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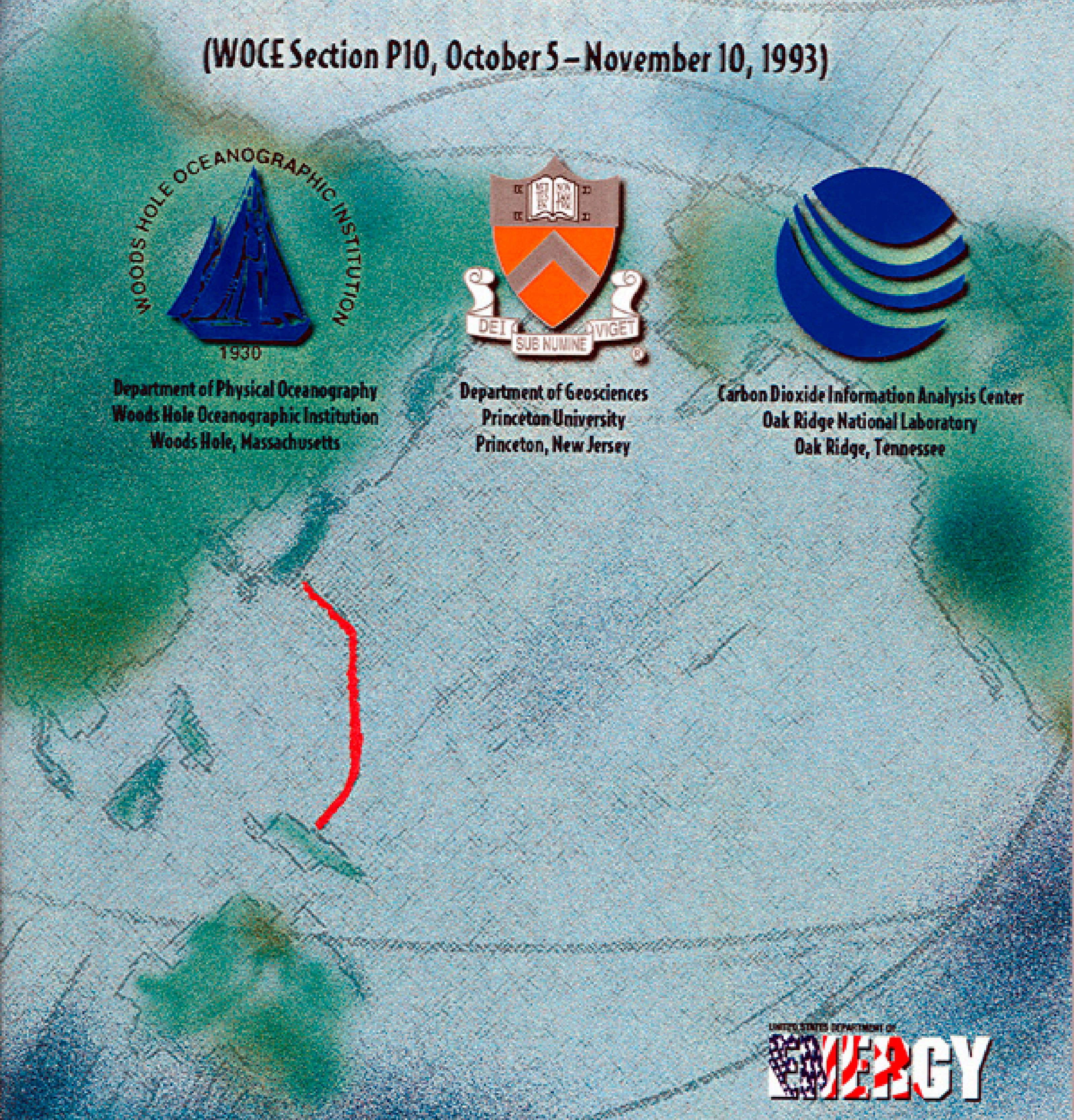
Carbon Dioxide, Hydrographic, and Chemical Data Obtained During the R/V *Thomas G. Thompson* Cruise in the Pacific Ocean

(WOCE Section P10, October 5 – November 10, 1993)



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UNITED STATES DEPARTMENT OF ENERGY

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CARBON DIOXIDE, HYDROGRAPHIC, AND CHEMICAL DATA OBTAINED DURING THE R/V *THOMAS G. THOMPSON* CRUISE IN THE PACIFIC OCEAN (WOCE SECTION P10, OCTOBER 5–NOVEMBER 10, 1993)

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ABSTRACT

Sabine, C. L., R. M. Key, M. Hall, and A. Kozyr (ed.). 1999. Carbon Dioxide, Hydrographic, and Chemical Data Obtained During the R/V *Thomas G. Thompson* Cruise in the Pacific Ocean (WOCE Section P10, October 5–November 10, 1993). ORNL/CDIAC-122, NDP-071. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee, U.S.A. 70 pp. doi: 10.3334/CDIAC/otg.ndp071

This data documentation discusses the procedures and methods used to measure total carbon dioxide (TCO_2), total alkalinity (TALK), and radiocarbon ($\Delta^{14}C$), at hydrographic stations, as well as the underway partial pressure of CO_2 (pCO_2) during the R/V *Thomas G. Thompson* oceanographic cruise in the Pacific Ocean (Section P10). Conducted as part of the World Ocean Circulation Experiment (WOCE), the cruise began in Suva, Fiji, on October 5, 1993, and ended in Yokohama, Japan, on November 10, 1993. Measurements made along WOCE Section P10 included pressure, temperature, salinity [measured by conductivity, temperature, and depth sensor (CTD)], bottle salinity, bottle oxygen, phosphate, nitrate, nitrite, silicate, chlorofluorocarbons (CFC-11, CFC-12), TCO_2, TALK, $\Delta^{14}C$, and underway pCO_2.

The TCO_2 was measured by coulometry using a Single-Operator Multiparameter Metabolic Analyzer (SOMMA). The overall precision and accuracy of the analyses was ±2 μmol/kg. Samples collected for TALK were measured by potentiometric titration; precision was ±4 μmol/kg. Small volume samples collected for ^{14}C were sent to shore and measured by use of an accelerator mass spectrometry technique. Underway xCO_2 was measured by infrared photometry with a precision of ±1 μatm. The CO_2-related measurements aboard the R/V *Thomas G. Thompson* were supported by the U.S. Department of Energy.

P10 is the western most section of the U.S. WOCE survey of the North Pacific Ocean. It is important for understanding the dynamics of the far western equatorial Pacific. The results from this cruise can be used to infer the relative magnitude of various tracers to the North Pacific from the South China Sea and the Sea of Japan. WOCE Section P10 also provides a transect across the Kuroshio Current that can be used to better understand the northward transport of heat, salt, and other important ocean tracers.

The underway surface measurements show a small outgassing of CO_2 at the equator. The TCO_2, TALK, and radiocarbon values show profiles typical for the North Pacific. TALK correlates strongly with salinity. ^{14}C correlates strongly with silicate. Deflection of the isolines of all parameters at the northern end of the cruise results from the Kuroshio Current.

The WOCE Section P10 data set is available free of charge as a numeric data package (NDP) from the Carbon Dioxide Information Analysis Center. The NDP consists of four oceanographic data files, four FORTRAN 90 data-retrieval routine files, a documentation file, and this printed report, which describes the contents and format of all files as well as the procedures and methods used to obtain the data. Instructions on how to access the data are provided.

Keywords: carbon dioxide; coulometry; World Ocean Circulation Experiment; Pacific Ocean; hydrographic measurements; alkalinity; partial pressure of carbon dioxide; radiocarbon; carbon cycle

PART 1:

OVERVIEW

1. BACKGROUND INFORMATION

The World Ocean plays a dynamic role in the Earth's climate: it captures heat from the sun, transports it, and releases it thousands of miles away. These oceanic-solar-atmospheric interactions affect winds, rainfall patterns, and temperatures on a global scale. The oceans also play a major role in global carbon-cycle processes. Carbon is unevenly distributed in the oceans because of complex circulation patterns and biogeochemical cycles. The oceans are estimated to hold 38,000 gigatons of carbon, 50 times more than that in the atmosphere and 20 times more than that in plants, animals, and soil. If only 2% of the carbon stored in the oceans were released, the level of atmospheric carbon dioxide (CO_2) would double. Every year, the amount of CO_2 exchanged across the sea surface is more than 15 times that produced by the burning of fossil fuels, deforestation, and other human activities (Williams 1990).

To better understand the ocean's role in climate and climatic changes, several large experiments have been conducted, and others are under way. The largest oceanographic experiment ever attempted is the World Ocean Circulation Experiment (WOCE). A major component of the World Climate Research Program, WOCE brings together the expertise of scientists and technicians from more than 30 nations. In the United States, WOCE is supported by the federal government under the Global Change Research Program. The multiagency U.S. effort is led by the National Science Foundation and is supported by major contributions from the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of Energy (DOE), the Office of Naval Research, and the National Aeronautics and Space Administration. Although total carbon dioxide (TCO_2) is not an official WOCE measurement, a coordinated effort, supported in the United States by DOE, was made on WOCE cruises to measure the global distributions of TCO_2 and other carbon-related parameters [total alkalinity (TALK), partial pressure of CO_2 (pCO_2), and pH]. The goal of the DOE's CO_2 survey includes estimation of the meridional transport of inorganic carbon in a manner analogous to the oceanic heat transport (Bryden and Hall 1980; Brewer et al. 1989; Roemmich and Wunsch 1985), evaluation of the exchange of CO_2 between the atmosphere and the ocean, preparation of a database suitable for carbon-cycle modeling, and subsequent assessment of anthropogenic CO_2 in the oceans. The final data set is expected to cover ~23,000 stations.

This report presents CO_2-related measurements obtained during the 37 days of the Research Vessel (R/V) *Thomas G. Thompson* expedition along the WOCE meridional Section P10 (Fig. 1).

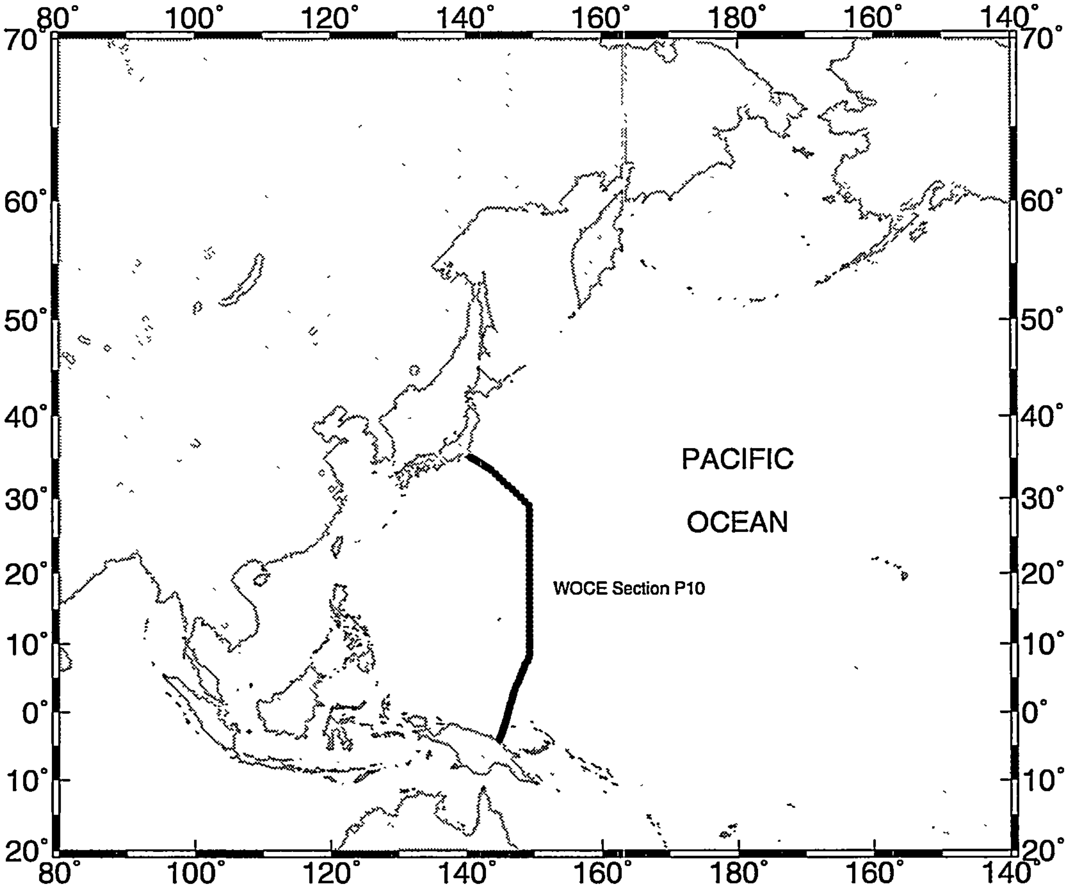

Fig. 1. The cruise track during the R/V *Thomas G. Thompson* expedition in the Pacific Ocean along WOCE Section P10.

2. DESCRIPTION OF THE EXPEDITION

2.1 R/V *Thomas G. Thompson* Cruise Information

R/V *Thomas G. Thompson* cruise information follows:

Ship name	*Thomas G. Thompson*
Expedition code	3250TN026/1
WOCE Section	P10
Location	Suva, Fiji, to Yokohama, Japan
Dates	October 5–November 10, 1993
Chief Scientist	Melinda Hall (WHOI)

Parameters measured	**Institution**	**Principal investigators**
CTD,[1] salinity, oxygen	WHOI	M. Hall
Nutrients	OSU	L. Gordon
Chlorofluorocarbons (CFCs)	UW	M. Warner
Tritium and helium	WHOI	W. Jenkins
TCO_2, TALK, and underway xCO_2	PU	C. Sabine
Radiocarbon (^{14}C)	PU	R. Key
Underway ADCP[2]	WHOI	T. Joyce
Lowered ADCP	UH	P. Hacker and E. Firing

Participating Institutions

WHOI	Woods Hole Oceanographic Institution
OSU	Oregon State University
UW	University of Washington
PU	Princeton University
UH	University of Hawaii

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[1] Conductivity, temperature, and depth sensor.
[2] Acoustic Doppler current profiler.

2.2 Brief Cruise Summary

The objective of this cruise was to occupy a hydrographic section nominally along 149° E from Papua, New Guinea, to the shelf of Japan near Yokohama as part of the one-time WOCE Hydrographic Program (WHP) survey of the Pacific Ocean. A CTD with a 36-place, 10-L rosette was used on a total of 94 small-volume (SV) stations with water sampling for salinity, oxygen, nutrients, CFCs, tritium/helium, TALK, TCO_2, and ^{14}C. The station spacing ranged from 5 to 40 nautical miles (nm), and most lowerings were made to within 10 m of the bottom. A lowered ADCP was attached to the rosette on 53 of the stations. At seven stations, additional casts were made for large-volume (LV) sampling of ^{14}C in the deep and mid-depth waters. These LV casts were usually made with nine, 250-L Gerard barrels. Underway measurements along the cruise track included pCO_2, ADCP, digital echo-sounding, thermosalinograph, and meteorology.

The P10 cruise was the third in a series of three WHP one-time cruises aboard the R/V *Thomas G. Thompson* in 1993, following P17N and P14N. The ship departed Suva, Fiji, on November 5, 1993, and steamed northwest to the northern coastline of Papua, New Guinea, where the section began at the 200-m isobath. During the 7-day deadhead, three test stations were occupied (not included in the station numbering scheme) to shake down equipment and water-sampling methodology. The station track, designed in early planning documents for 145° E, was shifted eastward in an effort to depart the New Guinea coastline perpendicular to the bathymetry, then skirt the Mariana Ridge and Trough to the east, thus making the whole section in the East Mariana Basin, rather than in both that basin and the Philippine Basin farther west. Where bottom depths changed rapidly (near the coast and passing the Caroline Seamounts around 6–8° N), station spacing was dictated by topographic changes; within 3° of the Equator, spacing was every 15 min of latitude along the ship track (nominally 15 nm, but slightly more due to the track angle), stretching to 30 nm up to 10.5° N, then 40 nm from there to station 73 at 28.5° N. At that point the cruise track was going straight toward the Japan coast in order to cross the Kuroshio Current. The ADCP results indicated that this crossing was approximately perpendicular to the current. Over the northern dogleg, station spacing gradually decreased to resolve the strong front of the Kuroshio Current, and ultimately, to accommodate rapid topographic changes near the coast. Stations generally went to within 10 m of the bottom except over the Japan Trench and a few other stations where bottom depths exceed 6000 dbar. No stations were lost due to weather, and the ship arrived in Yokohama on November 10, 1993.

The general sampling strategy for the carbon work was to collect and analyze as many full profiles for TCO_2 and TALK as practical. The TCO_2 analysis was slightly faster than the TALK analysis and generally determined the frequency of sampling. Full profiles were collected at 32 of the 94 hydrographic stations occupied on this leg, with gaps of no more than two consecutive stations between profiles (Fig. 2). Duplicate samples were collected at every sample station from Niskins tripped in shallow, mid-depth, and deep waters for both TCO_2 and TALK to evaluate the quality and precision of sampling and analysis. All TCO_2 samples were analyzed at sea; however ~20% (220 samples) of the TALK samples were returned to Princeton University for shore-based analysis. To preserve the continuity of the profiles, all of the TALK samples at select stations were bottled for return to the laboratory. At least three additional replicate TALK samples were collected at these stations and analyzed at sea to ensure the compatibility of the two data sets [see further explanation in quality assurance/ quality control (QA/QC) section]. In addition to the TCO_2 samples collected for on-board analysis, 40 samples were collected at 10 stations for shore-based TCO_2 analysis by vacuum extraction and manometry by Charles D. Keeling of Scripps Institute of Oceanography (SIO).

