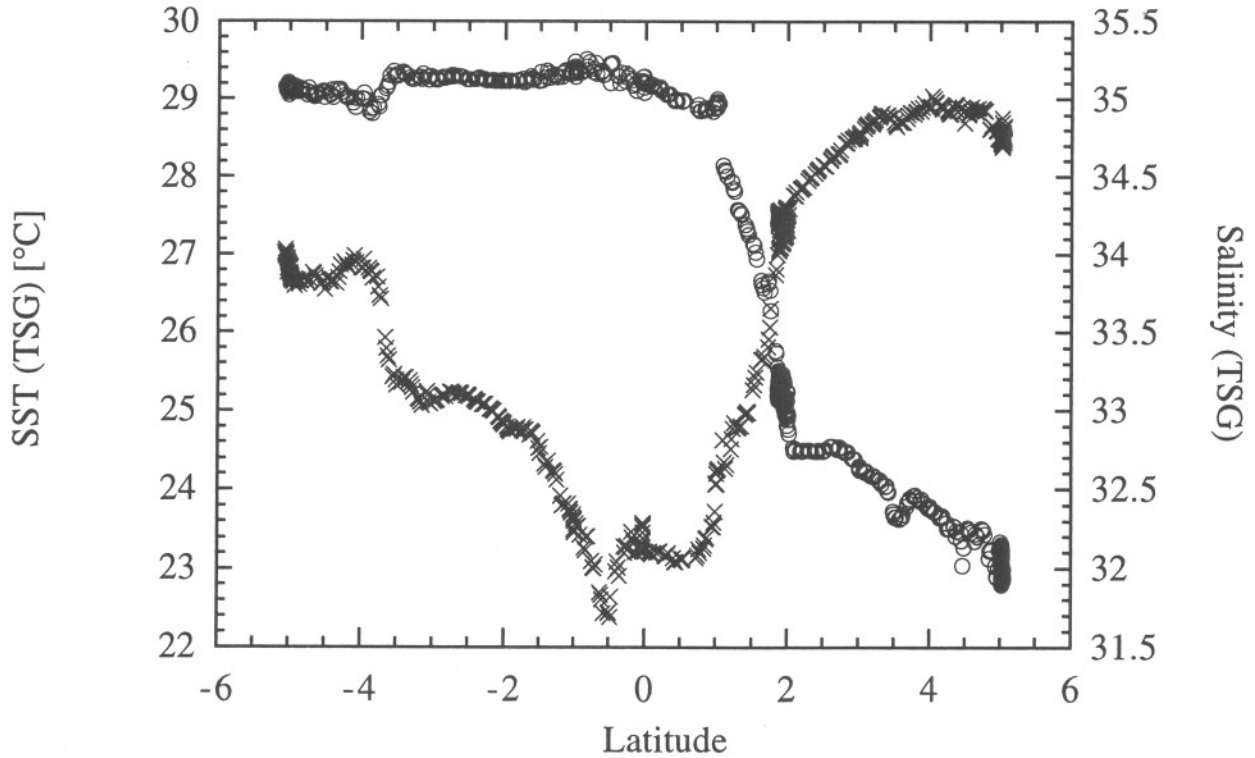
or via the World Wide Web:

<<http://www.aoml.noaa.gov/ocd/oaces/>>

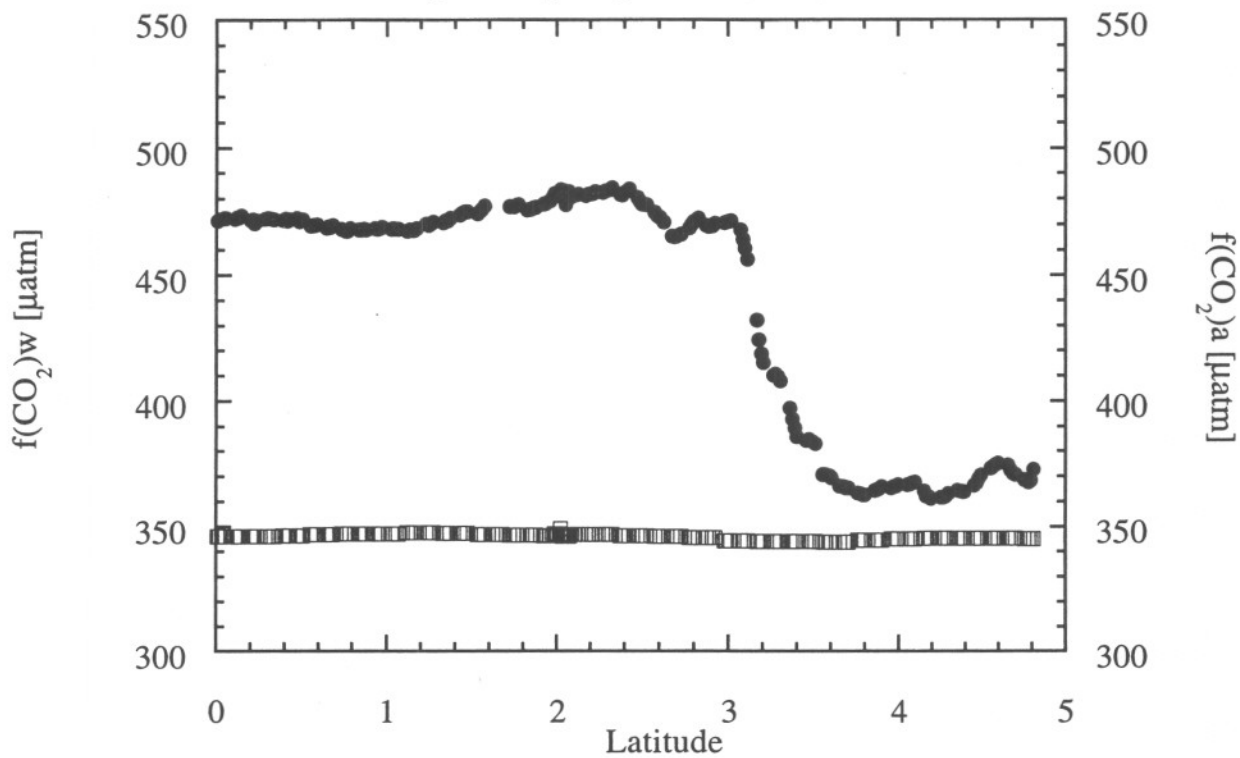
Eq Pac Spring 1994 (April) 95°W



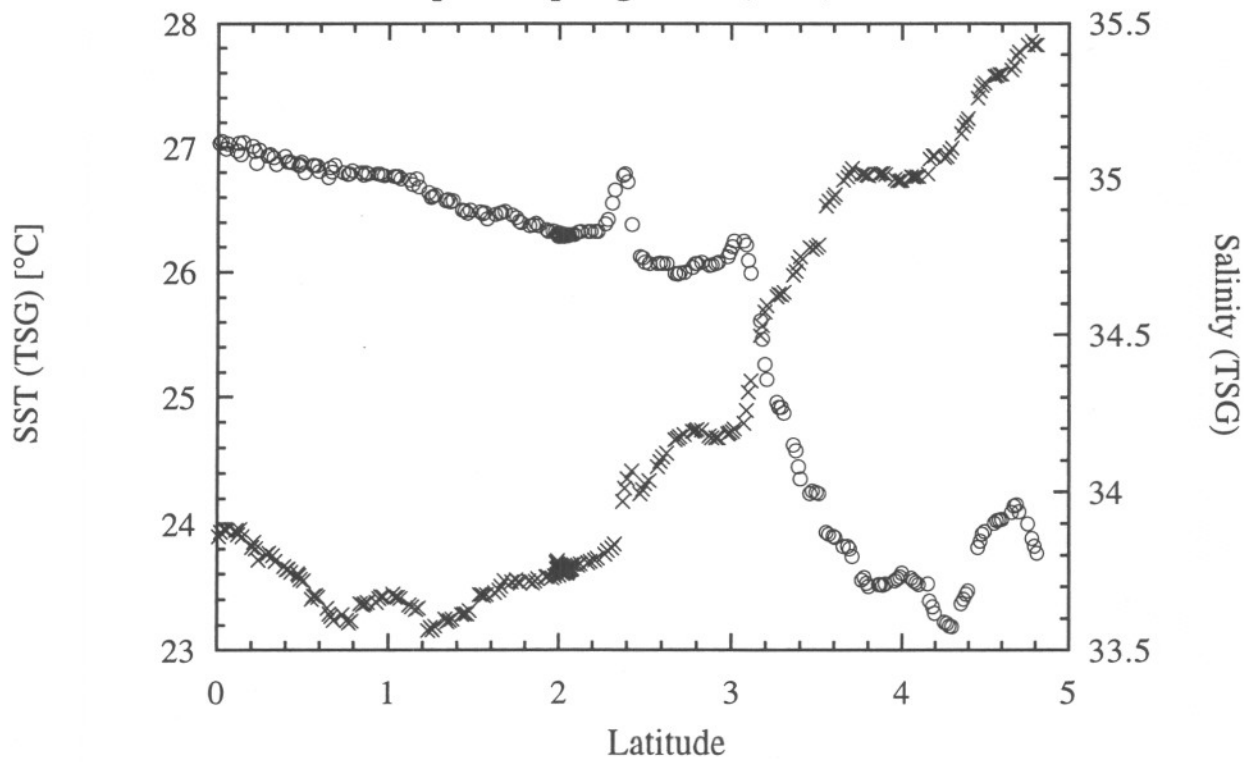