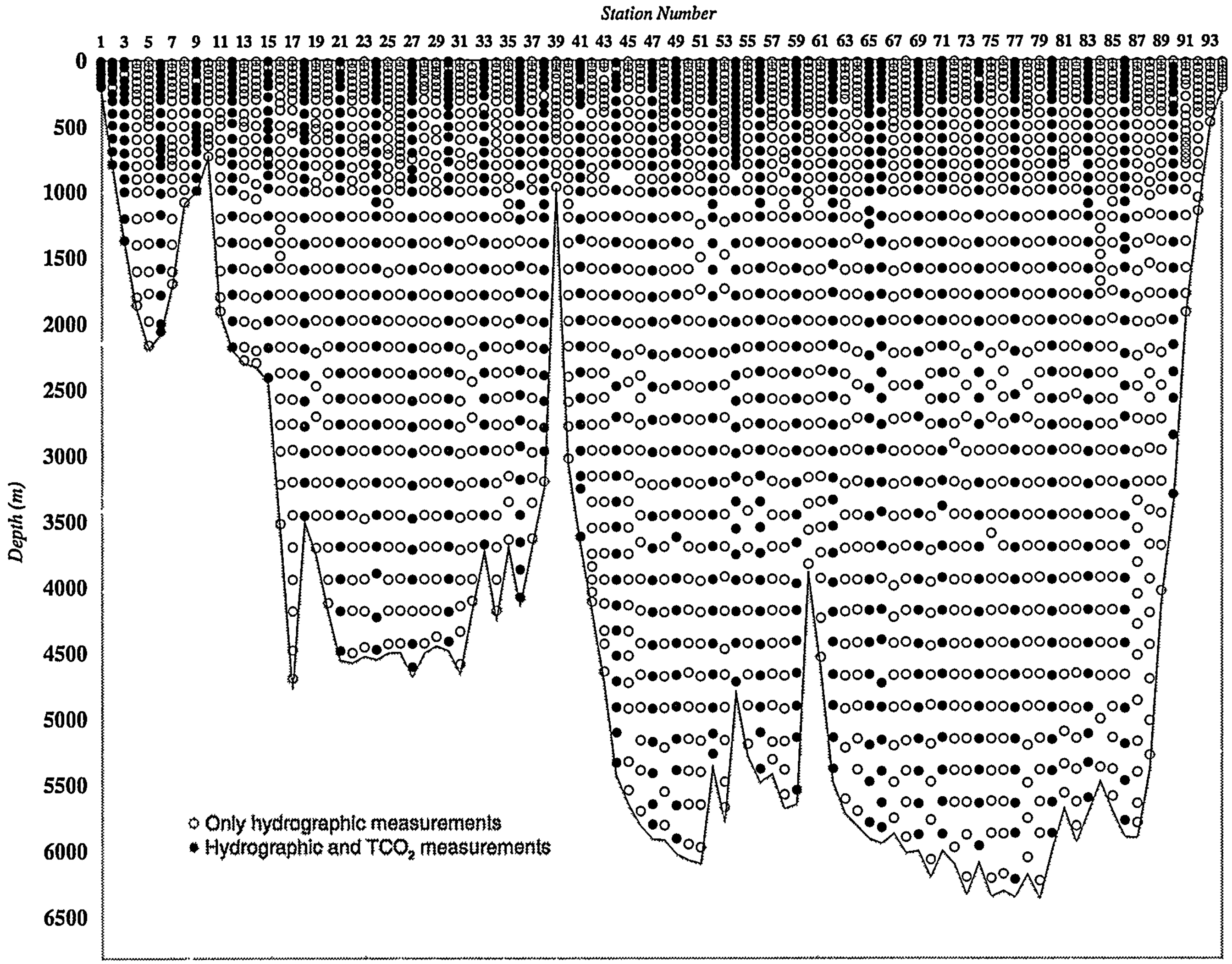

Fig. 2. Sampling depths at all hydrographic stations occupied during the R/V *Thomas G. Thompson* expedition along WOCE Section P10.

3. DESCRIPTION OF VARIABLES AND METHODS

3.1 Hydrographic Measurements

Two WHOI-modified EG&G Mk-III CTDs were provided for the cruise, although only one was used throughout the entire cruise (CTD #10). It was provided with an optional oxygen current and temperature channel and modified at WHOI to include a thermally isolated titanium pressure transducer, with a separately digitized pressure and temperature channel. The temperature and pressure calibrations were made at WHOI prior to and following the cruise. The CTD pressure, temperature, and conductivity data were processed and corrected according to laboratory calibrations. Pressure values are expected to be accurate to ±3 dbar; temperature values to ±0.002°C.

The water samples for the analysis of salinity, dissolved oxygen, and nutrients were collected from each of the 36 10-L bottles tripped on the upcast of each CTD station, in accordance with the recommendations of the WOCE Hydrographic Office. The vertical distribution of these samples was a compromise between the need to obtain deep samples for the calibration of the CTD conductivity and oxygen sensors and the requirement to define the characteristics of the water masses by the distributions of the various measured parameters.

Salinity samples were drawn into 120-mL Boston Round flint glass bottles with screw caps equipped with Poly-Seal® cones to prevent leakage and evaporation. After determining some problems with the quality of salinity measurements, it was decided to change the bottles. Beginning with station 59, samples for salinity measurements were collected in 200-mL square Kimax bottles, with polyethylene caps and inserts, owned by SIO, and a dramatic improvement was seen. Salinity was determined on the basis of electrical conductivity with a Guildline Autosal® salinometer.

Samples for dissolved oxygen were collected soon after the rosette sampler was brought on board and after CFC and helium samples were collected. Samples were titrated in the volume-calibrated iodine flasks with a 1-mL microburette, using whole-bottle automated Winkler titration. Estimated accuracy was 0.02 mL/L.

Nutrient samples were drawn from all CTD/rosette casts at stations 1 through 94 and at several test stations that preceded station 1. High-density polyethylene bottles of ~30-mL volume were used as sample containers, and these same bottles were positioned directly in the autosampler tray. These bottles were routinely rinsed at least three times with one-third to one-half of their volume of sample before filling and were thoroughly cleaned with 10% HCl every two or three days. The measurements were performed with an Alpkem Rapid Flow Analyzer, model 300. A Keithley data acquisition system was used in parallel with analog strip-chart recorders to acquire the absorbance data. The software used to process the nutrient data was developed at OSU. All of the reagent and standard materials were provided by OSU.

3.2 TCO_2 Measurements

During the R/V *Thomas G. Thompson* expedition along WOCE Section P10, 1072 TCO_2 samples were collected according to methods outlined in the DOE Handbook (DOE 1994) and stored in 300-mL borosilicate glass bottles in a 20°C water bath until the samples could be processed (maximum of 12 h). Samples were poisoned immediately after collection with 200 μL of saturated $HgCl_2$ solution to minimize biological activity prior to analysis. Samples were analyzed using a computer controlled single-operator multiparameter metabolic analyzer (SOMMA) system and UIC model 5011 coulometer following standard methods (Johnson et al. 1985, 1987; DOE 1994).

The SOMMA temperature sensors (National Semiconductor, Santa Clara, Calif., model LM34CH) were calibrated against a certified mercury thermometer and thermistors certified to 0.01°C (Thermometrics, Edison, N.J., part number CSP60BT103M). These sensors monitored the pipette, the gas sample loops, and the coulometer cell temperatures. The Digiquartz Transducer barometer (Paroscientific, Redmond, Wash., model 216B-101) was factory-calibrated prior to the cruise. The SOMMA sample delivery pipette volume was gravimetrically determined before the cruise to be 21.7758 ± 0.0016 mL using deionized water at a temperature of 20.32°C. Post-cruise calibration confirmed that the pipette volume remained constant throughout the cruise. Sample weight was calculated from the pipette volume, the measured sample temperature, and the bottle salinity value measured by the WHOI CTD group on all but three samples. The bottle salinity values from station 18, Niskins 25, 26, and 27, had values significantly different (>0.1) from the CTD salinity values and from other bottle salinity values from equivalent depths of the surrounding casts. This difference was large enough to result in an error in the calculated density that was greater than the sample precision; therefore, the sample density was recalculated for those three samples using the CTD salinity. Cylinders of compressed ultrahigh-purity nitrogen and 350-ppm CO_2 in air were used as the system's carrier gas and headspace gas, respectively.

Titration cells were prepared with fresh cathode and anode solutions at the beginning of each cast. A system blank was determined for each cell by keeping track of the total number of counts accumulated by the coulometer's voltage-to-frequency converter over a 10-min period. The counts used for determining the TCO_2 of a sample were then determined by subtracting the blank counts (average blank value in counts per minute times the length of the titration in minutes) from the total counts registered for that titration.

Two methods were used to evaluate the calibration of the TCO_2 system. The first method titrated a known volume of CO_2 gas to determine a system efficiency. This method involved filling one of two different-sized gas loops with primary standard-grade CO_2 gas (Scott Grade 5 CO_2, 99.999% pure). Based on the loop volume, pressure, and temperature, a known amount of CO_2 was introduced into the coulometer and titrated. Gas calibrations using both the large (1.5224 mL) and small (1.0586 mL) loops were run at the beginning and end of each titration cell. The second calibration method involved the titration of certified reference materials (CRMs) provided by Andrew Dickson of SIO at the beginning and end of every titration cell. The CRMs were analyzed in the same manner as a sample and the results compared to the certified value determined by vacuum extraction and manometry.

Although the gas loop and CRM calibration methods are very different (pure CO_2 gas vs seawater), the results can be directly compared by examining the titration efficiency (TE; coulometer counts per μmole of carbon titrated) determined for each sample. The TE for the CRM samples (TE_{CRM}) was determined from the blank corrected coulometer counts, sample volume (vol), sample density (ρ) (Millero and Poisson 1981), and certified CRM value (T_{cert}; 2031.65 μmol/kg):

$$TE_{CRM} = \text{counts} / (T_{cert} \times \text{vol} \times \rho) .$$

The TE for the gas loop calibrations was determined by dividing the blank corrected coulometer counts by the amount of CO_2 (μmoles) introduced to the coulometer. The amount of CO_2 was determined by dividing the loop volume by the molar volume of CO_2 (V_{CO2}) at the measured loop temperature (T) and pressure (P) using an iterative approach:

$$V_{CO2} = RT / P \times [1 + B(T) / V_{CO2}] ,$$

where B(T) is the first viral coefficient for pure CO_2, and R is the gas constant.

Generally, the gas loop calibration is very reliable and accurate for SOMMA system calibrations (Johnson et al. 1987); however, a plot of the CRM and gas loop TE values shows that during the first half of the cruise, the gas loop efficiency was lower than the TE_{CRM} values (Fig. 3). Because the loop calibration system was new and untested on this system, and there was no reason to think that the CRM values would not be stable over the length of the cruise, the TE_{CRM} values were deemed to be more representative of the system efficiency. The gas loop TE values determined near the end of the cruise were more consistent with the TE_{CRM} values. Despite post-cruise recalibration of the SOMMA at Brookhaven National Laboratory (BNL) and extensive conversations with Ken Johnson of BNL, the exact cause of the gas loop problem has not been determined.

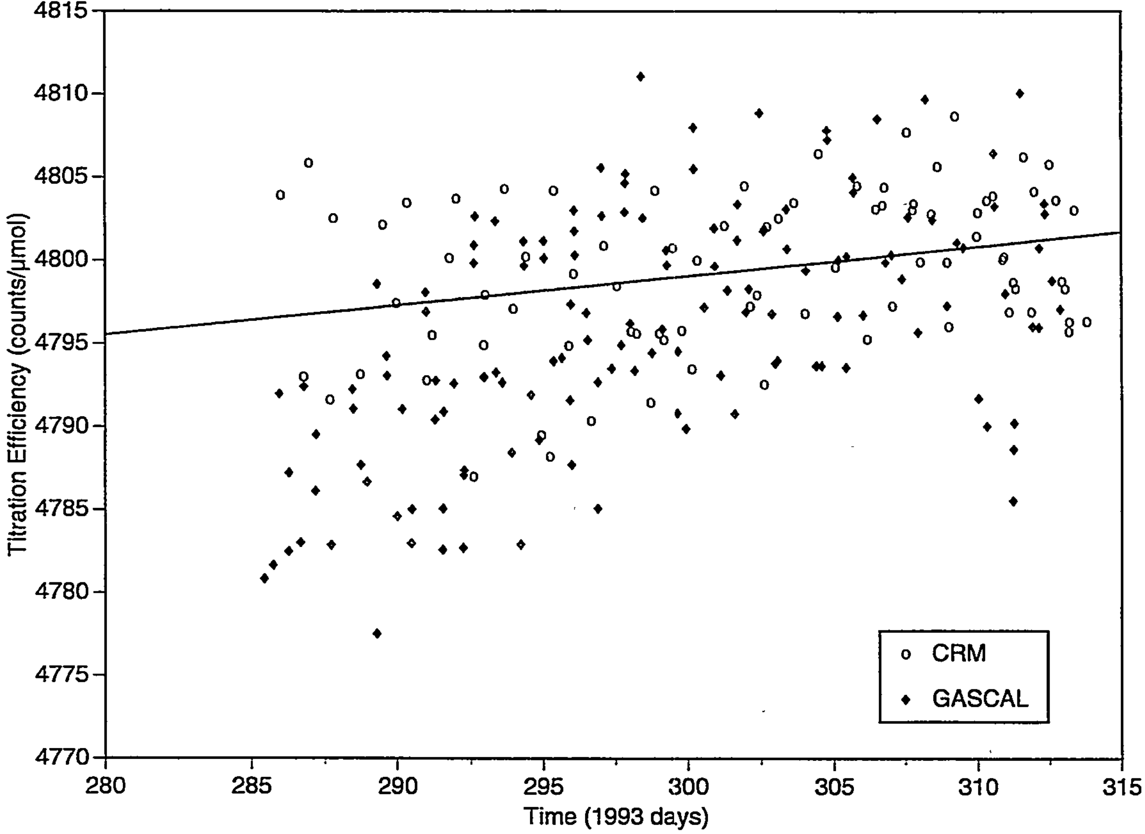

Fig. 3. Plot of certified reference materials (CRMs) and gas loop titration efficiency (GASCAL) values vs time during R/V *Thomas G. Thompson* expedition along WOCE Section P10.

A small increase in efficiency was observed in the TE_{CRM} values during the cruise. The TE values used to calibrate the sample TCO_2 values, therefore, were determined by fitting the TE_{CRM} values with a linear regression as a function of time (Fig. 3). The TCO_2 of samples in μmol/kg was determined using the following equation:

$$\mathrm{TCO_2} = \mathrm{counts} / (0.1763148 \times \mathrm{day} + 4746.161) \times [1000 / (\mathrm{vol} \times \rho)] \times 1.00067,$$

where counts are the blank corrected coulometer counts, day includes the fractional day determined from the titration time, vol is the "to deliver" volume of the pipette corrected for the thermal expansion of glass, ρ is the density of seawater, and 1.00067 corrects for the dilution of the sample by the addition of 200 μL of $HgCl_2$ to the 300-mL sample bottle.

The analytical precision of the TCO_2 analyses can be estimated from the standard deviation (SD) of the 83 CRMs analyzed throughout the cruise. The SD of the calibrated batch 15 CRM values was ±1.91 μmol/kg. The sample precision can be evaluated from the 70 sets of duplicate samples collected in shallow, mid-depth, and deep waters at every station. The average difference between duplicates was 0.16 ± 1.71 μmol/kg, suggesting that sample precision was not significantly different from the analytical precision of the CRMs. As a further check on the accuracy of the TCO_2 analyses, duplicate samples from the surface and the 3000-m Niskins were collected from 10 stations along the cruise track and returned to SIO for analysis by vacuum extraction and manometry in C. D. Keeling's laboratory. Ten samples have been analyzed to date, giving a mean difference (shore – sea) of 0.64 ± 1.79 μmol/kg, which is not statistically different from zero (Table 1). Note that one sample was considered bad and was excluded from the calculation because it was more than three standard deviations from the mean. These replicates also further corroborate the use of the CRM calibration since the mean difference for the gas loop calibration values would have been 2.97 ± 2.49 μmol/kg.

Table 1. Comparison of shipboard TCO_2 analyses to shore-based TCO_2 analyses made by C. D. Keeling at SIO

Station no.	Niskin no.	TCO_2 (PU) (μmol/kg)	TCO_2 (SIO) (μmol/kg)	ΔCO_2 (SIO–PU) (μmol/kg)
18	3	2332.0	2332.2	0.2
27	36	1895.4	1894.6	–0.8
38	36	1857.6	1856.5	–1.1
47	36	1893.5	1897.2	3.7
47	14	2337.8	2336.3	–1.5
65	12	2330.0	2336.1	6.1
71	13	2336.9	2337.2	0.3
80	13	2344.9	2346.1	1.2
86	35	1946.6	1949.7	3.1
86	12	2343.3	2344.0	0.7
			Mean Δ[1]	0.64
			SD[1]	1.79

[1] does not include sample from station no. 65, Niskin no. 12.

3.3 TALK Measurements

During the expedition, 1099 TALK samples were collected according to methods outlined in the DOE Handbook (DOE 1994) and stored in 250-mL borosilicate glass bottles until the samples could be processed. Samples were poisoned immediately after collection with 200 μL of a saturated solution of $HgCl_2$ in deionized water to minimize biological activity prior to analysis. A total of 879 samples were analyzed at sea, and the remaining 220 were returned to the laboratory for analysis. The samples returned for shore-based analysis were from six stations: 30, 41, 54, 71, 77, and 86.

Samples analyzed at sea were brought to 25°C in a water bath, then pumped into a water-jacketed, 100-cm^3, closed titration cell with a peristaltic pump. The cell design is described in the DOE Handbook (DOE 1994). The acid titrant was made by adding concentrated HCl to a 0.5 molar NaCl solution to give a normality of approximately 0.2. The calibrated acid normality (0.195091 ± 0.000041 mol/kg solution) was determined immediately after the cruise by A. Dickson of SIO using the coulometric technique described by Millero et al. (1993). The titration system consisted of a personal computer, a Metrohm 665 Dosimat digital burette, an Orion 720A pH meter, and a Corning semi micro pH electrode. Using a program similar to those used by previous investigators (Bradshaw and Brewer 1988; Millero et al. 1993), the system automatically titrated the sample past the carbonic acid endpoint with electromotive force (emf) intervals of approximately 13 mV. The TALK was calculated from the full titration curve using the nonlinear least-squares approach described in the DOE Handbook (DOE 1994), with the exception that the effect of temperature on the dissociation constants was determined for every titration point based on the measured sample temperature. Sample weight was calculated from the cell volume, the measured sample temperature, and the bottle salinity value measured by the WHOI CTD group on all but three samples. The bottle salinity values from station 18, Niskins 25, 26, and 27, were significantly different (>0.1) from the CTD salinity values and from other bottle salinity values from equivalent depths for the surrounding casts. This difference was large enough to result in an error in the calculated density that was greater than the sample precision, therefore the sample density was recalculated for those three samples using the CTD salinity.

To evaluate the performance of the alkalinity system, CRMs were titrated between each set of samples from a station. Two titration cells were used to run the at-sea samples. The first cell was used for stations 1 to 33. This cell was replaced with a new cell before running the station 36 samples, because the CRM values titrated on first cell had a steady upward drift with time for the 8 days it was in use. The replacement cell gave a much more satisfactory performance and was used for the remainder of the cruise. Sodium carbonate standards were dried and stored in airtight vials following the procedures described in the DOE Handbook (DOE 1994). Sets of four solutions were made in precalibrated volumetric flasks using a 0.7 molar NaCl solution with nominal concentrations of 600, 1200, 2400, and 2800 μmol/kg. Four replicate titrations of each solution were made to generate a calibration curve for the cell. Fresh standards were prepared and titrated at the beginning of the cruise, before replacing the first alkalinity cell, after the replacement cell was in place, and at the end of the cruise.

The time-dependent increase in the first-cell TALK values was removed using a linear fit of the CRM TALK values as a function of time (Fig. 4). The mean TALK of the corrected CRM values was adjusted to match the mean of the second cell CRM values. The final calibration of all samples run at sea was then determined by fitting the sodium carbonate titration data as outlined in the DOE Handbook (DOE 1994). The fit of the nominally measured alkalinity vs the alkalinity calculated from the weight of sodium carbonate gave a slope of 0.987 ± 0.006 and an intercept of 12 ± 11 (Fig. 5). The final cell volume was

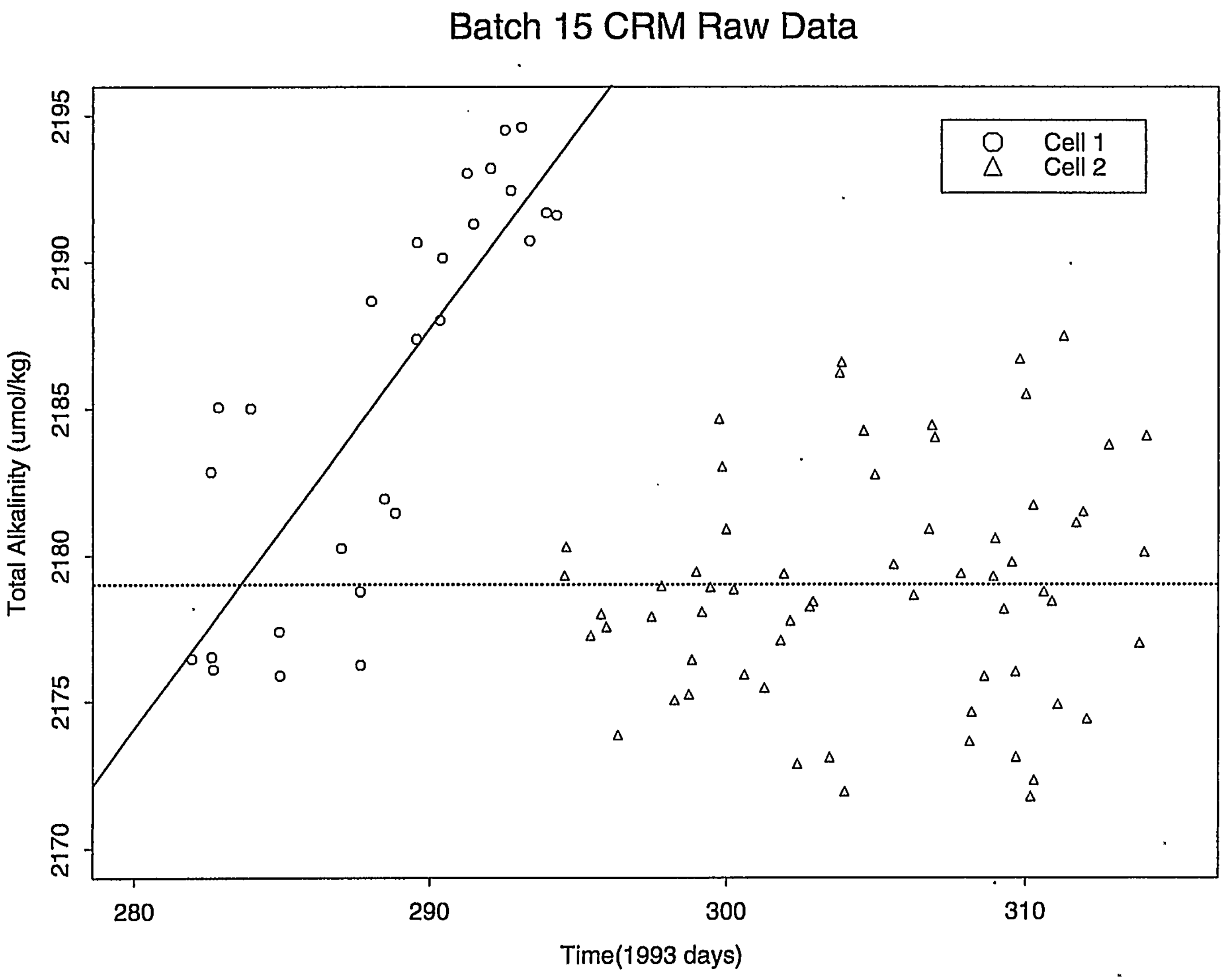

Fig. 4. Linear fit of the CRM TALK values as a function of time.

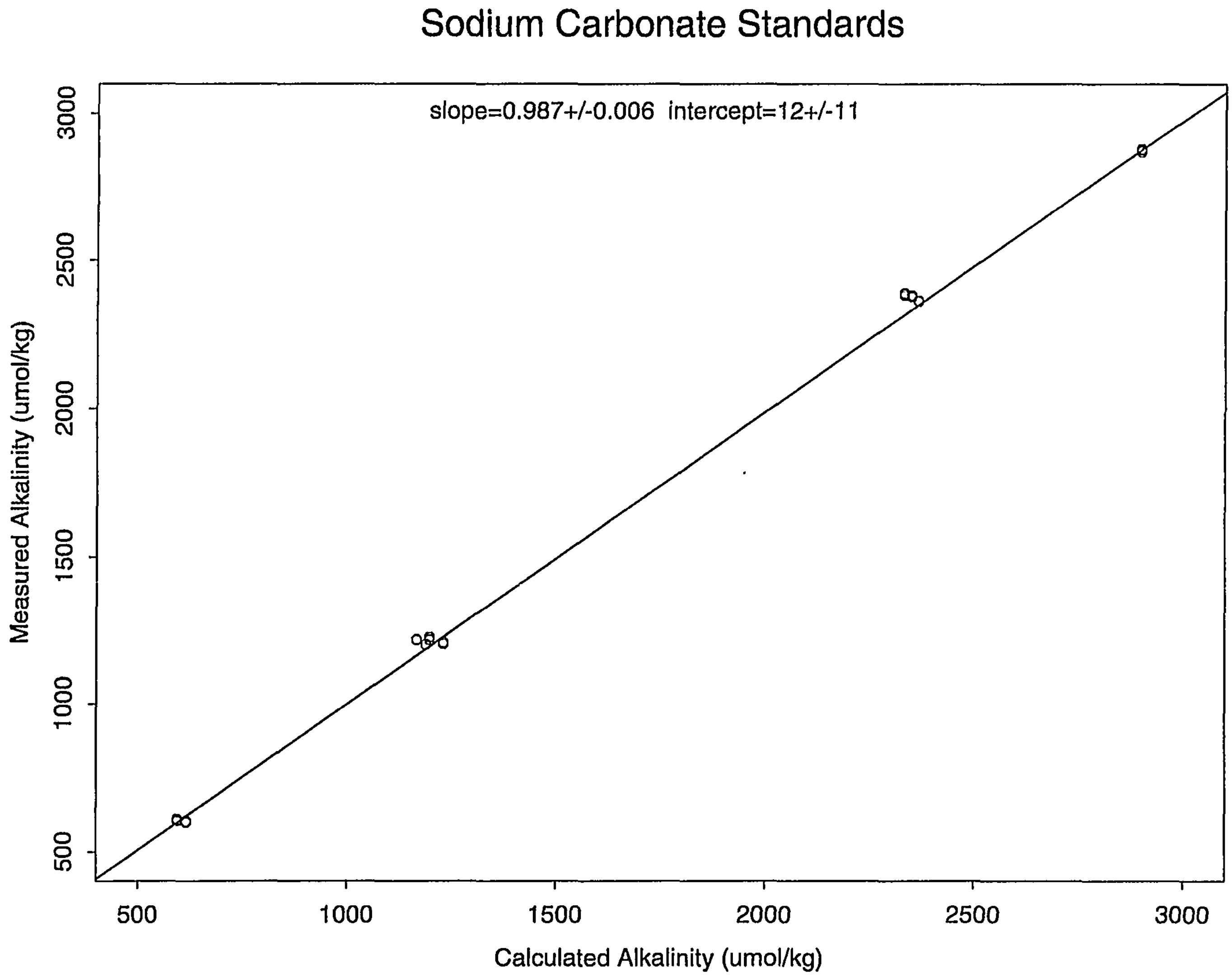

Fig. 5. Plot of the nominally measured TALK vs TALK values calculated from the weight of sodium carbonate.

determined by dividing the nominal cell volume by the slope. Applying this correction resulted in a mean batch 15 CRM alkalinity value of 2207.2 ± 3.9 μmol/kg (N = 98) for the cruise. The mean difference for sample replicates run at sea was 0.5 ± 3.8 μmol/kg (N = 71).

The P10 alkalinity samples returned to the laboratory for analysis were titrated using the same methods described for the at-sea samples. However, since accurate analytical balances were available, the cell volume was determined by careful weighing of the titration cell both empty and full of deionized water at a known temperature. The sample weight was converted to a cell volume based on density. A CRM sample (batch 17) was titrated every working day that the P10 samples were titrated to confirm the stability of the titration cell. The mean value for CRMs titrated over this period (~35 days) was 2207.6 ± 3.5 μmol/kg (N = 40). The mean difference between duplicate P10 samples run in the lab was 3.8 ± 5.2 μmol/kg (N = 12), not quite as good as the samples run at sea but not significantly different from zero. The mean difference between the samples run in the laboratory and the replicates run at sea immediately after collection was 3.8 ± 4.0 μmol/kg indicating that the storage of the samples did not affect the TALK values.

3.4 Underway xCO_2 Measurements

The R/V *Thomas G. Thompson* departed Suva, Fiji, on October 5, 1993, for WOCE leg P10. C. Sabine started the Princeton underway pCO_2 system the following day and provided necessary maintenance until the system was shut down the day before entering Yokohama, Japan, on November 10, 1993. Major problems with the gas selection valve were encountered on the cruise, resulting in a gap in data collection between 14° and 29° N. On average, one set of surface water and atmospheric CO_2 mole fraction (xCO_2) measurements was collected by the Princeton underway system approximately every 5 min while the system was operating normally. The sample locations along the cruise track are shown in Fig. 6.

3.4.1 Methods for Measurement and Computation

The Princeton underway CO_2 system uses a rotating disk equilibrator design with an infrared detector that has been shown to provide stable, consistent results with minimal attention by the operator (Sabine and Key 1996, 1997). The equilibrator is a modified disk-stripper design that was found to be very efficient at removing radon from seawater (Schink et al. 1970). The components of the system are linked to a computer and sample analysis is fully automated. The primary advantages of this system are the rapid response time of the equilibrator and the low level of expertise necessary to maintain the system relative to a gas chromatographic detector design. The gain in equilibrator response time sacrifices simplicity relative to the shower-head equilibrator, since the disk equilibrator has moving parts in addition to the air-circulation pump present on all seagoing pCO_2 instruments. On the other hand, the disk equilibrator design is not sensitive to changes in water pressure from the bow pump.

Figure 7 shows the major components of the Princeton system. Uncontaminated water from the ship's bow pump flows through the lower half of a disk equilibrator at approximately 18 L/min. CO_2 in the water equilibrates with recirculated air in the top half of the chamber. Equilibrator air, air pumped from the ship's bow/stern (depending on wind direction), and four standard gases (reference, low, mid, and high) are plumbed into a computer-controlled gas-sampling valve that determines which gas is directed to the detector. The mole fraction of the sample gas is determined by a Li-Cor 6251 nondispersive dual-beam infrared detector. During

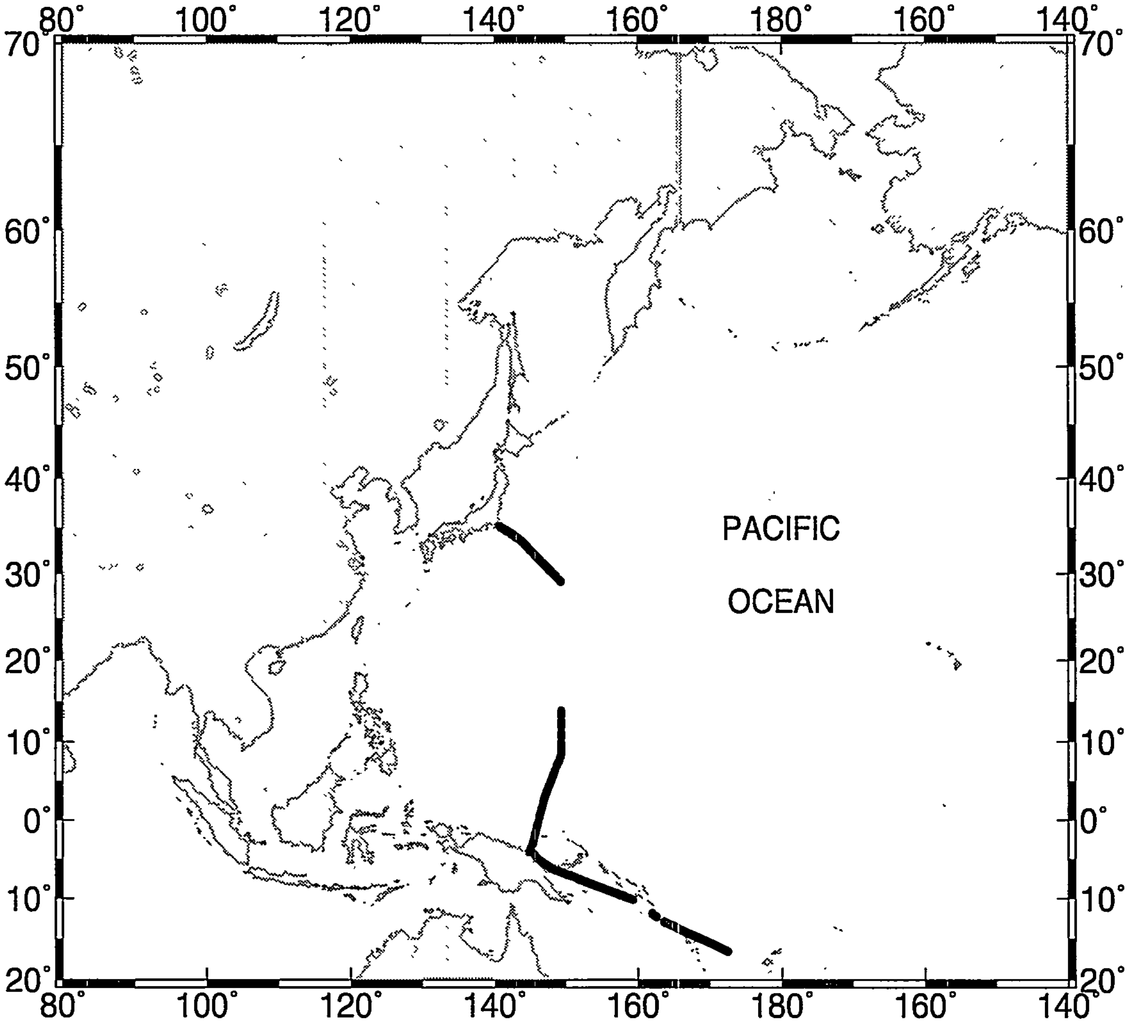

Fig. 6. Underway pCO_2 sampling locations along the cruise track for WOCE Section P10. The gap in the sampling track indicates the underway system problem that occurred during the cruise.

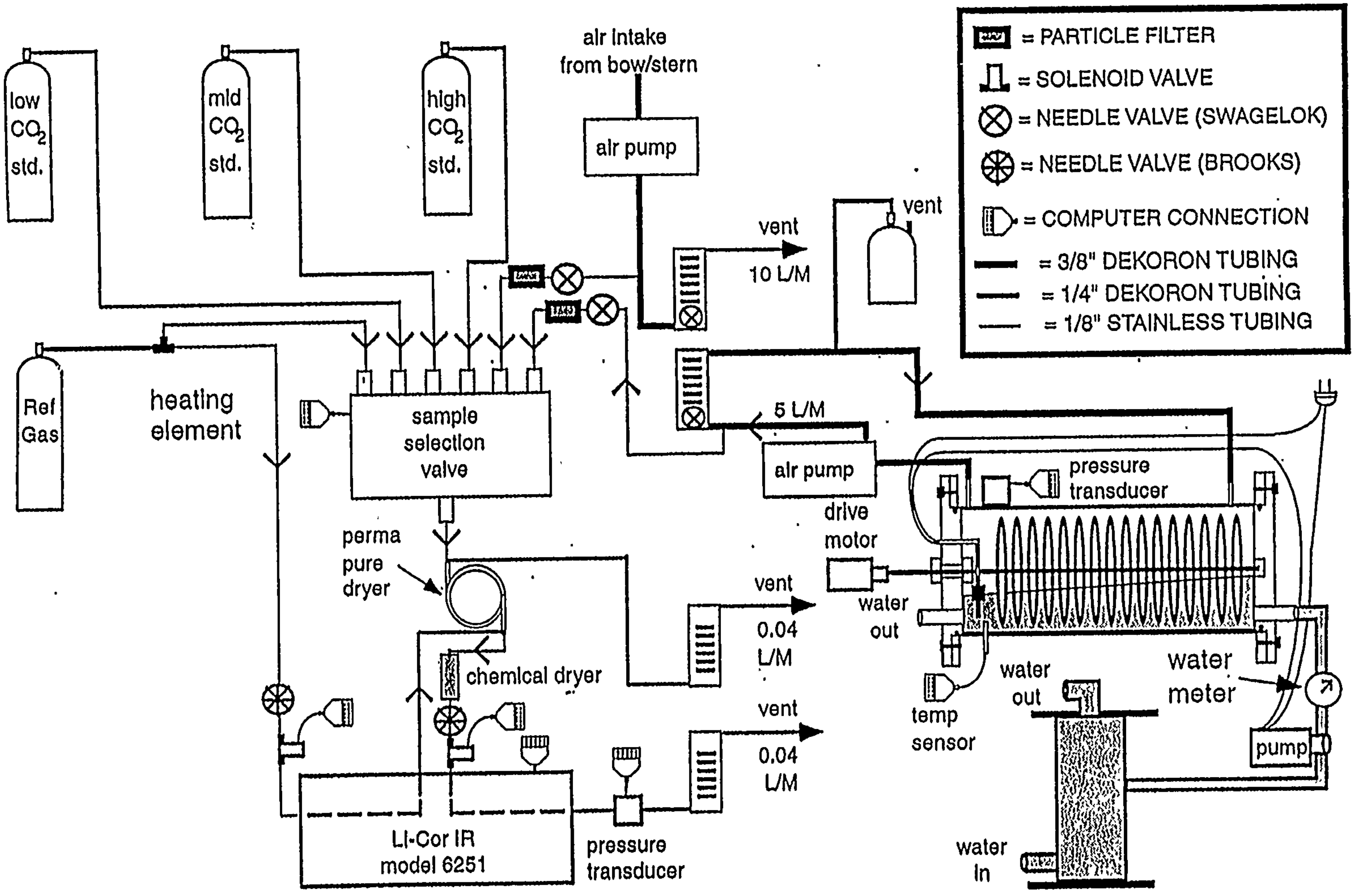

Fig. 7. Princeton underway CO_2 system.

calibration, the instrument measures the concentrations of four standards that have a range of CO_2 concentrations in air, normalizes the detector voltage to temperature and pressure, and fits the results with a third-order polynomial. A full description of the system is presented by Sabine and Key (1997) with a few minor differences as noted in the following sections.