Eq Pac Spring 1994 (April) 95°W



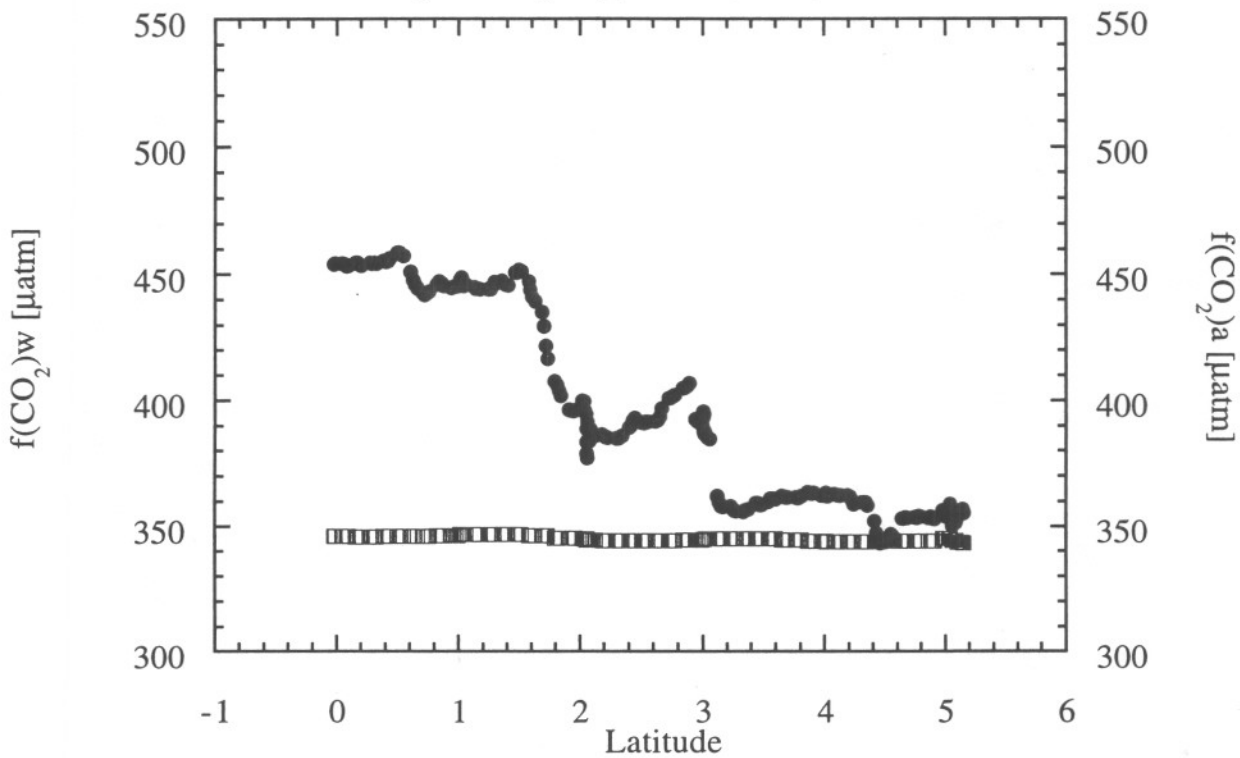
Eq Pac Spring 1994 (June) 95°W



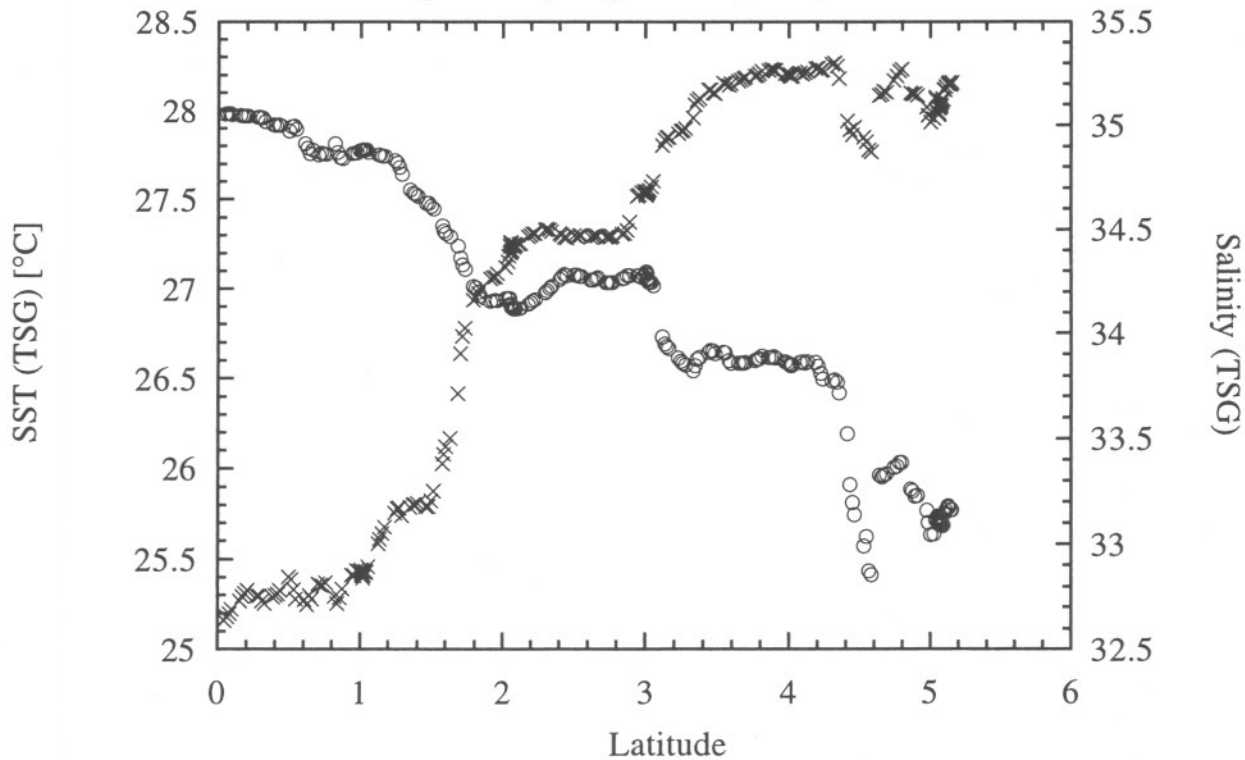
Eq Pac Spring 1994 (June) 95°W



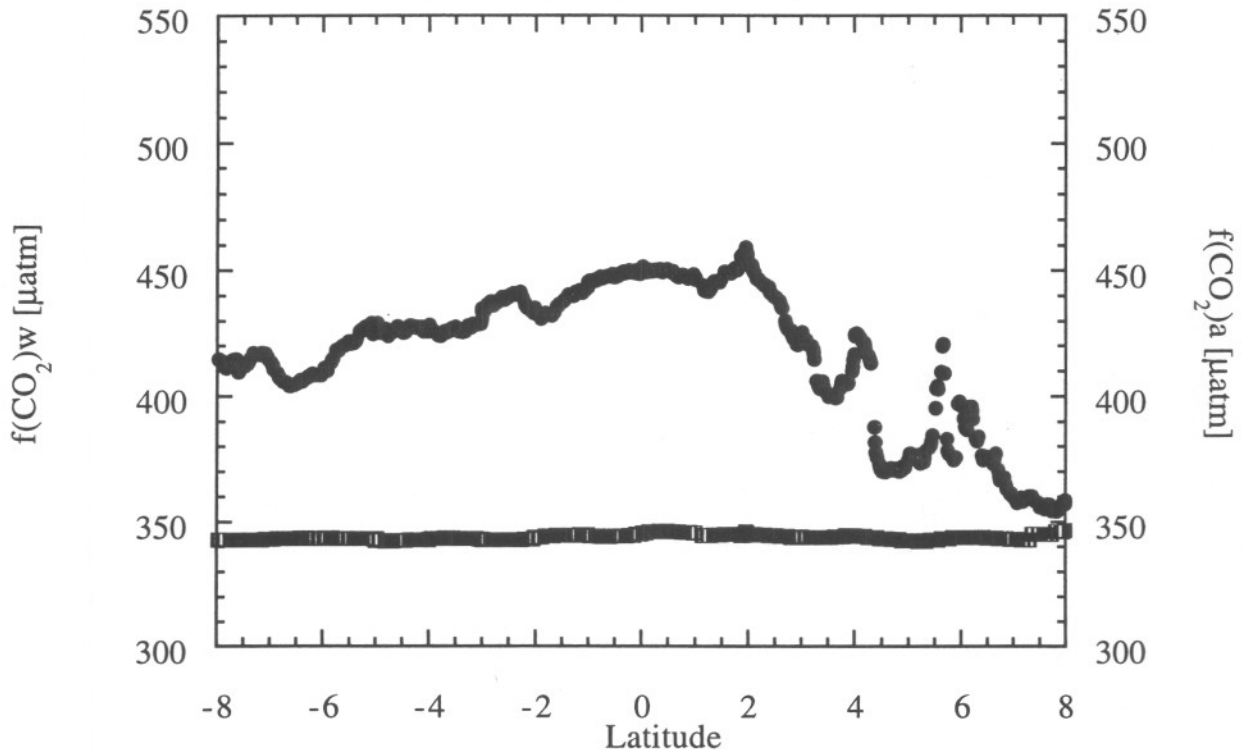
Eq Pac Spring 1994 (June) 110°W



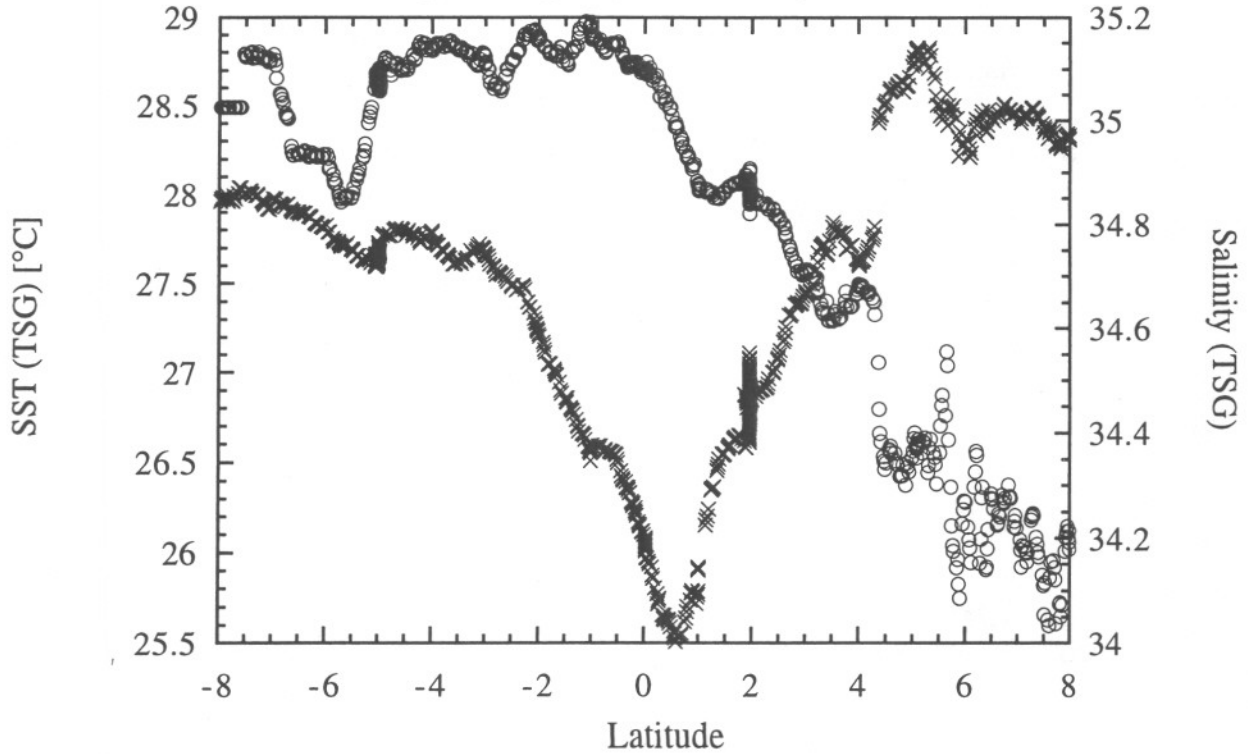
Eq Pac Spring 1994 (June) 110°W



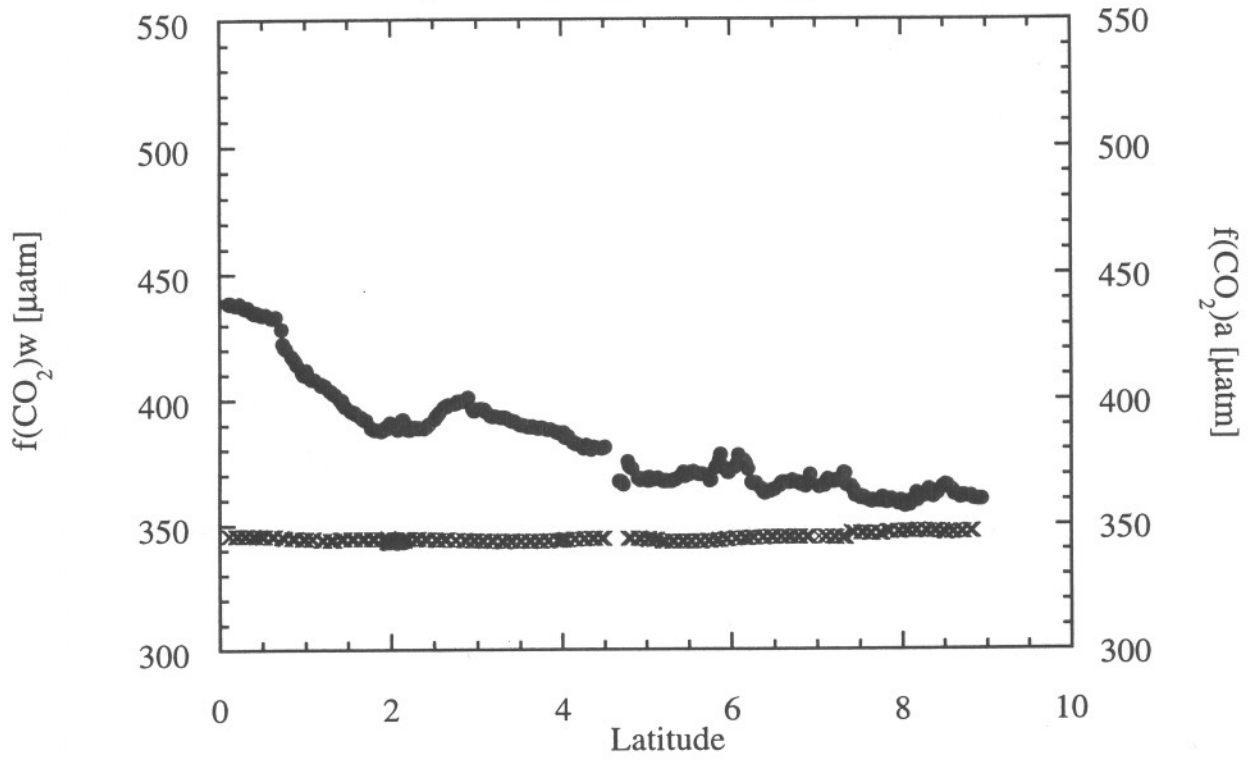