3.4.2 Thermal Control

The system used on this cruise was a predecessor of the system described by Sabine and Key (1997) used during the WOCE Indian Ocean cruises. The primary physical difference between the systems was the lack of thermal control on the detector rack on the earlier system. Although normalizing the detector response to the measured temperature removed most of the short-term variability in the detector response to standards, the remaining variability was still correlated with detector temperature. This variability was removed in the calibration routine (see discussion in Sect. 3.4.3), but it was decided to minimize this complicating effect in later versions of the system by enclosing the detector and associated plumbing in a temperature-controlled box.

3.4.3 Component Calibration

The working standard gas concentrations were calibrated against primary CO_2 standards, provided by P. Tans (NOAA/CMDL), in the laboratory using the seagoing detector prior to the cruise. Working standards were a mixture of CO_2 in artificial air prepared by Scott Specialty Gases. Multiple measurements of the working standards (0.00, 282.51, 349.77, and 400.70 ppm CO_2) were made with the detector calibrated against the primary standards. Measurement precision was better than 0.1 ppm on all standards.

Equilibrator temperature was monitored by a Rosemont ultralinear platinum resistance thermometer (PRT). The PRT was calibrated in the laboratory against a National Institute of Standards and Technology (NIST) traceable mercury thermometer. Estimated accuracy was ±0.01°C on the ITS90 scale.

Temperature readings from the Li-Cor detector were not explicitly calibrated for this survey because the final results are only a function of the relative changes in temperature between the standard gases and the sample.

The sensor used to monitor the system pressure (Setra Systems Inc.) was factory-calibrated against NIST-traceable primary standards prior to the cruise. Estimated accuracy was ±0.05%.

All system inputs were read into the computer as voltages using a Keithly A/D board. Accuracy of the board's readings was confirmed with a Fluke model 8840A 5-digit voltmeter prior to the cruise. The resolution of the readings was a function of the voltage range being measured, but in all cases was at least an order of magnitude smaller than the estimated precision of the measurement.

Both the sea surface temperature and salinity values were calibrated against the WOCE preliminary surface bottle values at each station. Although the exact trip time is not generally recorded in the WOCE ".SEA" files, the ".SUM" files do record the beginning and ending times of each cast. Since the Niskin bottles were tripped on the upcast, the surface bottle was tripped immediately before the rosette was brought aboard and the cast was completed. The end time for the cast was taken, therefore, as the trip time for the surface bottle at each station. The surface station data were then tied to the underway data by calculating the mean and median values of the underway data for the 15 min prior to the recorded cast end time. Although the ship was not underway while the cast was in progress, there was the potential that differences between the underway temperature readings and the discrete samples could have been real in very high gradient regions. Stations where the mean and median values were greater than 0.01 units apart were flagged, therefore, as questionable and not considered in the calibration fits.

3.4.4 Analysis Sequence

The Princeton system normally operates automatically with a single microcomputer (80486 CPU) controlling sample selection, valve switching, and data logging. Figure 8 shows a typical record of detector voltages recorded for one full calibration and measurement cycle. The details of exactly how the system selects the standards and determines sample stability is described by Sabine and Key (1997). The primary difference between the operation of this version of the system and that described by Sabine and Key (1997) is the frequency at which the system sampled each gas. For this cruise, a full set of standards (reference, low, mid, and high standards) was analyzed every 3 h with a partial standard set (low, mid, and high standards) run every hour in-between full calibrations. An hourly calibration sequence was chosen to ensure that detector drift was captured, but this was found to be well in excess of what was necessary. The reference gas was analyzed only at 3 h intervals because the detector took a long time to stabilize with the 0-ppm CO_2 reference and the 0-ppm detector readings were very stable. After calibration, the system alternately collected six marine air and six equilibrator sample gases until it was time for another calibration.

3.4.5 Data Calibration

Listed below, in order of calculation, are the steps that were used to calibrate the results with the Princeton system.

1. Average the readings (four per calibration) for the reference gas and each standard gas for each calibration run.

2. Estimate the response for each gas as a function of time by calculating the set of linear regression lines that connect the estimated responses from the calibration runs. In other words, "connect the dots" generated by step 1 plotted as a function of time. Various smoothing curves could be used here, but this procedure yields the lowest uncertainty of any tried to date (possibly because of the short time scale correlation among the four results).

3. Based on the four sets (one set for each standard gas) of regression lines generated by step 2, calculate the response for each standard gas at the time each equilibrator gas or bow air sample was measured.

4. Use the results of step 3 with the detector response for the measurements to calculate the concentration of the unknown samples. Here it is assumed that the relationship between detector response and gas concentration follows a third-order polynomial; therefore, this step requires finding the real roots of a third-order polynomial for each unknown sample measurement.

The result obtained from these four steps is the xCO_2 of the measured dry gas. This value can be corrected to pCO_2 or fugacity of CO_2 (fCO_2) at in situ conditions. These

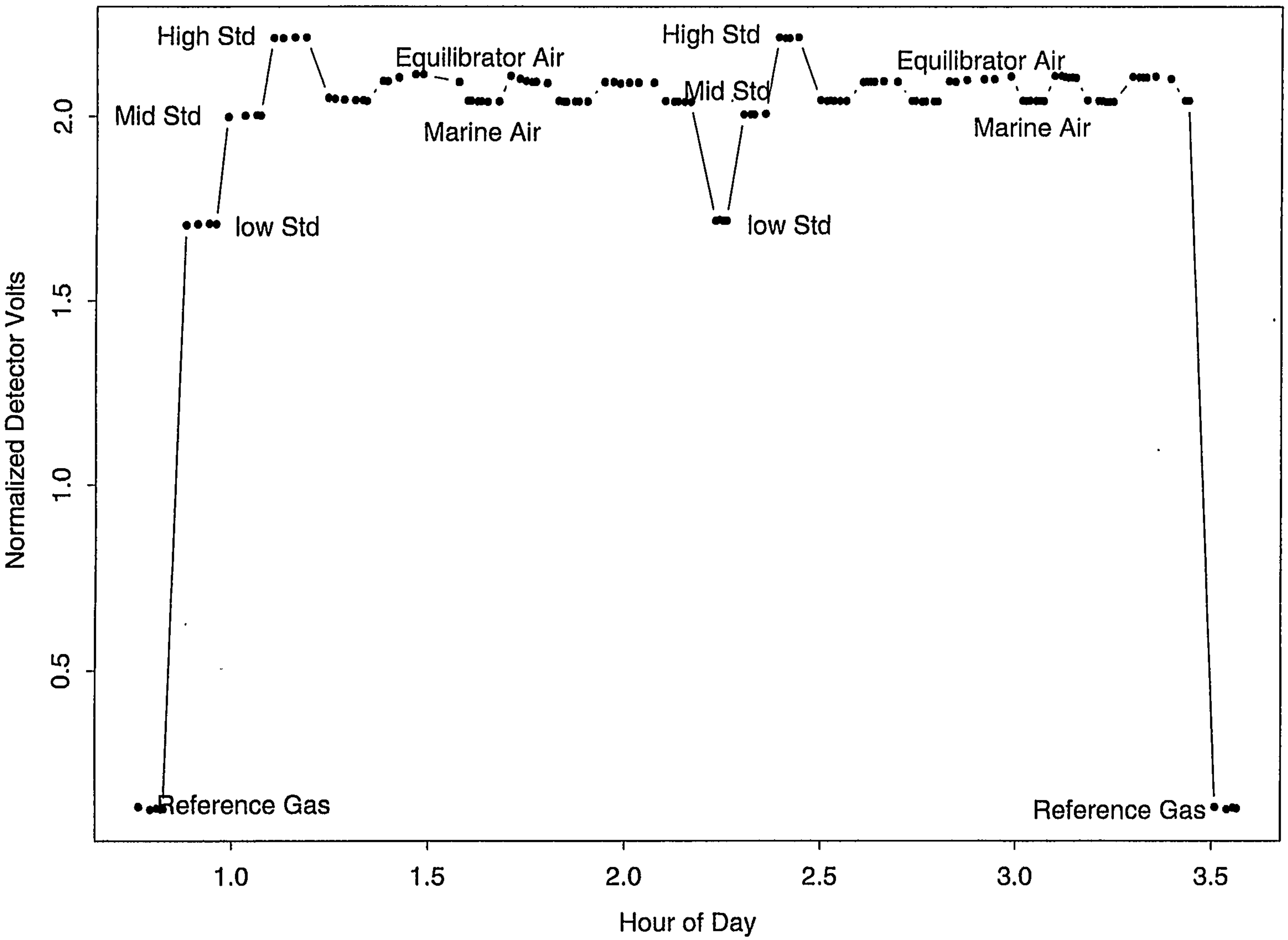

Fig. 8. A typical analysis sequence for the Princeton system during measurements along WOCE Section P10.

adjustments have been described in great detail in DOE Handbook (DOE 1994). The CO_2 concentrations reported in the final data tables were given at the measured equilibrator temperature (average 0.49 ± 0.1°C greater than sea surface temperature) and were corrected to in situ temperature using the relationship of Weiss et al. (1982). In order to calculate ΔxCO_2 between surface water and the atmosphere, the atmospheric results were interpolated to the times surface water measurements were made. A separate file with the measured atmospheric values is also provided.

3.4.6 Precision and Accuracy

The primary calibration method for the system is periodic analysis of gas standards using known CO_2 concentrations. The infrared detector response is slightly curvilinear (i.e., not straight) with respect to CO_2 concentration in the sample gas path. Additionally, the detector has been found to have a slow drift over a period of several hours. Frequent calibration against standards can give an estimate of the analytical precision; however, this technique has the potential of systematic error with respect to accuracy. There is currently no known rigorous statistical test to determine optimal instrumental settings, or, for that matter, even to estimate the expected uncertainty of the results; however, it was attempted to estimate the precision and accuracy of these results with the best available information.

One estimate of precision was obtained by looking at the standard deviation of repeated measurements of the gas standards. The mean of the standard deviations determined for this instrument was 0.007 V, which was approximately equivalent to 0.9 ppm CO_2. This can be interpreted as a crude estimate of the analytical precision if one assumes (1) that the precision obtained when analyzing sample gas is the same as for a standard and (2) that no additional uncertainty is incurred when interpolating calibration runs to the sampling time. This estimate assumes that no significant error was incurred in converting to in situ conditions. This assumption is reasonable with respect to precision, but not necessarily for accuracy. The primary correction to get xCO_2 at in situ conditions was the warming of the water as it passed through the ship and equilibrator. A 1-degree increase in temperature results in roughly a 4% or ~14 ppm change in xCO_2 (Takahashi et al. 1993; Copin-Montegut 1988; Weiss et al. 1982); therefore, both sea surface and equilibrator water temperatures must be known to an accuracy of ~.05°C to calculate xCO_2 values accurate to ±1 ppm. A second estimate of accuracy can be obtained by comparison with other systems. No other pCO_2 systems were running on this cruise, but the Princeton system has given very consistent results with R. Weiss's gas-chromatograph-based/shower-type system when the two systems were run in parallel (Sabine and Key 1997). It was estimated that the accuracy of this system was ~1 ppm.

3.4.7 Major Problems

Two days after the cruise began, the underway CO_2 system started to have problems with the Valco gas-sampling valve. Occasionally during position switching, the valve actuator would not stop, and the valve would continue to spin until the fuse blew or the power was switched off and back on again. By October 9 the problem had become more frequent. The valve was completely dismantled and cleaned. Valco technical support was contacted by phone. The problem was deduced to be in the Valco logic board, which could not be repaired at sea. Upon reassembly the valve seemed to work better. It was watched carefully and the spinning was corrected when necessary by switching the power to the valve off and on again. On the morning of October 14, the air flow in the bow air line had dropped substantially. The tubing was flushed with deionized water to remove any salt deposits in the line, and the valve port was cleaned with a cotton-tipped swab. The pump head was also replaced on the air cadet pump, and the flow returned to normal. On October 15, the Valco gas-sampling valve was disassembled and cleaned because sample gas flow was very low. Flow rate was much better after cleaning. On October 17 at 18:30 h, a problem was discovered with the drying tube while the system was running a standardization. The Nafion® tubing had apparently pulled out of the fitting. This problem could not have occurred too long before it was discovered because the sample was contaminated with 0-ppm gas, which was giving very unusual readings. The entire drying tube assembly was replaced, and the system was recalibrated. On October 18, the Valco spinning problem was too severe for the automated sampling program. The system was run using a program that required the operator to hit a key on the computer to change valve positions. This way, if the valve started spinning, it could be fixed right away. An attempt was made to run the system on the same schedule that the automated system was programmed to run. On October 23 at 22:30, the water pump failed, and the equilibrator was found drained. The system was switched to sample bow air while the water pump was repaired. On October 25, the bow and equilibrator gas flow rates were very low. The Valco was taken apart and cleaned. Upon reassembly, the actuator would do nothing but spin. Many unsuccessful attempts were made to repair the problem. The system was shut down until a solution could be found. On November 3, the ship's engine room crew managed to manufacture a handle that would allow the rotor to be manually rotated. The system was started again and run using the manual program for the remainder of the cruise.

3.4.8 Results

Despite the many mechanical difficulties on this cruise, more than 11,600 surface seawater and 4,000 marine air measurements covering more than 50 degrees of latitude in the far western Pacific where collected. Figure 9 shows the surface water and atmospheric xCO_2 concentrations as a function of the day of the year on the cruise. It is clear that the surface water CO_2 concentration can vary significantly over relatively short time (space) scales. Values corrected to sea surface temperature ranged from a low of 314.8 ppm to a high of 389.9 ppm. Low xCO_2 values were observed at the beginning of the cruise (near Fiji) and at the end of the cruise (near Japan). The highest xCO_2 values were observed near the equator, crossed on day 289.

3.5 Radiocarbon Measurements

During the R/V *Thomas G. Thompson* expedition along WOCE Section P10, 588 accelerator mass spectrometry (AMS) $\Delta^{14}C$ samples were collected at 38 stations. In addition to the AMS samples, LV Gerard samples were also collected during this cruise. The LV measurements will be published in a separate report.

Sampling of ^{14}C during the cruise was carried out by R. Key of the Ocean Tracer Laboratory at Princeton University. Sample extraction, $\delta^{13}C$ analyses, and ^{14}C analyses were performed by the National Ocean Sciences AMS Facility (NOSAMS) at Woods Hole Oceanographic Institution. Key collected the data from the originators, merged the files, assigned quality control flags to the ^{14}C results, and submitted the data files to the WOCE office in April 1998.

All SV samples were collected from standard CTD/rosette casts into 500-mL glass bottles fitted with high-quality ground-glass stoppers. The samples were poisoned with $HgCl_2$

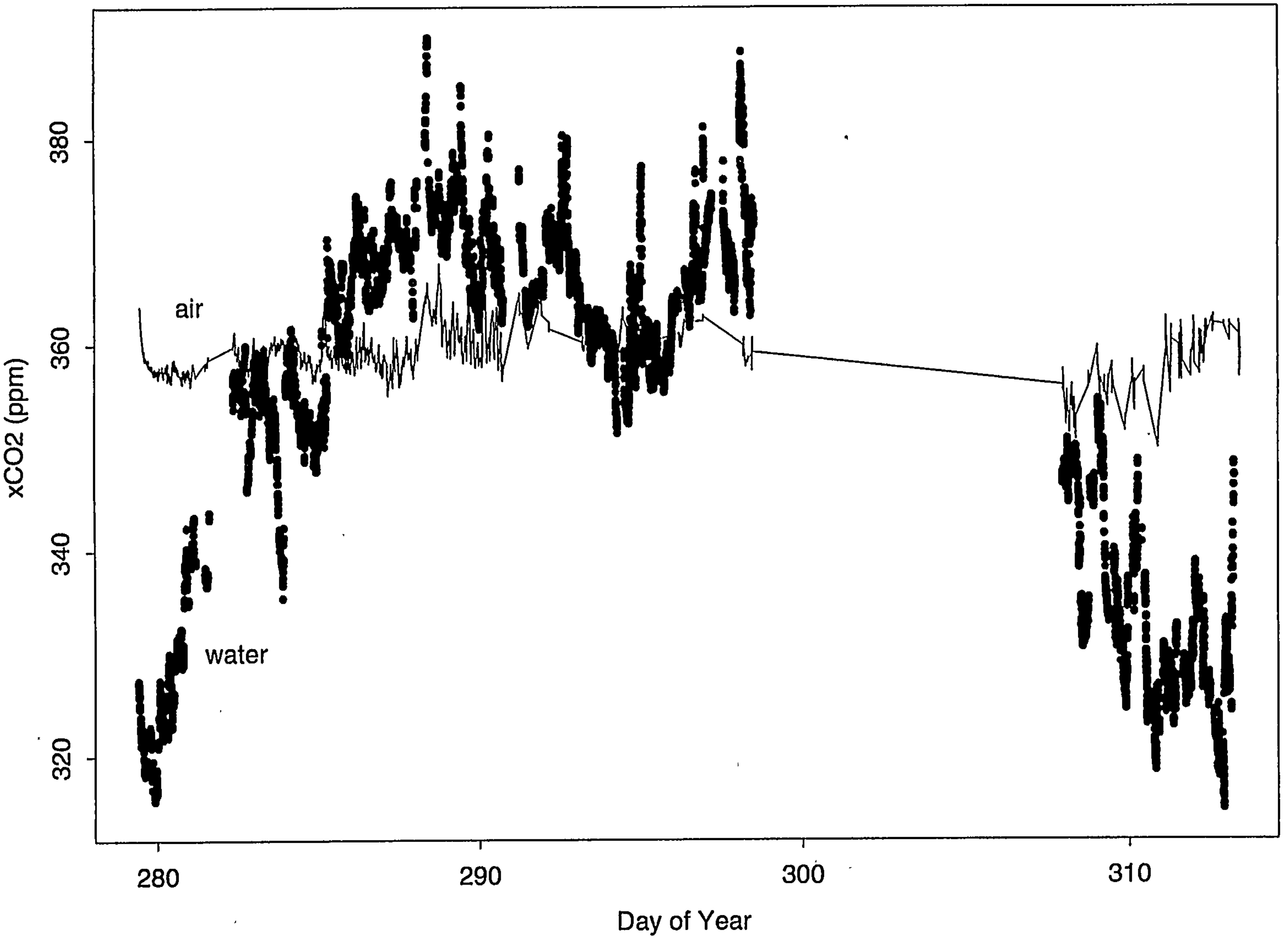

Fig. 9. Surface seawater (points) and atmospheric CO_2 concentrations (lines) vs time during WOCE Section P10.

immediately after collection and were sent for extraction and analysis at NOSAMS after the cruise. Details of the extraction, counting, etc., are available from Key (1991), McNichol and Jones (1991), Gagnon and Jones (1993), and Cohen et al. (1994).

The $\Delta^{14}C$ values reported here were originally published in a NOSAMS data report (NOSAMS, March 13, 1998). That report included results that had not been through the WOCE quality control procedures.

All 588 of the AMS samples from this cruise have been measured and presented in this report. Replicate measurements were made on 21 water samples. These replicate analyses are tabulated in Table 2.

Table 2. Summary of Replicate Analyses

Sta-cast-bottle	$\Delta^{14}C$	Error	Error-weighted mean[a]	Uncertainty[b]
6-1-3	−209.4	2.8	−211.0	2.3
	−212.6	2.8		
6-1-5	−187.3	2.7	−189.2	4.4
	−193.5	4.2		
31-1-29	90.8	6.0	89.4	3.4
	88.7	4.2		
34-3-18	−159.8	6.9	−155.2	5.1
	−152.6	5.3		
34-3-25	−52.8	4.5	−55.3	2.6
	−56.5	3.1		
34-3-27	70.2	5.3	71.5	3.4
	72.4	4.5		
36-1-24	−80.0	3.5	−79.8	2.8
	−79.4	4.9		
65-3-33	135.0	4.1	134.6	2.5
	134.4	3.1		
65-3-35	118.0	3.4	118.6	2.6
	119.5	4.0		
68-1-30	117.2	4.6	117.0	3.1
	116.7	4.1		
71-1-25	−126.5	3.1	−129.1	4.1
	−132.3	3.4		

71-1-30	109.8	4.1	107.4	3.6
	104.6	4.5		
74-3-15	−235.1	2.7	−234.1	3.6
	−229.9	5.6		
76-1-28	53.7	3.5	50.3	5.0
	46.6	3.6		
78-1-31	128.4	4.1	123.0	6.8
	118.8	3.6		
83-1-34	121.0	4.1	120.2	2.7
	119.6	3.6		
85-1-24	−110.6	4.0	−115.2	5.8
	−118.8	3.5		
85-1-27	34.9	5.3	30.6	4.9
	28.0	4.0		
90-1-4	−232.2	2.7	−230.4	3.6
	−227.1	3.7		
90-1-17	−76.5	3.6	−71.9	6.5
	−67.4	3.6		
90-1-20	2.9	3.1	1.6	4.3
	−3.2	5.8		

[a] Error-weighted mean reported with data set.

[b] Larger of the standard deviation and the error-weighted standard deviation of the mean.

Table 2 shows the error-weighted mean and uncertainty for each set of replicates. Uncertainty is defined here as the larger of the standard deviation and the error-weighted standard deviation of the mean. For these replicates, the simple average of the tabulated uncertainties for the replicates is 4.0‰ (equal weight for each replicate set). This precision is typical for the time frame over which these samples were measured (February–October 1997). Note that the errors given for individual measurements in the final data report (with the exception of the replicates) include only counting errors and errors due to blanks and backgrounds. The uncertainty obtained for replicate analyses is an estimate of the true error that includes errors due to sample collection, sample degassing, etc. For a detailed discussion of this see Key (1996).

Figures 10–14 summarize the $\Delta^{14}C$ data collected on the P10 Section. Only $\Delta^{14}C$ measurements with a quality flag value of 2 ("good") or 6 ("replicate") are included in each figure. Figure 10 shows the $\Delta^{14}C$ values with 2σ error bars plotted as a function of pressure.

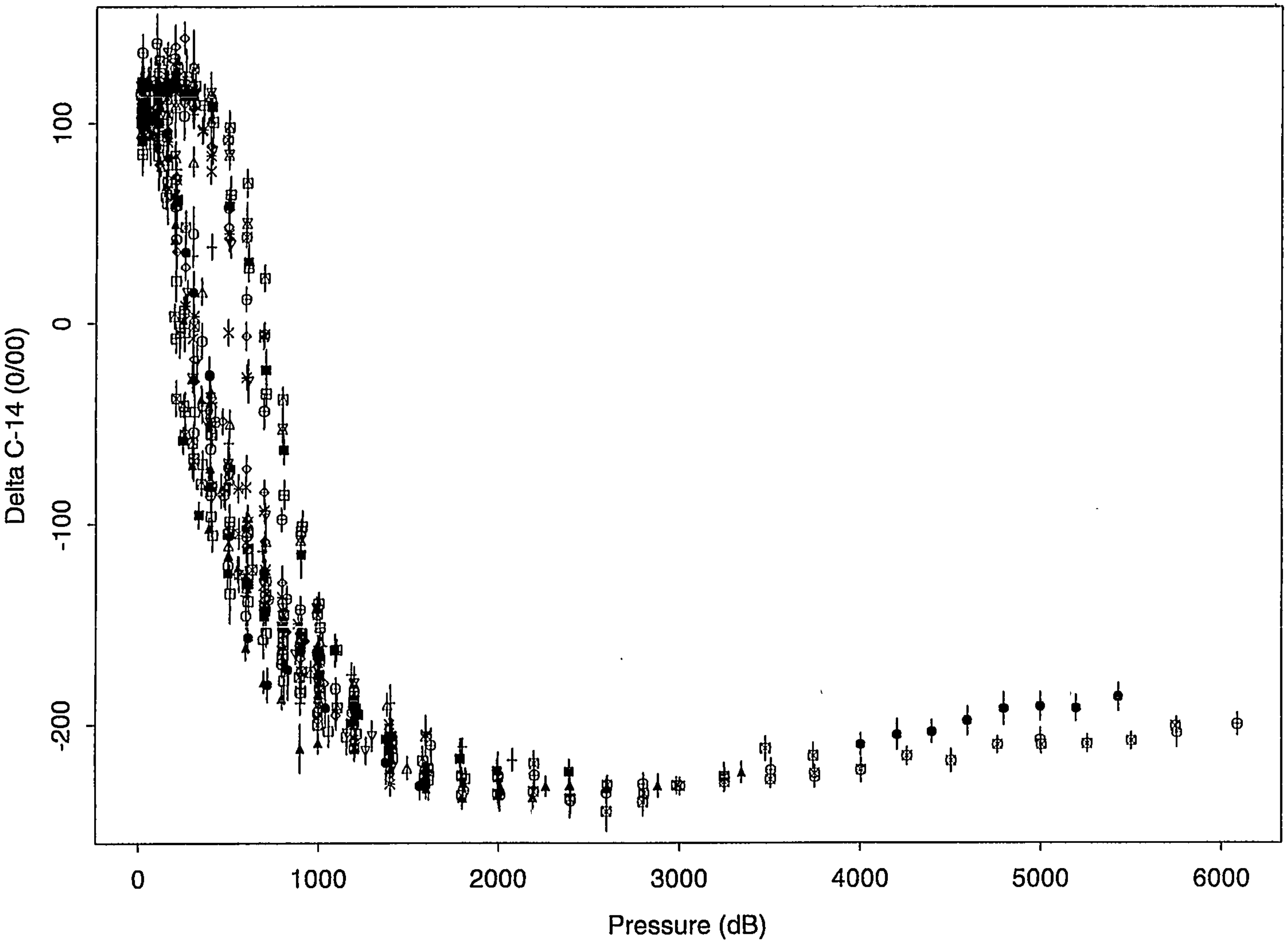

Fig. 10. $\Delta^{14}C$ **results for P10 stations shown with** 2σ **error bars.**
Only measurements with quality control flag values of 2 or 6 are plotted.

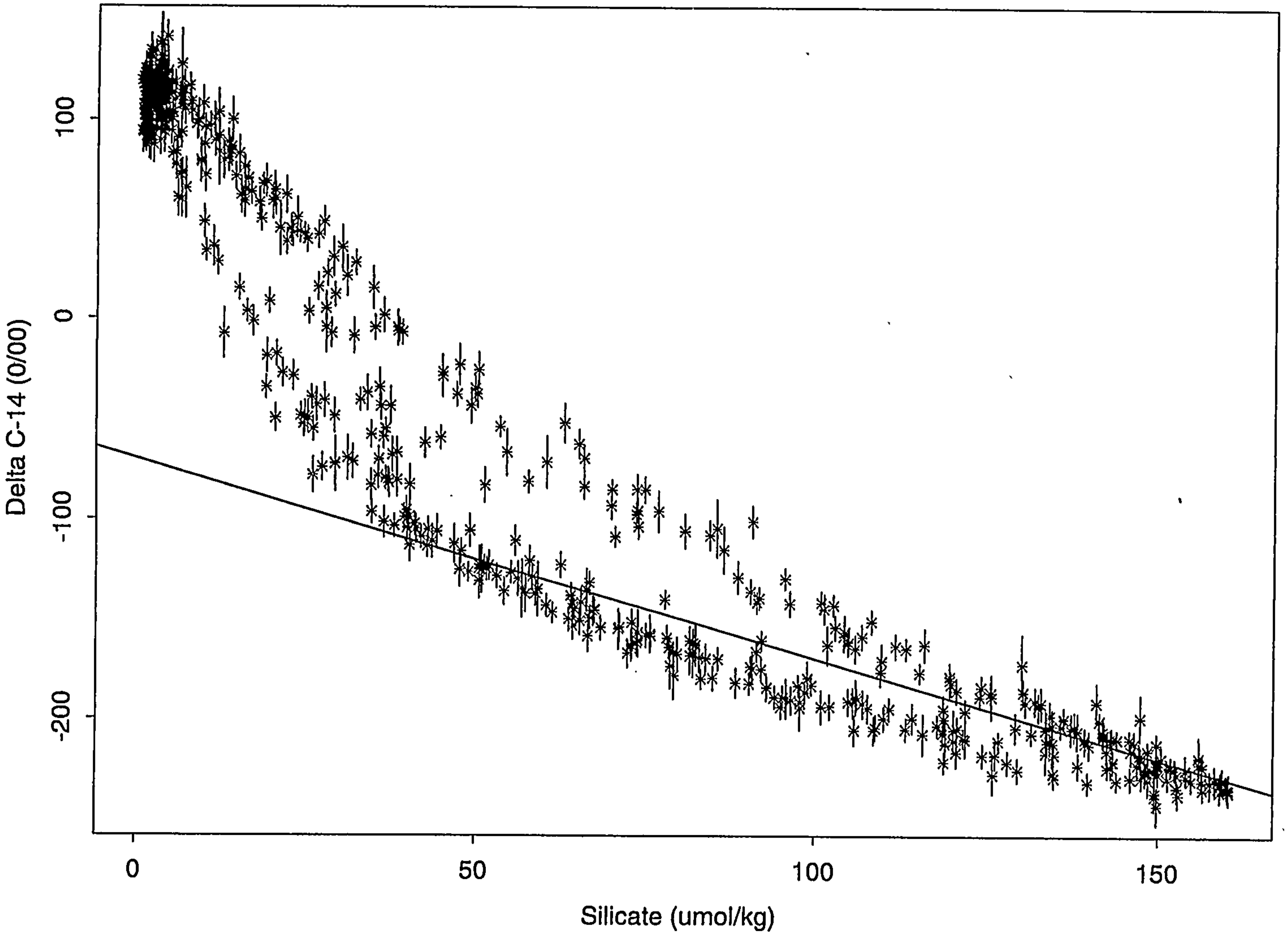

Fig. 11. Δ^{14}C **as a function of silicate for P10 AMS samples.**
The straight line shows the relationship proposed by Broecker et al. 1995 ($\Delta^{14}C = -70 - Si$ with radiocarbon in $^0/_{00}$ and silicate in μmol/kg).

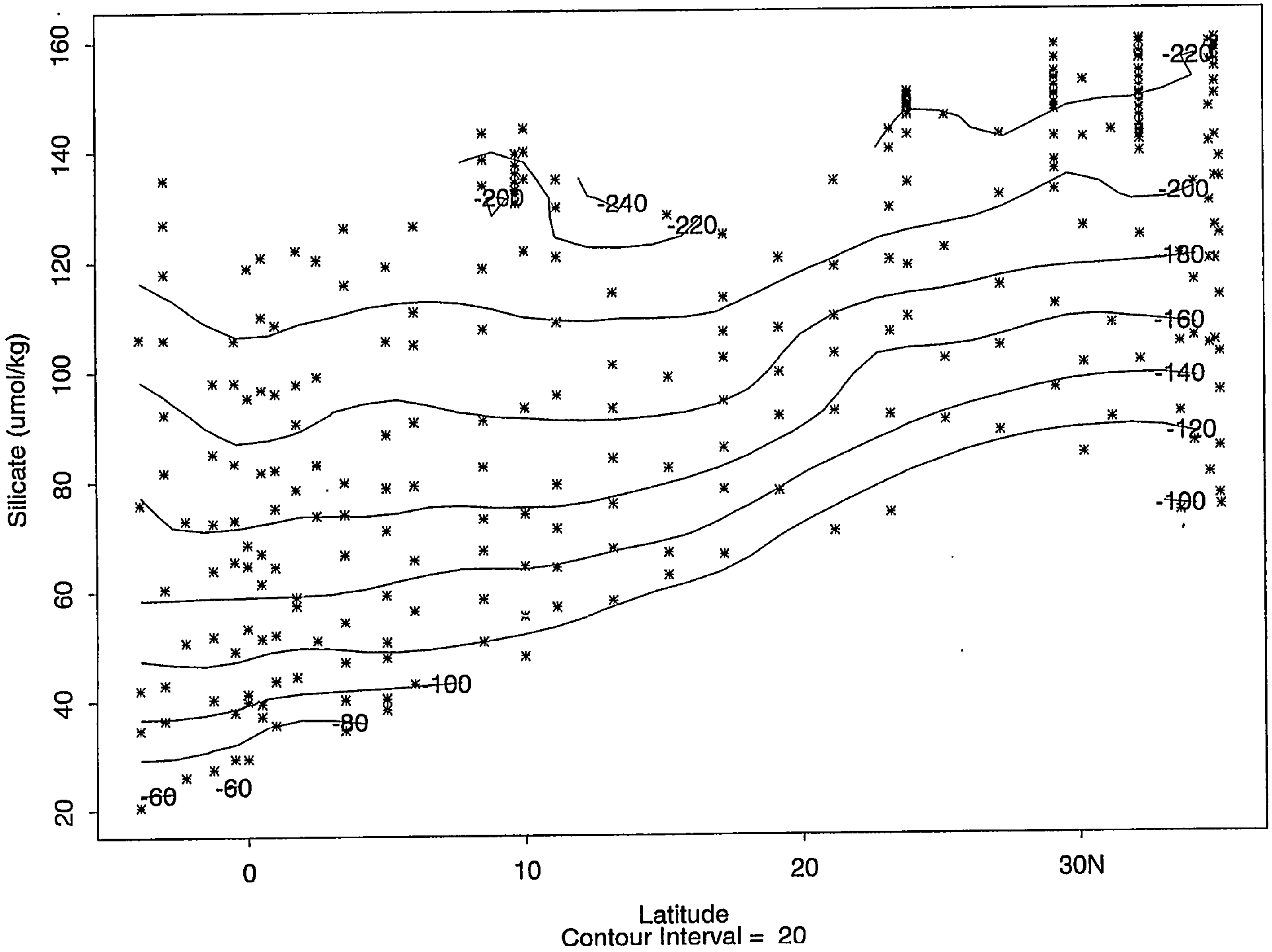

Fig. 12. Section of $\Delta^{14}C$ contours along latitude in silicate space for the 500–2500 m depth range. Note that for this section, "shallow" is toward the bottom.

The mid-depth Δ^{14}C minimum occurs around 2000 to 2400 m, but is weak in this data set relative to the eastern North Pacific. Measurements in the thermocline region fall into two distinct groups with the higher values being from the southern end of the section and the extreme northern end while the lower grouping is from the central portion (see Figs. 11 and 12).

Figure 11 shows the Δ^{14}C values plotted against silicate. The straight line shown in the figure is the least squares regression relationship derived by Broecker et al. (1995) on the basis of the GEOSECS global data set. According to their analysis, this line ($\Delta^{14}\text{C} = -70 - \text{Si}$) represents the relationship between naturally occurring radiocarbon and silicate for most of the ocean. Broecker et al. interpret deviations in Δ^{14}C above this line to be due to input of bomb-produced radiocarbon; however, they note that the interpretation can be problematic at high latitudes. Samples collected from shallower depths at these stations show an upward trend with decreasing silicate values reflecting the addition of bomb-produced ^{14}C. As in Fig. 10, two distinct trends are apparent. Here the upper grouping is from the northern end of the section and the lower from the southern end.