Eq Pac Spring 1994 (May) 125°W



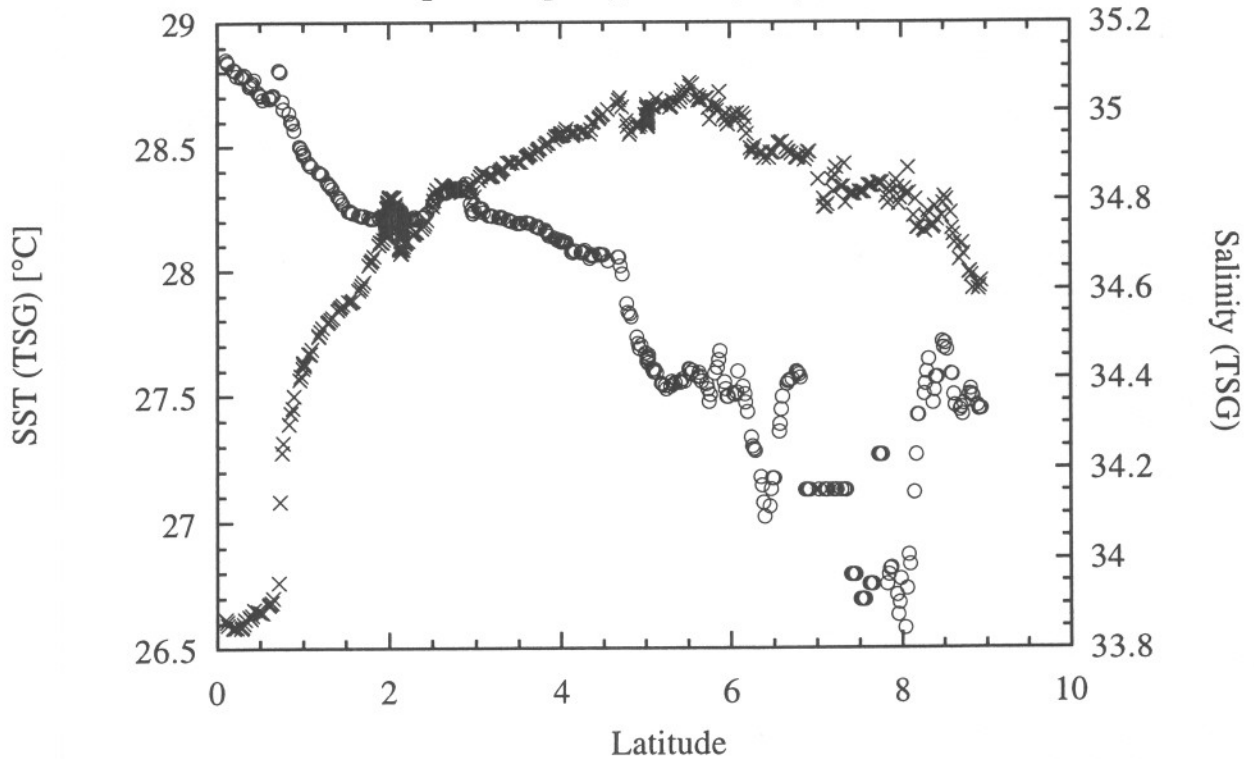
Eq Pac Spring 1994 (May) 125°W



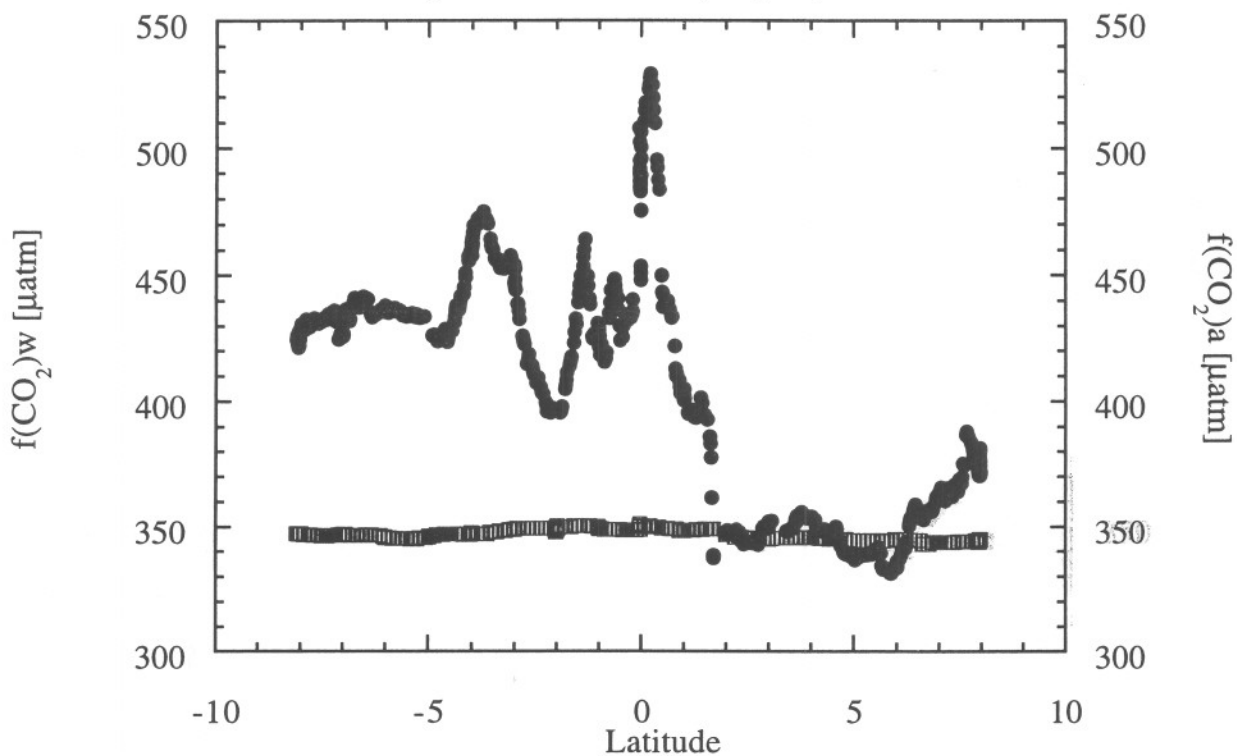