Another way to visualize the ^{14}C–silicate correlation is as a section. Figure 12 shows Δ^{14}C as contour lines in silicate-latitude space for samples having a potential density greater than 26.9, which corresponds to ~500 m. In this space, shallow waters are toward the bottom of the figure. The density cutoff was selected to eliminate those samples with a very large bomb-produced ^{14}C component. For this data set, Broecker's hypothesis does not work very well. The Δ^{14}C isolines trend upward to the north, and the spacing between the isolines decreases northward, for contours that fall below the depth of bomb-radiocarbon contamination. The upward curvature of the isolines at the northern end of the section is due to the addition of bomb-produced radiocarbon via ventilation or due to an "anomalous" silicate signal (Talley and Joyce 1992).

Figures 13–14 show Δ^{14}C contoured along the section. Figure 13 is a normal section in latitude-depth space whereas Fig. 14 shows the same data set in potential density-latitude space. The depth section was gridded by means of LeTraon's (1990) objective technique, and the density section was gridded using the "loess" methods described in Chambers et al. (1983), Chambers and Hastie (1991), Cleveland (1979), and Cleveland and Devlin (1988).

In Fig. 13, the primary structure of the isopleths is due to the presence of the Pacific North Equatorial Current which flows westward across the southern end of the section and the Japan current that flows northeastward across the far northern end of the section. Upwelling near the equator is not particularly evident in Fig. 13 but is the source of most of the structure seen in the isopleths in Fig. 14 in the low-latitude zone. The deep and bottom water AMS results are too sparse to contour.

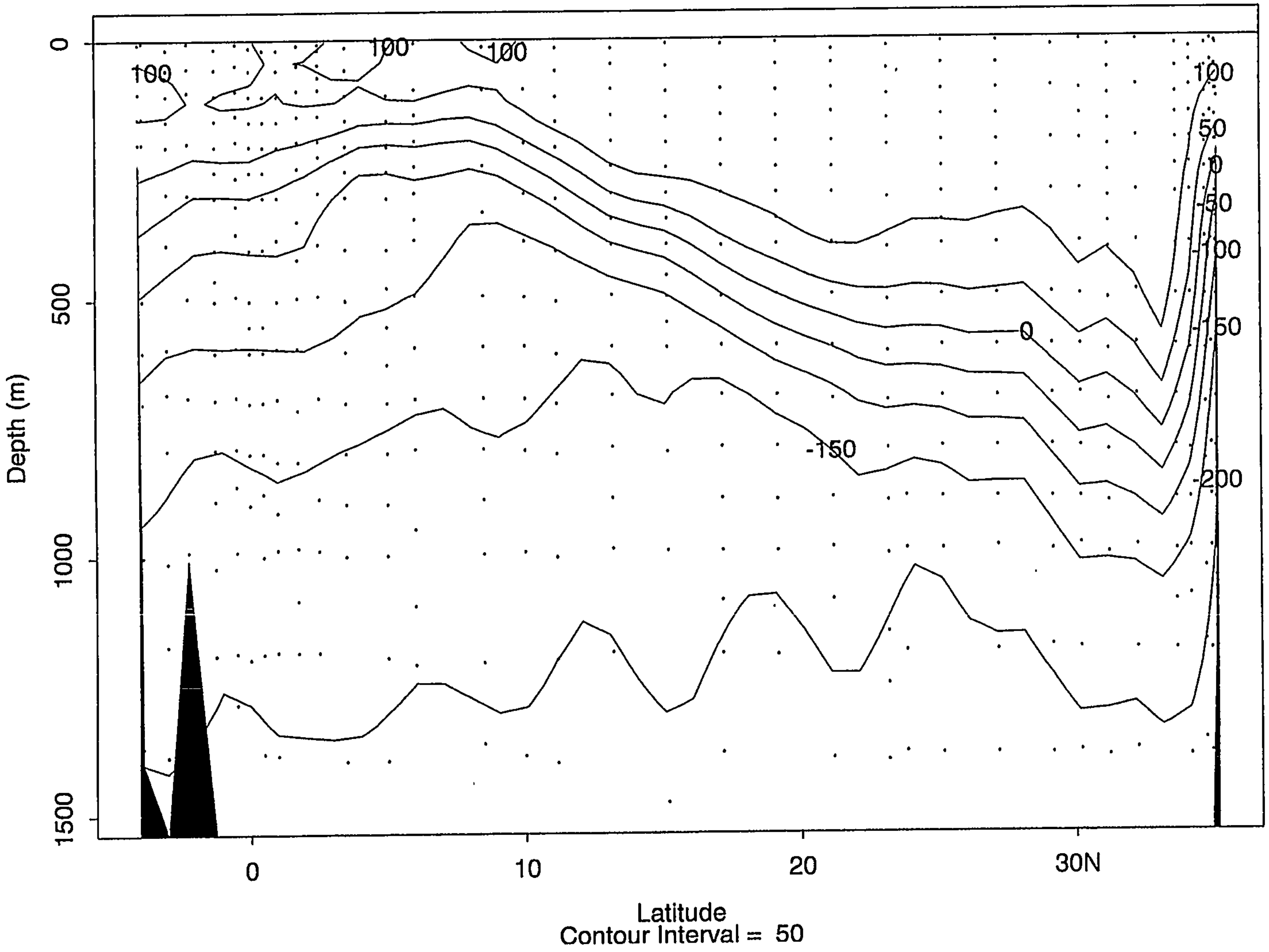

Fig. 13. Plot-section of $\Delta^{14}C$ along WOCE Section P10. Most of the deep and bottom waters along this section were sampled with the LV technique. The few AMS samples collected below 1500 m were omitted from this section.

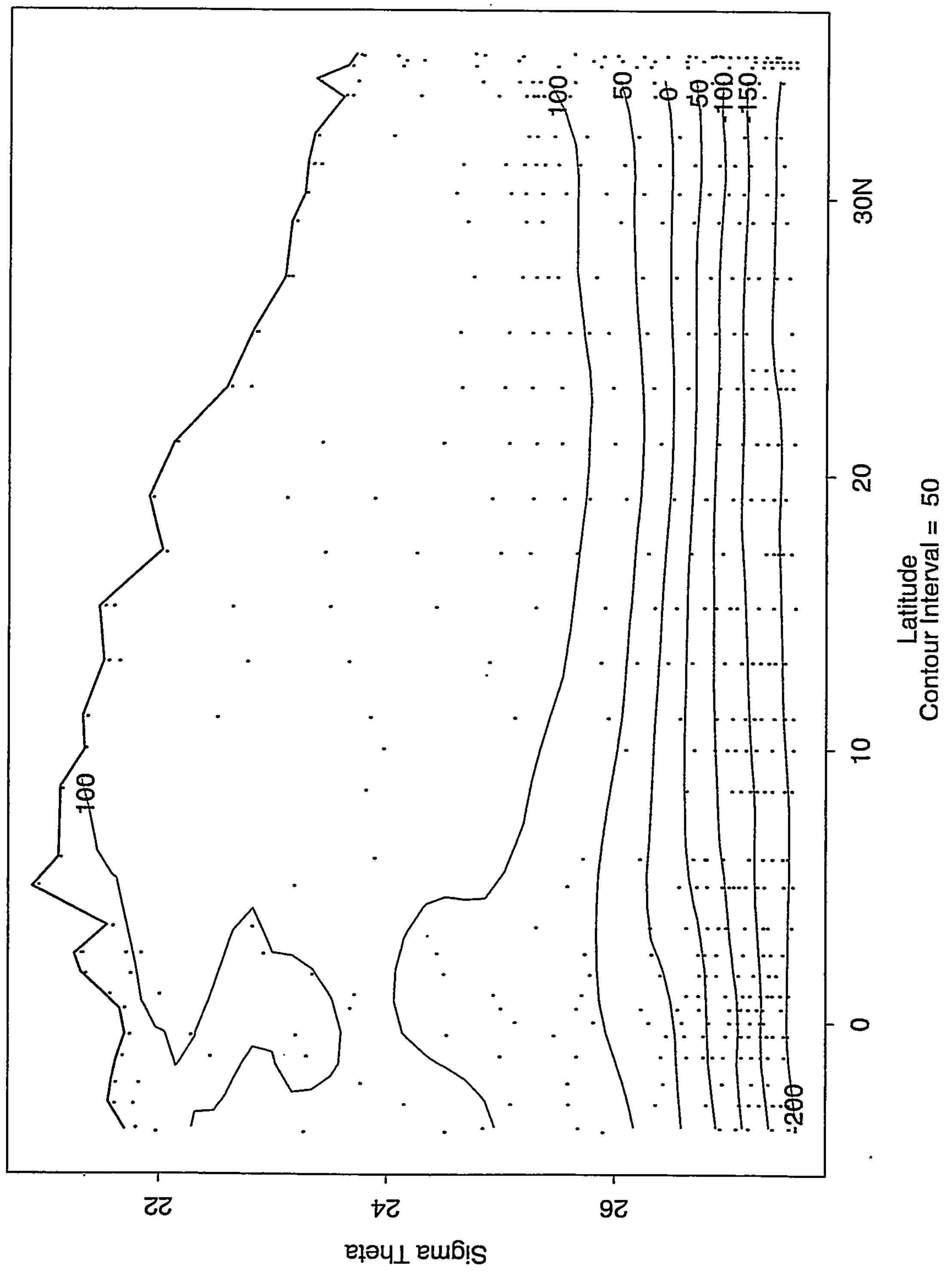

Fig. 14. Plot-section of $\Delta^{14}C$ contoured in a potential density space.

4. DATA CHECKS AND PROCESSING PERFORMED BY CDIAC

An important part of the NDP process at the Carbon Dioxide Information Analysis Center (CDIAC) involves the quality assurance (QA) of data before distribution. Data received at CDIAC are rarely in a condition that would permit immediate distribution, regardless of the source. To guarantee data of the highest possible quality, CDIAC conducts extensive QA reviews that involve examining the data for completeness, reasonableness, and accuracy. The QA process is a critical component in the value-added concept of supplying accurate, usable data for researchers.

The following information summarizes the data processing and QA checks performed by CDIAC on the data obtained during the R/V *Thomas G. Thompson* cruise along WOCE Section P10 in the Pacific Ocean.

1. The final carbon-related data and radiocarbon measurements were provided to CDIAC by Chris Sabine and Bob Key of Princeton University. The final hydrographic and chemical measurements and the station information files were provided by the WOCE Hydrographic Program Office (WHPO) after quality evaluation. A FORTRAN 90 retrieval code was written and used to merge and reformat all data files.

2. To check for obvious outliers, all data were plotted by use of a PLOTNEST.C program written by Stewart C. Sutherland (Lamont-Doherty Earth Observatory). The program plots a series of nested profiles, using the station number as an offset; the first station is defined at the beginning, and subsequent stations are offset by a fixed interval (Figs. 15 and 16). Several outliers were identified and marked with the quality flags of "3" (questionable measurement) or "4" (bad measurement) (see File Descriptions in Part 2 of this documentation).

3. To identify "noisy" data and possible systematic, methodological errors, property-property plots for all parameters were generated (Fig. 17), carefully examined, and compared with plots from previous expeditions in the Pacific Ocean.

4. All variables were checked for values exceeding physical limits, such as sampling depth values that are greater than the given bottom depths.

5. Dates, times, and coordinates were checked for bogus values (e.g., values of MONTH < 1 or > 12; DAY < 1 or > 31; YEAR < or > 1993; TIME < 0000 or > 2400; LAT < –10.000 or > 40.000; and LONG < 140.000 or > 180.000).

6. Station locations (latitudes and longitudes) and sampling times were examined for consistency with maps and cruise information supplied by C. Sabine and R. Key of Princeton University.

7. The designation for missing values, given as –9.0 in the original files, was changed to –999.9.

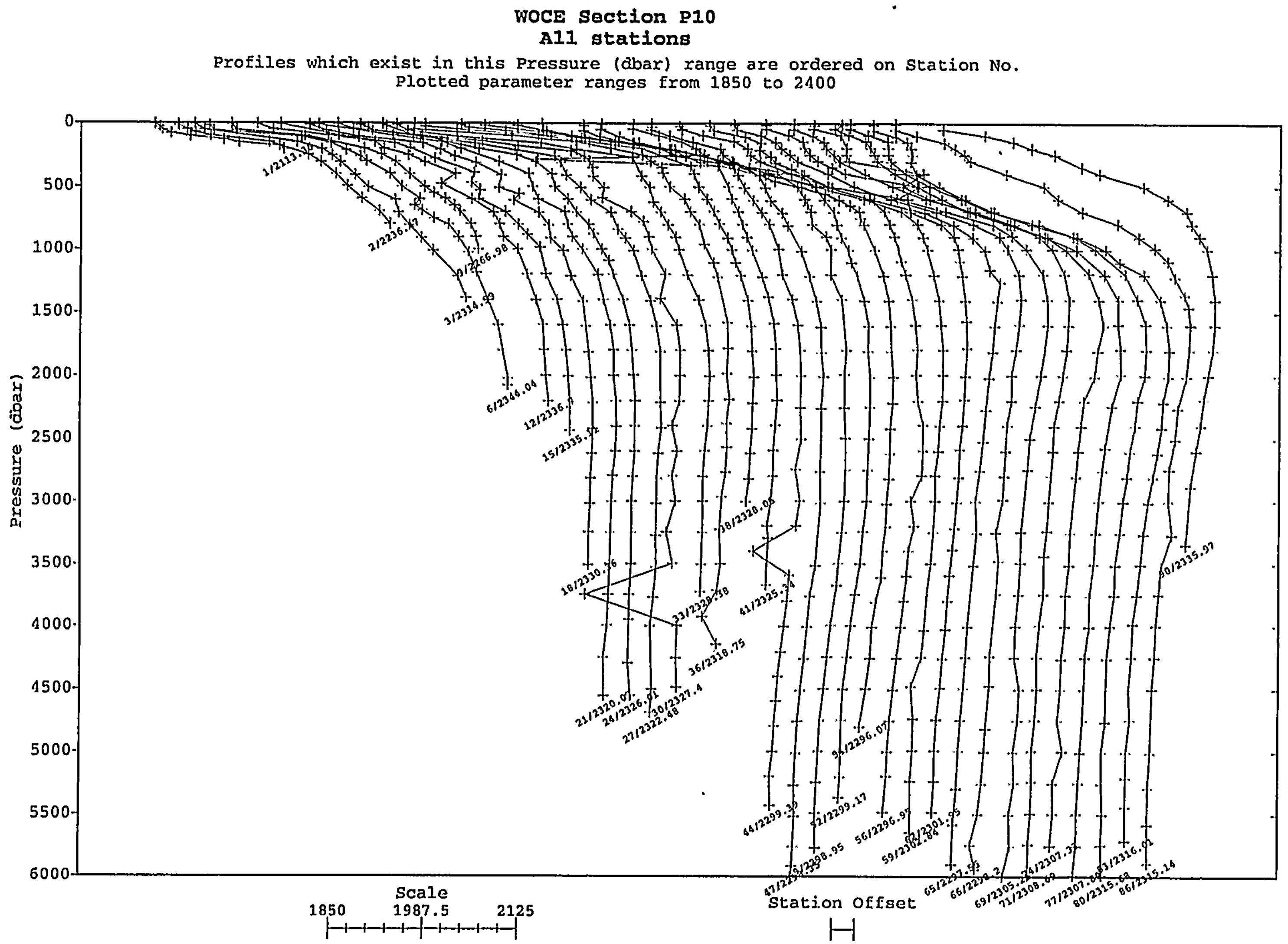

Fig. 15. Nested profiles: total carbon dioxide (μmol/kg) vs pressure (dbar) for all stations of WOCE Section P10.

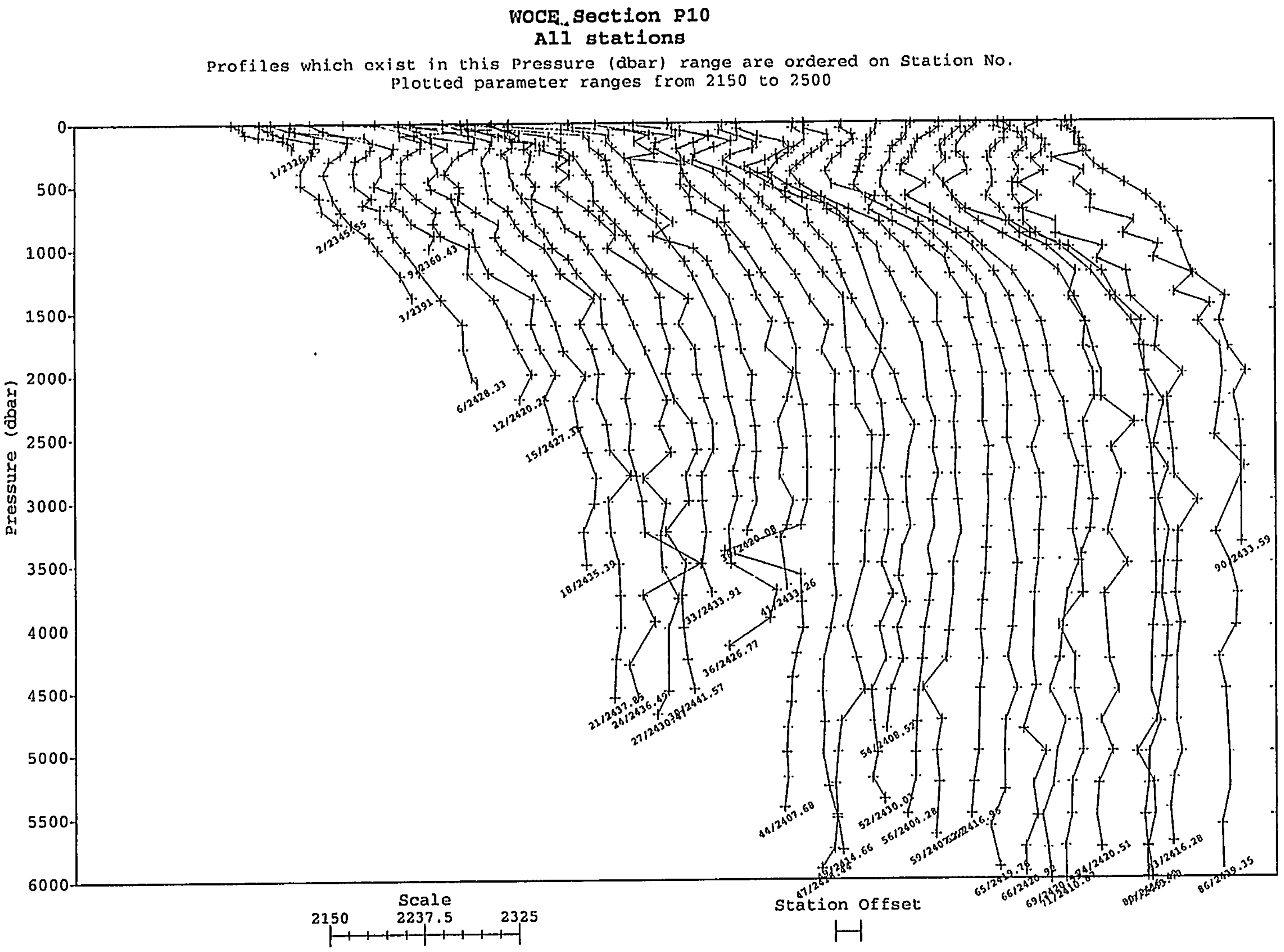

Fig. 16. Nested profiles: total alkalinity (μmol/kg) vs pressure (dbar) for all stations of WOCE Section P10.