Eq Pac Spring 1994 (May) 140°W



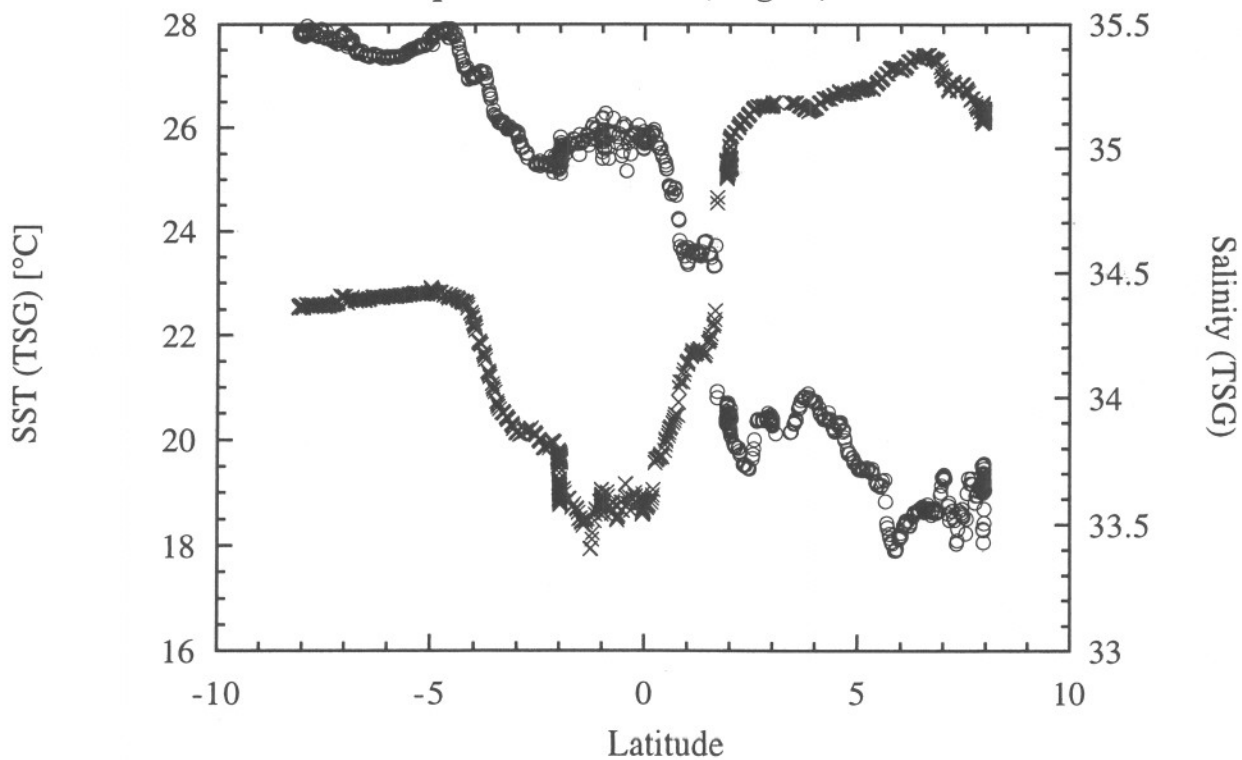
Eq Pac Spring 1994 (May) 140°W

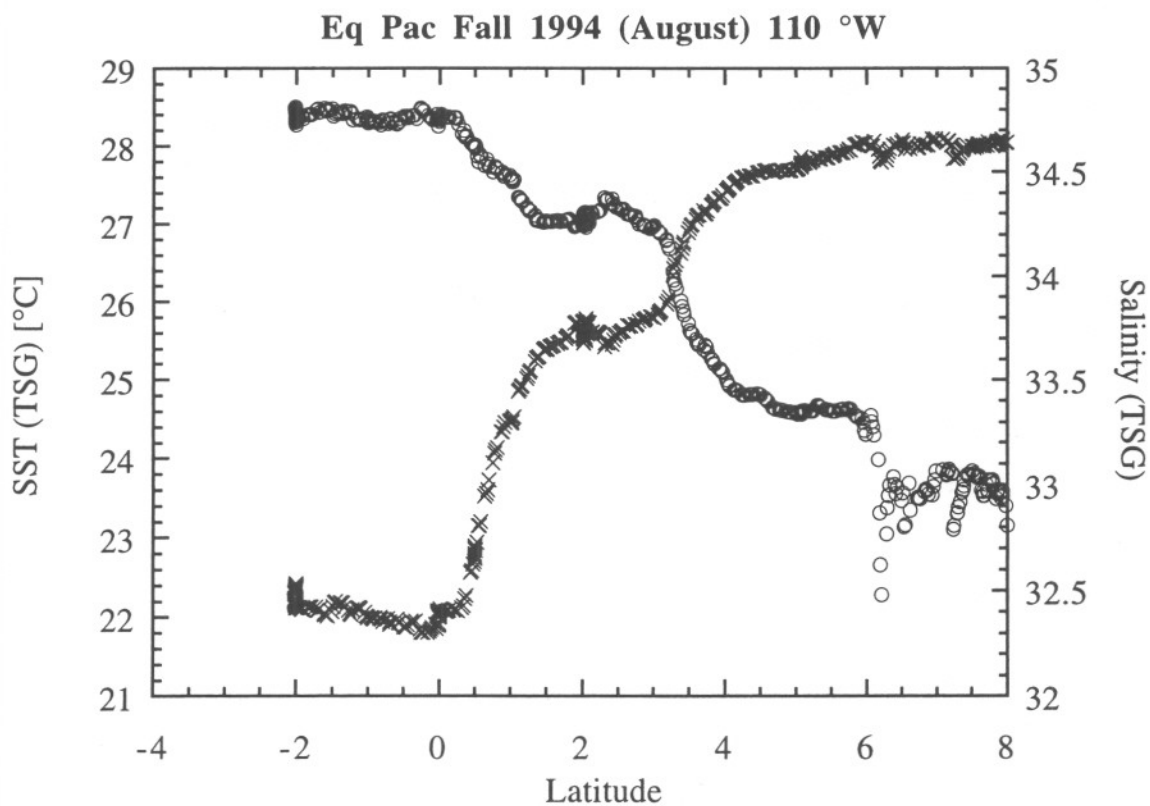
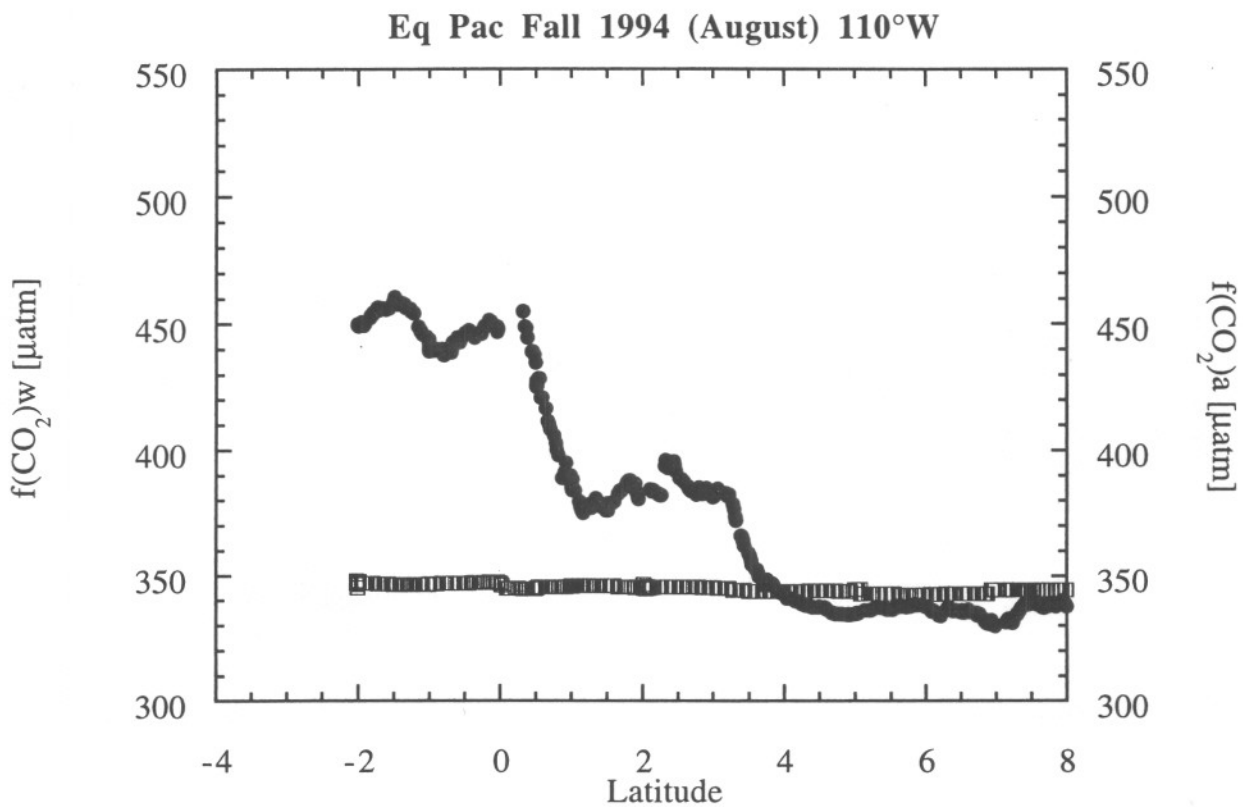


Eq Pac Fall 1994 (August) 95°W

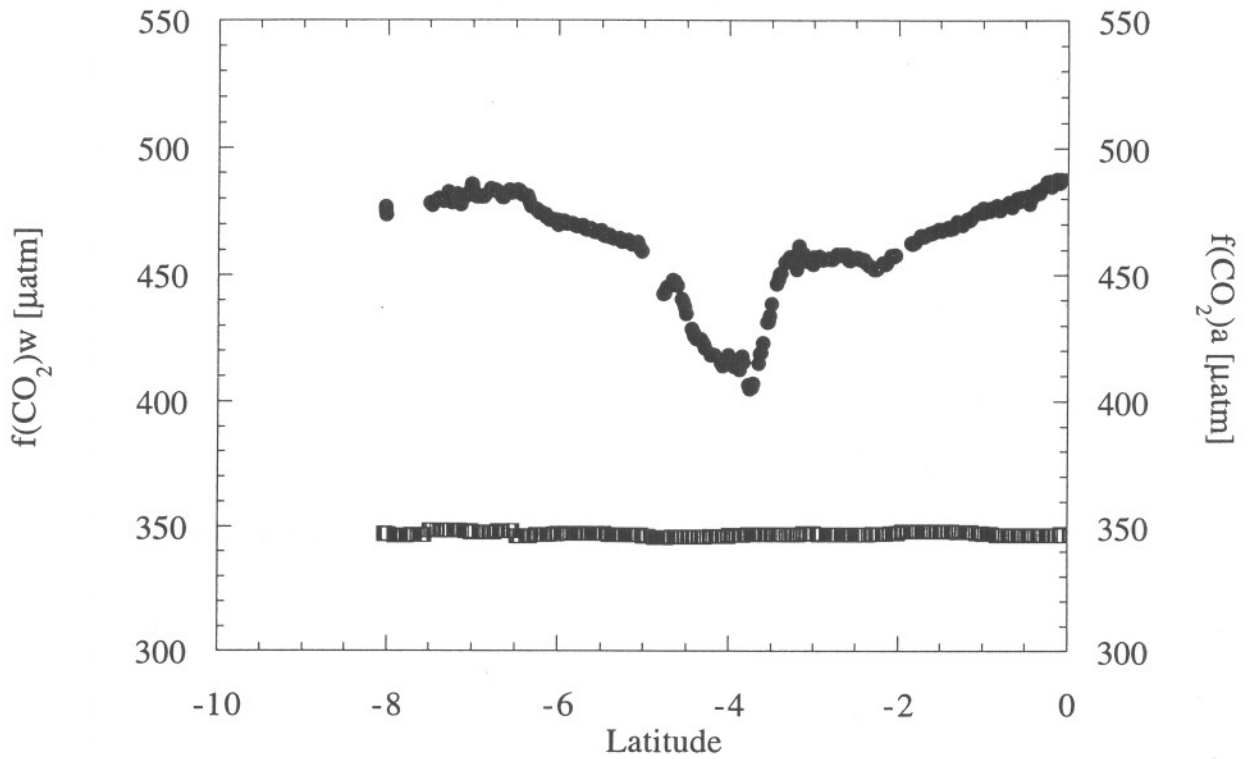


Eq Pac Fall 1994 (August) 95°W

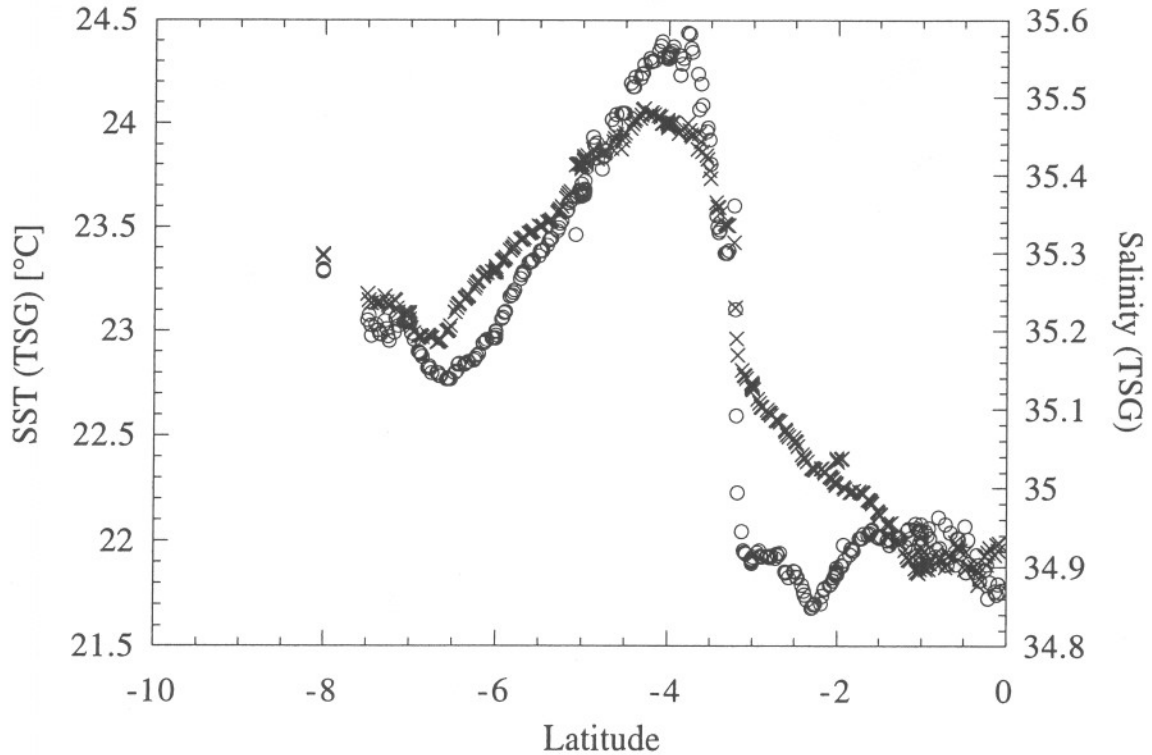




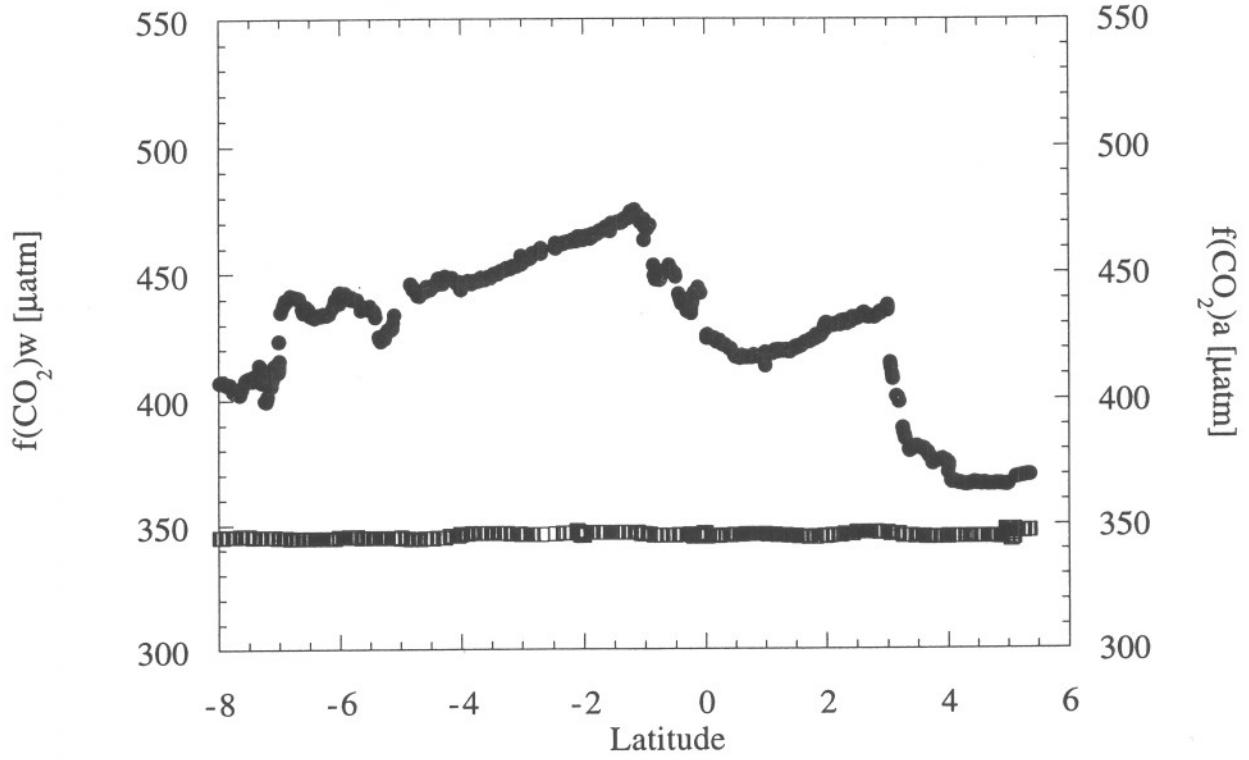
Eq Pac Fall 1994 (September) 110°W



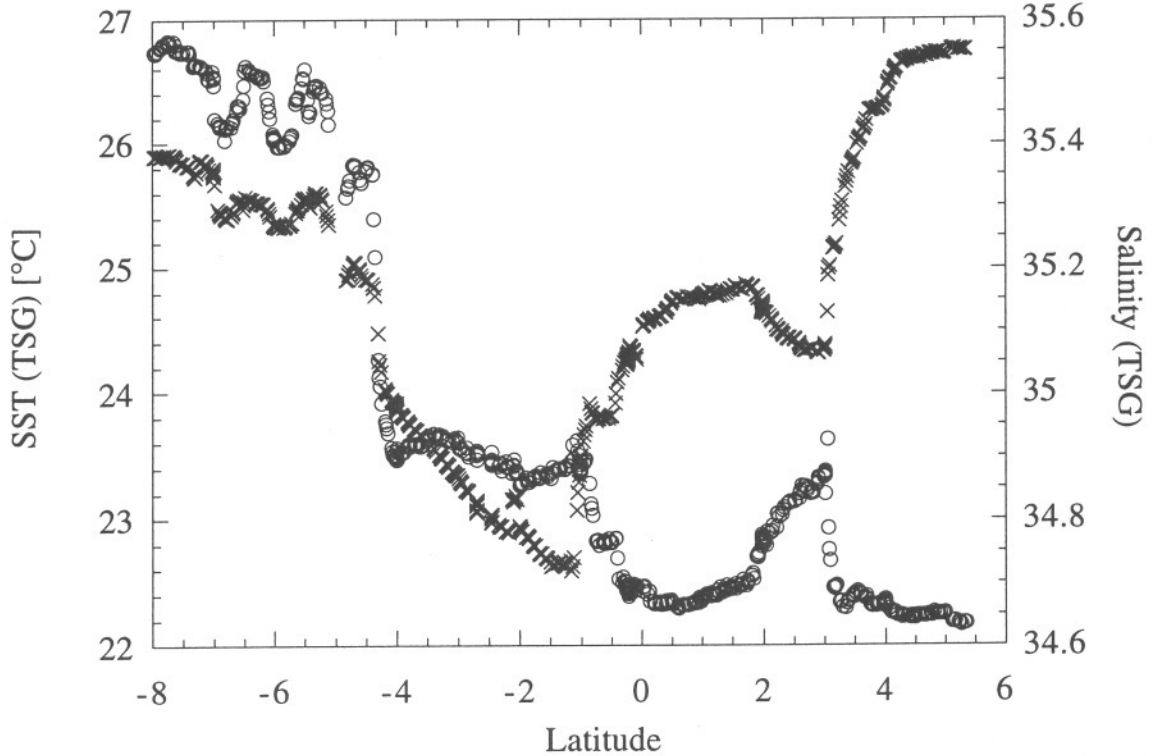
Eq Pac Fall 1994 (September) 110°W



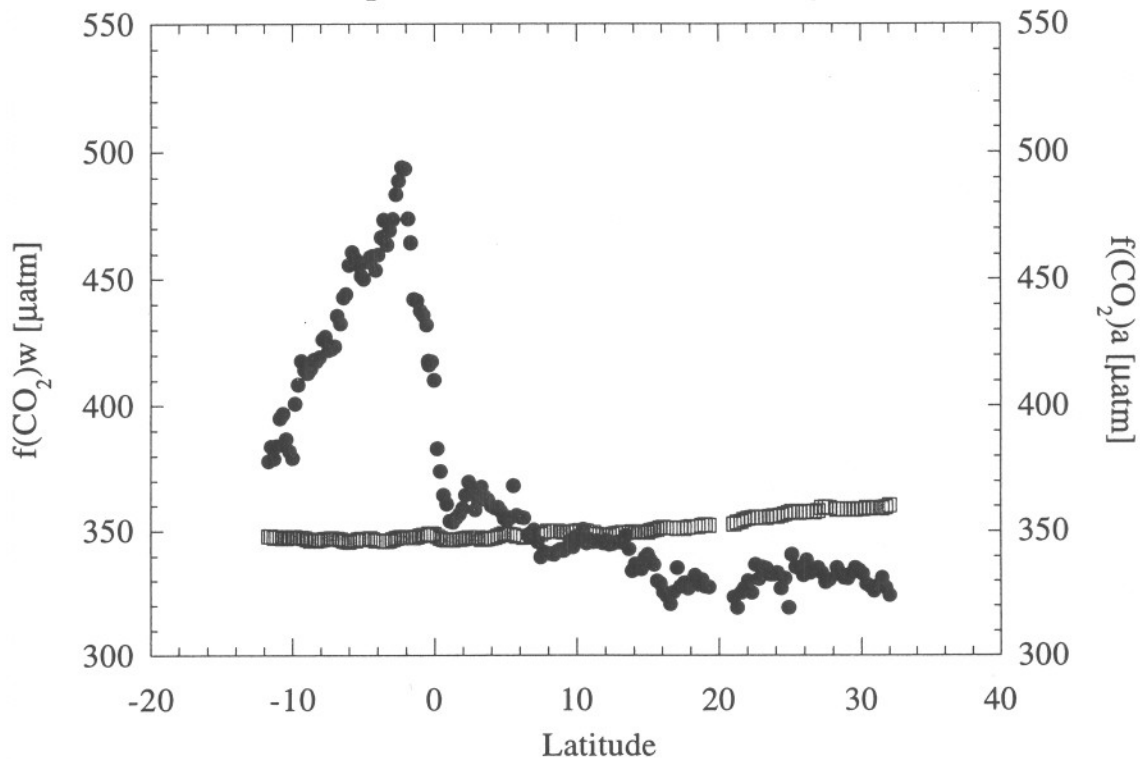