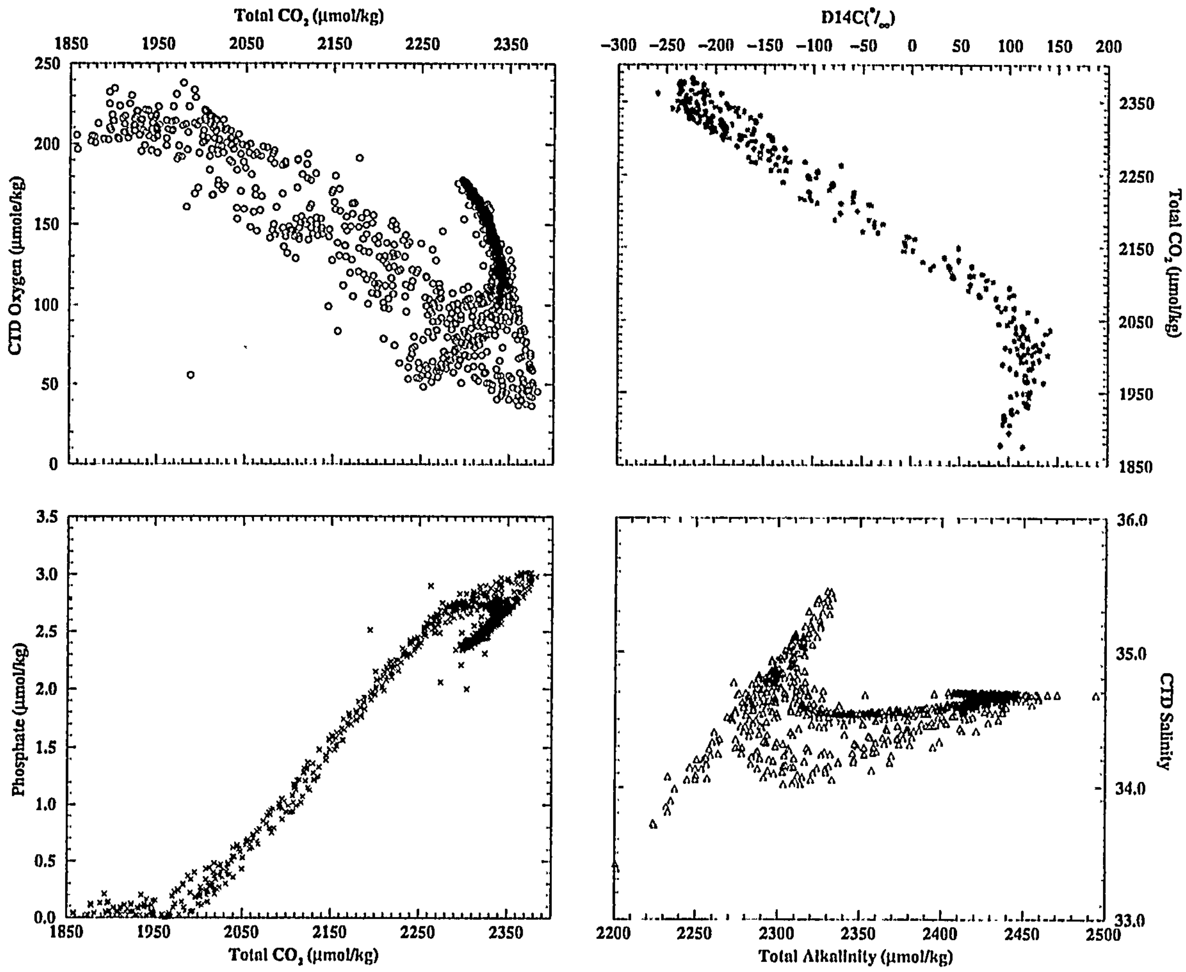

Fig. 17. Property-property plots for all stations occupied during the R/V *Thomas G. Thompson* cruise along WOCE Section P10.

5. HOW TO OBTAIN THE DATA AND DOCUMENTATION

This database (NDP-071) is available free of charge from CDIAC. The data are available from CDIAC's anonymous file transfer protocol (FTP) area via the Internet. Please note: Your computer needs to have FTP software loaded on it (this is built in to most newer operating systems). Use the following commands to obtain the database.

```
>ftp cdiac.esd.ornl.gov  or  >ftp 128.219.24.36
Login: "anonymous" or "ftp"
Password: your e-mail address
ftp> cd pub/ndp071/
ftp> dir
ftp> mget (files)
ftp> quit
```

The complete documentation and data may also be obtained from the CDIAC oceanographic Web site at the following URL: http://cdiac.esd.ornl.gov/oceans/doc.html.

You may also order through CDIAC's online ordering system (http://cdiac.esd.ornl.gov/pns/how_order.html) or by contacting CDIAC directly to request the data on your choice of media.

For additional information, contact CDIAC.

Address: Carbon Dioxide Information Analysis Center
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, Tennessee 37831-6335
U.S.A.

Telephone: (423) 574-3645 (Voice)
(423) 574-2232 (Fax)
Electronic mail: cdiac@ornl.gov
Internet: http://cdiac.esd.ornl.gov/

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PART 2:

CONTENT AND FORMAT OF DATA FILES

7. FILE DESCRIPTIONS

This section describes the content and format of each of the nine files that comprise this NDP (see Table 3). Because CDIAC distributes the data set in several ways (e.g., via anonymous FTP and on floppy diskette), each of the nine files is referenced by both an ASCII file name, which is given in lower-case, bold-faced type (e.g., **ndp071.txt**) and a file number. The remainder of this section describes (or lists, where appropriate) the contents of each file.

Table 3. Content, size, and format of data files

File number, name, and description	Logical records	File size in bytes
1. **ndp071.txt**: a detailed description of the cruise network, the four FORTRAN 90 data-retrieval routines, and the four oceanographic data files	1,908	123,028
2. **stainv.for**: a FORTRAN 90 data-retrieval routine to read and print **p10sta.txt** (File 6)	47	1,439
3. **p10dat.for:** a FORTRAN 90 data-retrieval routine to read and print **p10dat.txt** (File 7)	55	2,144
4. **p10pco2a.for**: a FORTRAN 90 data-retrieval routine to read and print **p10pco2a.txt** (File 8)	43	1,440
5. **p10pco2w.for**: a FORTRAN 90 data-retrieval routine to read and print **p10pco2w.txt** (File 9)	46	1,666
6. **p10sta.txt**: a listing of the station locations, sampling dates, and sounding bottom depths for each of the 94 stations of WOCE Section P10	104	8,372
7. **p10dat.txt:** hydrographic, carbon dioxide, and chemical data from 94 stations occupied on WOCE Section P10	2,833	475,105

Table 3. (continued)

File number, name, and description	Logical records	File size in bytes
8. **p10pco2a.txt:** underway atmospheric measurements of pCO_2 along the cruise track of WOCE Section P10	4,029	321,977
9. **p10pco2w.txt:** underway surface water measurements of pCO_2 along the cruise track of WOCE Section P10	11,656	1,223,329
Total	20,721	2,158,500

7.1 ndp071.txt (File 1)

This file contains a detailed description of the data set, the four FORTRAN 90 data-retrieval routines, and the four oceanographic data files. It exists primarily for the benefit of individuals who acquire this database as machine-readable data files from CDIAC.

7.2 stainv.for (File 2)

This file contains a FORTRAN 90 data-retrieval routine to read and print **p10sta.txt** (File 6). The following is a listing of this program. For additional information regarding variable definitions, variable lengths, variable types, units, and codes, please see the description for **p10sta.txt** in Sect. 7.6.

```
c*********************************************************************
c* FORTRAN 90 data retrieval routine to read and print the file
c* named "p10sta.txt" (File 6).
c*********************************************************************

c*Defines variables*

       INTEGER  stat, cast, depth
       REAL latdcm, londcm
       CHARACTER expo*11, sect*3, date*10, time*4
       OPEN (unit=1, file='p10.sta')
       OPEN (unit=2, file='p10.stat')
       write (2, 5)

c*Writes out column labels*
```

```
     6 4X,'PSS-78',1X,7('UMOL/KG',1X),1X,'/MILLE',2X,'/MILLE',12X,
     7 '*',/,
     8 25X,'*******',17X,2('*******',1X),10X,9('*******',1X),
     9 19X,'*')

c*Sets up a loop to read and format all the data in the file*

       read (1, 6)
 6     format (//////////)

 7     CONTINUE
       read (1, 10, end=999) sta, cast, samp, bot, pre, ctdtmp,
     1 ctdsal, ctdoxy, theta, sal, oxy, silca, nitrat, nitrit,
     2 phspht, tcarb, alkali, dc14, c14er, qualt

 10    format (5X, I3, 7X, I1, 6X, I2, 3X, A5, 1X, F7.1, 1X, F7.4,
     1 1X, F7.4, 1X, F7.1, 1X, F7.4, 1X, F9.4, 1X, F7.1, 1X, F7.2,
     2 1X, F7.2, 1X, F7.2, 1X, F7.2, 1X, F7.1, 1X, F7.1, 1X, F7.1,
     3 1X, F7.1, 1X, A12)

       write (2, 20) sta, cast, samp, bot, pre, ctdtmp,
     1 ctdsal, ctdoxy, theta, sal, oxy, silca, nitrat, nitrit,
     2 phspht, tcarb, alkali, dc14, c14er, qualt

 20    format (5X, I3, 7X, I1, 6X, I2, 3X, A5, 1X, F7.1, 1X, F7.4,
     1 1X, F7.4, 1X, F7.1, 1X, F7.4, 1X, F9.4, 1X, F7.1, 1X, F7.2,
     2 1X, F7.2, 1X, F7.2, 1X, F7.2, 1X, F7.1, 1X, F7.1, 1X, F7.1,
     3 1X, F7.1, 1X, A12)

       GOTO 7
 999   close(unit=1)
       close(unit=2)
       stop
       end
```

7.4 p10pco2a.for (File 4)

This file contains a FORTRAN 90 data-retrieval routine to read and print **p10pco2a.txt** (File 8). The following is a listing of this program. For additional information regarding variable definitions, variable lengths, variable types, units, and codes, please see the description for **p10pco2a.txt** in Sect. 7.8.

```
c********************************************************************
c* FORTRAN 90 data retrieval routine to read and print the file
c* named "p10pco2a.txt" (File 8).
c********************************************************************
       CHARACTER sect*8
       INTEGER year, qflag
       REAL jdate, latit, longit, surtmp, sursal, atmpre, xco2a
       OPEN (unit=1, file='p10pco2a.txt')
       OPEN (unit=2, file='p10pco2a.dat')
       write (2, 5)

c*Writes out column labels*

 5     format (2X,'SECTION',2X,'YEAR',3X,'JULIAN',4X,'LATIT',3X,
     1 'LONGIT',2X,'SUR_TMP',2X'SUR_SAL',1X,'ATM_PRE',3X,'XCO2A',
     2 1X,'QF',/,
     3 5X,'#',13X,'DATE',6X,'DCM',6X,'DCM',4X,'DEG_C',5X,'PSS',
```

```
     4 6X,'ATM',5X,'PPM')

c*Sets up a loop to read and format all the data in the file*

       read (1, 6)
 6     format (/////////)

 7     CONTINUE
       read (1, 10, end=999) sect, year, jdate, latit, longit,
     1 surtmp,sursal, atmpre, xco2a, qflag

 10    format (1X, A8, 2X, I4, 2X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
     1 F7.4, 2X, F7.4, 2X, F6.4, 2X, F7.3, 1X, I1)

       write (2, 20) sect, year, jdate, latit, longit,
     1 surtmp,sursal, atmpre, xco2a, qflag

 20    format (1X, A8, 2X, I4, 2X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
     1 F7.4, 2X, F7.4, 2X, F6.4, 2X, F7.3, 1X, I1)

       GOTO 7
 999   close(unit=1)
       close(unit=2)
       stop
       end
```

7.5 p10pco2w.for (File 5)

This file contains a FORTRAN 90 data-retrieval routine to read and print **p10pco2w.txt** (File 9). The following is a listing of this program. For additional information regarding variable definitions, variable lengths, variable types, units, and codes, please see the description for **p10pco2w.txt** in Sect. 7.9.

```
c*********************************************************************
c* FORTRAN 90 data retrieval routine to read and print the file
c* named "p10pco2w.txt" (File 9).
c*********************************************************************
       CHARACTER sect*8
       INTEGER year, qflag
       REAL jdate, latit, longit, surtmp, sursal, eqtmp, atmpre
       REAL xco2eq, xco2sst, xco2a
       OPEN (unit=1, file='p10pco2w.txt')
       OPEN (unit=2, file='p10pco2w.dat')
       write (2, 5)

c*Writes out column labels*

 5     format (2X,'SECTION',2X,'YEAR',3X,'JULIAN',4X,'LATIT',3X,
     1 'LONGIT',2X,'SUR_TMP',2X'SUR_SAL',1X,'EQTMP',1X,'ATM_PRE',
     2 2X,'XCO2_EQ',1X,'QF',1X,'XCO2_SST',3X,'XCO2A',/,
     3 5X,'#',13X,'DATE',6X,'DCM',6X,'DCM',4X,'DEG_C',5X,'PSS',
     4 3X,'DEG_C',4X,'ATM',5X,'PPM',9X,'PPM',6X,'PPM')

c*Sets up a loop to read and format all the data in the file*

       read (1, 6)
 6     format (/////////)
```

```
7      CONTINUE
       read (1, 10, end=999) sect, year, jdate, latit, longit,
     1 surtmp,sursal, eqtmp, atmpre, xco2eq, qflag, xco2sst, xco2a

10     format (1X, A8, 2X, I4, 2X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
     1 F7.4, 2X, F7.4, 2X, F4.1, 2X, F6.4, 2X, F7.3, 2X, I1, 2X,
     2 F7.3, 2X, F7.3)

       write (2, 20) sect, year, jdate, latit, longit, surtmp,
     1 sursal, eqtmp, atmpre, xco2eq, qflag, xco2sst, xco2a

20     format (1X, A8, 2X, I4, 2X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
     1 F7.4, 2X, F7.4, 2X, F4.1, 2X, F6.4, 2X, F7.3, 2X, I1, 2X,
     2 F7.3, 2X, F7.3)

       GOTO 7
999    close(unit=1)
       close(unit=2)
       stop
       end
```

7.6 p10sta.txt (File 6)

This file provides station inventory information for each of the 94 stations occupied during the R/V *Thomas G. Thompson* cruise along WOCE Section P10. Each line of the file contains an expocode, section number, station number, cast number, sampling date (month/date/year), sampling time, latitude, longitude, and sounding depth. The file is sorted by station number and can be read by using the following FORTRAN 90 code (contained in **stainv.for**, File 2):

```
       INTEGER stat, cast, depth
       CHARACTER expo*11, sect*3, date*10, time*4
       REAL latdcm, londcm

       read (1, 10, end=999) expo, sect, stat, cast, date, time,
     1 latdcm, londcm, depth

10     format (A11, 7X, A3, 4X, I3, 5X, I1, 3X, A10, 2X, A4, 3X,
     1 F7.3, 3X, F8.3, 3X, I4)
```

Stated in tabular form, the contents include the following:

Variable	Variable type	Variable width	Starting column	Ending column
expo	Character	11	1	11
sect	Character	3	19	21
stat	Numeric	3	26	28
cast	Numeric	1	34	34
date	Character	10	38	47
time	Character	4	50	53
latdcm	Numeric	7	58	63
londcm	Numeric	8	67	74
depth	Numeric	4	78	81

The variables are defined as follows:

expo	is the expedition code of the cruise;
sect	is the WOCE section number;
stat	is the station number;
cast	is the cast number;
date	is the sampling date (month/day/year);
time	is the sampling time [Greenwich mean time (GMT)];
latdcm	is the latitude of the station (in decimal degrees; negative values indicate the Southern Hemisphere);
londcm	is the longitude of the station (in decimal degrees; negative values indicate the Western Hemisphere);
depth	is the sounding depth of the station (in meters).