Eq Pac Fall 1994 (September) 125°W



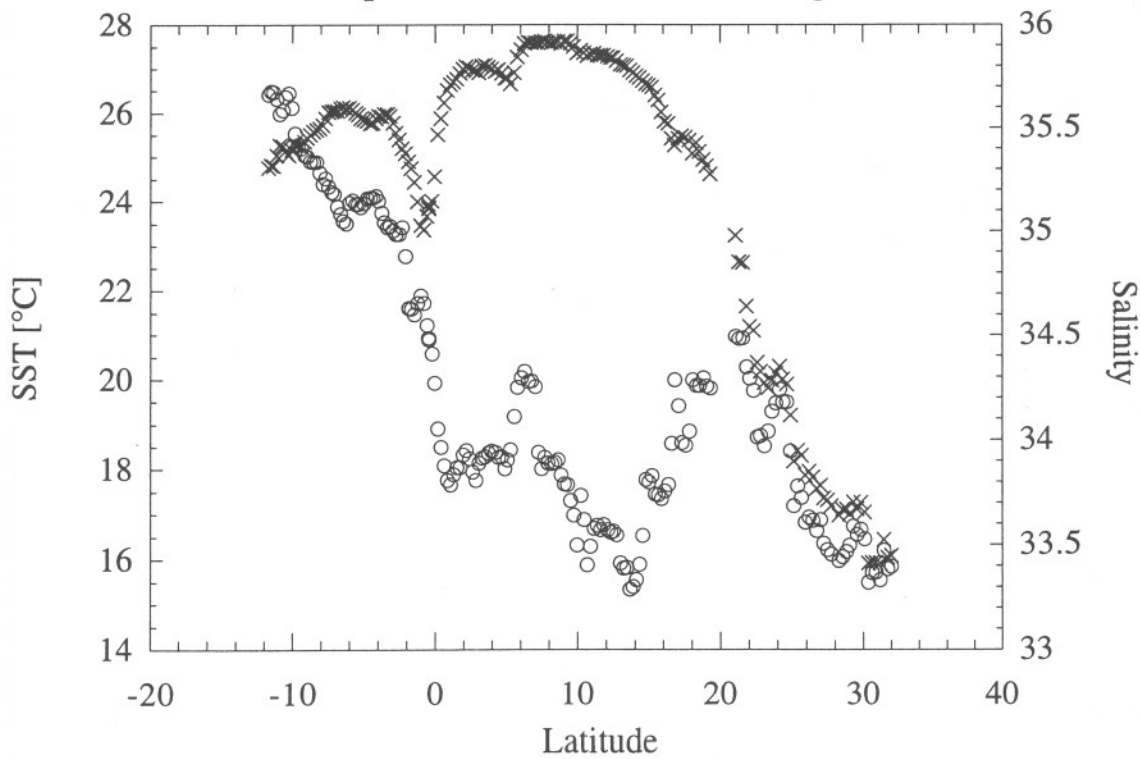
Eq Pac Fall 1994 (September) 125°W



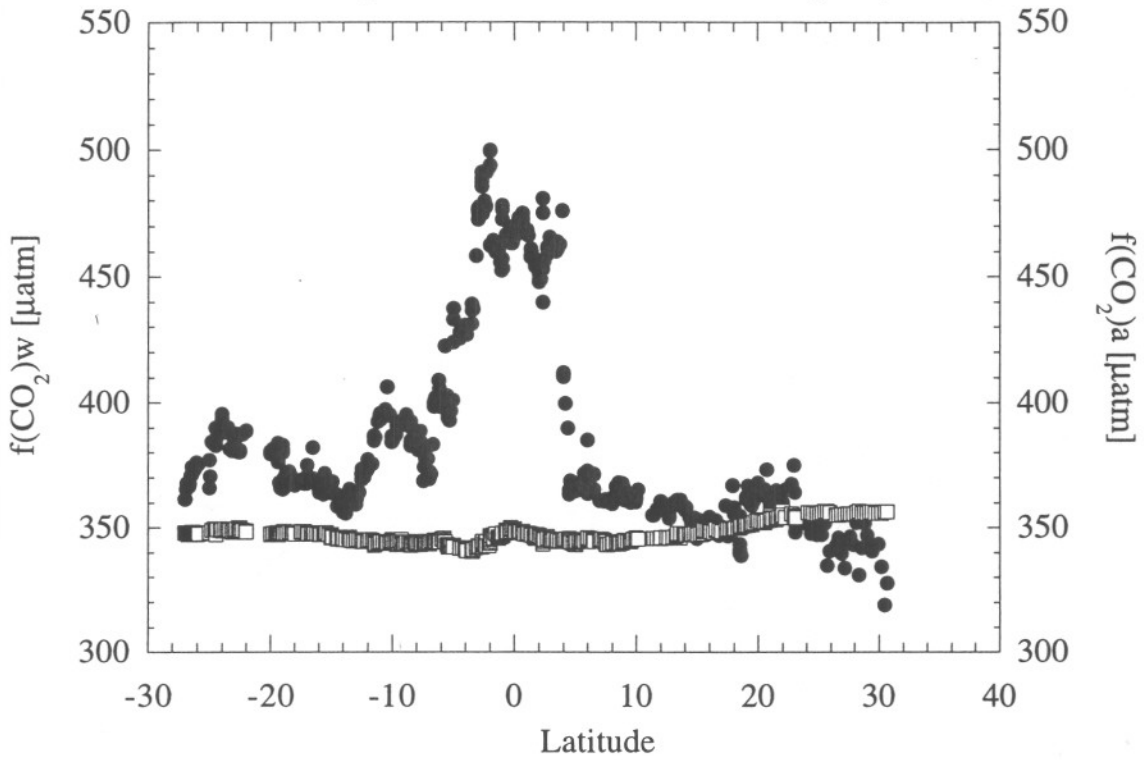
NOAA Ship DISCOVERER 1994 - Leg 1 (110°W)



NOAA Ship DISCOVERER 1994 - Leg 1 (110°W)



NOAA Ship DISCOVERER 1994 - Leg 3 (110°W)



NOAA Ship DISCOVERER 1994 - Leg 3 (110°W)