7.7 p10dat.txt (File 7)

This file provides hydrographic, carbon dioxide, and chemical data for the 94 stations occupied during the R/V *Thomas G. Thompson* cruise along WOCE Section P10. Each line consists of a station number, cast number, sample number, bottle number, CTD pressure, CTD temperature, CTD salinity, CTD oxygen, potential temperature, bottle salinity, oxygen, silicate, nitrate, nitrite, phosphate, total CO_2, total alkalinity, $\Delta^{14}C$, ^{14}C error, and data-quality flags. The file is sorted by station number and pressure and can be read by using the following FORTRAN 90 code (contained in **p10dat.for,** File 3):

```
      CHARACTER qualt*12, bot*5
      INTEGER sta, cast, samp
      REAL pre, ctdtmp, ctdsal, ctdoxy, theta, sal, oxy, silca
      REAL nitrat, nitrit, phspht, tcarb, alkali, dc14, c14er

      read (1, 10, end=999)sta, cast, samp, bot, pre, ctdtmp,
     1 ctdsal, ctdoxy, theta, sal, oxy, silca, nitrat, nitrit,
     2 phspht, tcarb, alkali, dc14, c14er, qualt

 10   format (5X, I3, 7X, I1, 6X, I2, 3X, A5, 1X, F7.1, 1X, F7.4,
     1 1X, F7.4, 1X, F7.1, 1X, F7.4, 1X, F9.4, 1X, F7.1, 1X, F7.2,
     2 1X, F7.2, 1X, F7.2, 1X, F7.2, 1X, F7.1, 1X, F7.1, 1X, F7.1,
     3 1X, F7.1, 1X, A12)
```

Stated in tabular form, the contents include the following:

Variable	Variable type	Variable width	Starting column	Ending column
sta	Numeric	3	7	8
cast	Numeric	1	16	16
samp	Numeric	2	23	24
bot	Character	5	28	32
pre	Numeric	7	34	40
ctdtmp	Numeric	7	42	48
ctdsal	Numeric	7	50	56
ctdoxy	Numeric	7	58	64
theta	Numeric	7	66	72
sal	Numeric	9	74	82
oxy	Numeric	7	84	90
silca	Numeric	7	92	98
nitrat	Numeric	7	100	106
nitrit	Numeric	7	108	114
phspht	Numeric	7	116	122
tcarb	Numeric	7	124	130
alkali	Numeric	7	132	138
dc14	Numeric	7	140	146
c14er	Numeric	7	148	154
qualt	Character	12	156	167

The variables are defined as follows:

sta	is the station number;
cast	is the cast number;
samp	is the sample number;
bot[a]	is the bottle number;
pre	is the CTD pressure (dbar);
ctdtmp	is the CTD temperature (°C);
ctdsal[a]	is the CTD salinity [on the Practical Salinity Scale (PSS)];
ctdoxy[a]	is the CTD oxygen (μmol/kg);
theta	is the potential temperature (°C);
sal[a]	is the bottle salinity (on the PSS);
oxy[a]	is the oxygen concentration (μmol/kg);

silca[a]	is the silicate concentration (μmol/kg);
nitrat[a]	is the nitrate concentration (μmol/kg);
nitrit[a]	is the nitrite concentration (μmol/kg);
phspht[a]	is the phosphate concentration (μmol/kg);
tcarb[a]	is the total carbon dioxide concentration (μmol/kg);
alkali[a]	is the total alkalinity concentration (μmol/kg);
dc14[a]	is the radiocarbon Δ^{14}C (per mille);
c14er	is the error of Δ^{14}C (percent);
qualt	is a 12-digit character variable that contains data-quality flag codes for parameters underlined with asterisks (*******) in the file header.

---

[a] Variables that are underlined with asterisks in the data file's header indicate they have a data-quality flag. Data-quality flags are defined as follows:

1 = sample for this measurement was drawn from water bottle but analysis was not received;
2 = acceptable measurement;
3 = questionable measurement;
4 = bad measurement;
5 = not reported;
6 = mean of replicate measurements;
7 = manual chromatographic peak measurement;
8 = irregular digital chromatographic peak integration;
9 = sample not drawn for this measurement from this bottle.

7.8 p10pco2a.txt (File 8)

This file provides underway measurements of pCO_2 in air during the R/V *Thomas G. Thompson* cruise along WOCE Section P10. Each line of the file contains a section number, sampling year, julian date (GMT), latitude, longitude, underway measurements of sea surface temperature, salinity, atmospheric pressure, air pCO_2, and quality flag. The file is sorted by julian date and can be read by using the following FORTRAN 90 code (contained in **p10pco2a.for**, File 4):

```
      CHARACTER sect*8
      INTEGER year, qflag
      REAL jdate, latit, longit, surtmp, sursal, atmpre, xco2a

      read (1, 10, end=999) sect, year, jdate, latit, longit,
    1 surtmp,sursal, atmpre, xco2a, qflag
```

```
10    format (1X, A8, 2X, I4, 2X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
    1 F7.4, 2X, F7.4, 2X, F6.4, 2X, F7.3, 1X, I1)
```

Stated in tabular form, the contents include the following:

Variable	Variable type	Variable width	Starting column	Ending column
sect	Character	8	2	9
year	Numeric	4	12	15
jdate	Numeric	7	18	24
latit	Numeric	7	27	33
longit	Numeric	7	36	42
surtmp	Numeric	7	45	51
sursal	Numeric	7	54	60
atmpre	Numeric	6	63	68
xco2a	Numeric	7	71	77
qflag	Numeric	1	79	79

The variables are defined as follows:

sect	is the WOCE Section number;
year	is the sampling year;
jdate	is the julian day of the year;
latit	is the latitude of the sampling (in decimal degrees; negative values indicate the Southern Hemisphere);
longit	is the longitude of the sampling (in decimal degrees; negative values indicate the Western Hemisphere);
surtmp	is the sea surface temperature (°C);
sursal	is the sea surface salinity (on the PSS);
atmpre	is the atmospheric pressure (atm);
xco2a	is the observed mole fraction of CO_2 in air [ppm (dry air)];
qflag	is the quality flag of **xco2a**: 2 = acceptable measurements of xco2a; 3 = questionable measurements of xco2a.

7.9 p10pco2w.txt (File 9)

This file provides underway measurements of pCO_2 in surface water during the R/V *Thomas G. Thompson* cruise along WOCE Section P10. Each line of the file contains a section number, sampling year, julian date (GMT), latitude, longitude, underway measurements of sea surface temperature, salinity, equilibrator temperature, atmospheric pressure, surface water xCO_2 measured at equilibrator temperature, quality flag for measured xCO_2, surface water xCO_2 measured at sea surface temperature, and observed mole fraction of CO_2 in air interpolated to the times when water measurements were made. The file is sorted by julian date and can be read by using the following FORTRAN 90 code (contained in **p10pco2w.for**, File 5):

```
      CHARACTER sect*8
      INTEGER year, qflag
      REAL jdate, latit, longit, surtmp, sursal, eqtmp, atmpre
      REAL xco2eq, xco2sst, xco2a

      read (1, 10, end=999)sect, year, jdate, latit, longit,
    1 surtmp,sursal,.eqtmp, atmpre, xco2eq, qflag, xco2sst, xco2a

 10   format (1X, A8, 2X, I4, 2X, F7.3, 2X, F7.3, 2X, F7.3, 2X,
    1 F7.4, 2X, F7.4, 2X, F4.1, 2X, F6.4, 2X, F7.3, 2X, I1, 2X,
    2 F7.3, 2X, F7.3)
```

Stated in tabular form, the contents include the following:

Variable	Variable type	Variable width	Starting column	Ending column
sect	Character	8	2	9
year	Numeric	4	12	15
jdate	Numeric	7	18	24
latit	Numeric	7	27	33
longit	Numeric	7	36	42
surmp	Numeric	7	45	51
sursal	Numeric	7	54	60
eqtmp	Numeric	4	63	66
atmpre	Numeric	6	69	74
xco2eq	Numeric	7	77	83
qflag	Numeric	1	86	86
xco2sst	Numeric	7	89	95
xco2a	Numeric	7	98	104

The variables are defined as follows:

sect	is the WOCE Section number;
year	is the sampling year;
jdate	is the julian day of the year;

latit	is the latitude of the sampling (in decimal degrees; negative values indicate the Southern Hemisphere);
longit	is the longitude of the sampling (in decimal degrees; negative values indicate the Western Hemisphere);
surtmp	is the sea surface temperature (°C);
sursal	is the sea surface salinity (on the PSS);
eqtmp	is the equilibrator temperature (°C);
atmpre	is the atmospheric pressure (atm);
xco2eq	is the observed mole fraction of CO_2 in surface seawater at the equilibrator temperature [ppm (dry air)];
qflag	is the xco2eq quality flag: 2 = acceptable measurements of xco2eq; 3 = questionable measurements of xco2eq;
xco2sst	is the mole fraction of CO_2 in surface seawater corrected to sea surface temperature [ppm (dry air)]. Temperature correction was determined from the equations of Weiss et al. (1982);
xco2a	is the atmospheric xCO_2 concentrations interpolated to the times when water measurements were made [ppm (dry air)].

Table 6. Partial listing of p10pco2a.txt (File 8)

First twenty-five lines of the file:

```
*******************************************
*  Source:  C. Sabine and R. Key          *
*           Princeton University          *
*              Princeton, NJ              *
*                                         *
*  NDP-071  July 1999 Underway pCO2 (air) *
*******************************************
* EXPOCODE 3250TN026/1  WHP-ID P10   CRUISE DATES 10/05/1993-11/10/1993
* SECTION  YEAR   JULIAN    LATIT    LONGIT   SUR_TMP   SUR_SAL  ATM_PRE   XCO2A QF
*    #             DATE      DCM      DCM     DEG_C      PSS      ATM       PPM
 WOCE_P10  1993  279.479  -16.442  172.219  24.9544  34.8887  1.0035  363.551 2
 WOCE_P10  1993  279.480  -16.440  172.214  24.9554  34.8873  1.0035  363.736 2
 WOCE_P10  1993  279.480  -16.439  172.213  24.9564  34.8868  1.0033  363.585 2
 WOCE_P10  1993  279.481  -16.438  172.209  24.9583  34.8859  1.0035  363.459 2
 WOCE_P10  1993  279.481  -16.437  172.207  24.9594  34.8859  1.0033  363.543 2
 WOCE_P10  1993  279.481  -16.436  172.205  24.9604  34.8858  1.0035  363.432 2
 WOCE_P10  1993  279.489  -16.417  172.164  24.9743  34.8867  1.0036  362.967 2
 WOCE_P10  1993  279.490  -16.414  172.158  24.9742  34.8859  1.0035  362.960 2
 WOCE_P10  1993  279.491  -16.412  172.153  24.9747  34.8864  1.0033  362.998 2
 WOCE_P10  1993  279.492  -16.411  172.148  24.9734  34.8868  1.0031  363.022 2
 WOCE_P10  1993  279.493  -16.410  172.146  24.9723  34.8860  1.0033  362.686 2
 WOCE_P10  1993  279.493  -16.409  172.144  24.9712  34.8849  1.0035  362.575 2
 WOCE_P10  1993  279.502  -16.389  172.097  25.0189  34.8889  1.0032  362.159 2
 WOCE_P10  1993  279.503  -16.387  172.092  25.0219  34.8930  1.0031  362.331 2
```

Last twenty-five lines of the file:

```
 WOCE_P10  1993  313.069   35.092  140.886  22.8056  34.7069  1.0113  361.778 2
 WOCE_P10  1993  313.070   35.092  140.885  22.8056  34.7047  1.0114  360.790 2
 WOCE_P10  1993  313.073   35.093  140.885  22.7894  34.7082  1.0114  361.405 2
 WOCE_P10  1993  313.074   35.093  140.885  22.7868  34.7062  1.0113  361.906 2
 WOCE_P10  1993  313.346   35.077  140.699  22.5957  34.6925  1.0133  360.936 2
 WOCE_P10  1993  313.347   35.077  140.699  22.5957  34.6925  1.0134  362.198 2
 WOCE_P10  1993  313.351   35.077  140.699  22.5957  34.6925  1.0136  361.668 2
 WOCE_P10  1993  313.355   35.077  140.699  22.5957  34.6925  1.0137  356.804 2
 WOCE_P10  1993  313.356   35.077  140.699  22.5957  34.6925  1.0136  357.078 2
 WOCE_P10  1993  313.357   35.077  140.699  22.5957  34.6925  1.0136  361.544 2
 WOCE_P10  1993  313.360   35.077  140.699  22.5957  34.6925  1.0136  357.720 2
 WOCE_P10  1993  313.362   35.077  140.699  22.5957  34.6925  1.0136  358.324 2
 WOCE_P10  1993  313.364   35.077  140.699  22.5957  34.6925  1.0136  360.752 2
 WOCE_P10  1993  313.364   35.077  140.699  22.5957  34.6925  1.0135  361.010 2
 WOCE_P10  1993  313.370   35.077  140.699  22.5957  34.6925  1.0136  357.927 2
 WOCE_P10  1993  313.373   35.077  140.699  22.5957  34.6925  1.0136  358.662 2
 WOCE_P10  1993  313.374   35.077  140.699  22.5957  34.6925  1.0136  359.086 2
 WOCE_P10  1993  313.378   35.077  140.699  22.5957  34.6925  1.0137  359.124 2
 WOCE_P10  1993  313.379   35.077  140.699  22.5957  34.6925  1.0136  360.472 2
 WOCE_P10  1993  313.382   35.077  140.699  22.5957  34.6925  1.0137  359.128 2
 WOCE_P10  1993  313.384   35.077  140.699  22.5957  34.6925  1.0136  358.169 2
 WOCE_P10  1993  313.385   35.077  140.699  22.5957  34.6925  1.0137  357.410 2
 WOCE_P10  1993  313.385   35.077  140.699  22.5957  34.6925  1.0137  357.378 2
 WOCE_P10  1993  313.386   35.077  140.699  22.5957  34.6925  1.0136  357.847 2
 WOCE_P10  1993  313.387   35.077  140.699  22.5957  34.6925  1.0137  357.331 2
```

Table 7. Partial listing of p10pco2w.txt (File 9)

First twenty-five lines of the file:

```
**********************************************
*  Source:  C. Sabine and R. Key             *
*           Princeton University             *
*              Princeton, NJ                 *
*                                            *
*  NDP-071  July 1999  Underway pCO2 (water) *
**********************************************
*EXPOCODE 3250TN026/1  WHP-ID P10   CRUISE DATES 10051993-11101993
* SECTION  YEAR   JULIAN    LATIT   LONGIT  SUR_TMP   SUR_SAL  EQTMP ATM_PRE  XCO2_EQ QF XCO2_SST   XCO2A
*    #             DATE      DCM      DCM    DEG_C      PSS    DEG_C   ATM      PPM          PPM       PPM
 WOCE_P10  1993  279.420  -16.574  172.519  24.9960  34.9220  25.5  1.0040  334.032  2  327.262  363.551
 WOCE_P10  1993  279.421  -16.572  172.514  25.0023  34.9200  25.5  1.0038  334.059  2  327.373  363.551
 WOCE_P10  1993  279.423  -16.568  172.505  25.0249  34.9183  25.5  1.0040  334.065  2  327.311  363.551
 WOCE_P10  1993  279.424  -16.566  172.501  25.0379  34.9203  25.5  1.0038  333.866  2  327.043  363.551
 WOCE_P10  1993  279.425  -16.564  172.496  25.0476  34.9298  25.6  1.0040  333.951  2  327.133  363.551
 WOCE_P10  1993  279.433  -16.547  172.456  25.0267  34.9210  25.5  1.0038  333.839  2  326.989  363.551
 WOCE_P10  1993  279.433  -16.545  172.452  25.0286  34.9171  25.5  1.0040  333.198  2  326.387  363.551
 WOCE_P10  1993  279.434  -16.544  172.450  25.0292  34.9176  25.5  1.0038  332.751  2  325.955  363.551
 WOCE_P10  1993  279.435  -16.542  172.446  25.0279  34.9189  25.5  1.0041  332.530  2  325.722  363.551
 WOCE_P10  1993  279.435  -16.540  172.443  25.0277  34.9183  25.5  1.0038  333.617  2  326.785  363.551
 WOCE_P10  1993  279.438  -16.534  172.426  25.0173  34.9179  25.5  1.0037  332.665  2  325.837  363.551
 WOCE_P10  1993  279.447  -16.515  172.386  25.0140  34.9095  25.5  1.0040  331.778  2  324.925  363.551
 WOCE_P10  1993  279.447  -16.514  172.382  25.0168  34.9112  25.5  1.0040  331.498  2  324.686  363.551
 WOCE_P10  1993  279.448  -16.512  172.378  25.0177  34.9104  25.5  1.0038  331.550  2  324.749  363.551
```

Last twenty-five lines of the file:

```
 WOCE_P10  1993  313.137   35.161  140.761  22.7287  34.6720  23.2  1.0107  348.520  2  342.453  361.680
 WOCE_P10  1993  313.147   35.143  140.796  22.8101  34.7079  23.3  1.0108  358.675  3  351.749  361.644
 WOCE_P10  1993  313.148   35.142  140.798  22.8165  34.7054  23.3  1.0106  356.027  3  349.175  361.642
 WOCE_P10  1993  313.149   35.141  140.800  22.8175  34.7101  23.3  1.0106  354.690  3  347.810  361.639
 WOCE_P10  1993  313.149   35.139  140.803  22.8175  34.7138  23.3  1.0106  352.185  3  345.352  361.637
 WOCE_P10  1993  313.150   35.138  140.805  22.8233  34.7091  23.3  1.0109  350.912  3  344.054  361.634
 WOCE_P10  1993  313.152   35.135  140.813  22.8578  34.7018  23.3  1.0109  347.521  2  341.208  361.626
 WOCE_P10  1993  313.155   35.130  140.823  22.8950  34.7053  23.4  1.0107  347.819  2  341.376  361.616
 WOCE_P10  1993  313.157   35.126  140.828  22.9147  34.7121  23.4  1.0108  346.201  2  339.931  361.610
 WOCE_P10  1993  313.158   35.125  140.830  22.9189  34.7141  23.4  1.0108  345.310  2  339.113  361.606
 WOCE_P10  1993  313.159   35.125  140.831  22.9201  34.7184  23.4  1.0109  344.826  2  338.271  361.602
 WOCE_P10  1993  313.161   35.124  140.830  22.9150  34.7208  23.4  1.0109  343.663  2  337.187  361.595
 WOCE_P10  1993  313.162   35.124  140.830  22.9148  34.7212  23.3  1.0108  344.565  2  339.222  361.591
 WOCE_P10  1993  313.173   35.126  140.830  22.9128  34.7226  23.4  1.0108  362.996  3  356.408  361.553
 WOCE_P10  1993  313.173   35.126  140.830  22.9133  34.7212  23.4  1.0108  361.850  3  355.357  361.551
 WOCE_P10  1993  313.174   35.126  140.830  22.9127  34.7216  23.4  1.0108  359.334  3  352.942  361.548
 WOCE_P10  1993  313.178   35.126  140.831  22.9136  34.7228  23.3  1.0108  354.218  2  348.319  361.533
 WOCE_P10  1993  313.179   35.126  140.832  22.9145  34.7215  23.3  1.0107  354.444  2  348.555  361.529
 WOCE_P10  1993  313.181   35.127  140.832  22.9125  34.7230  23.3  1.0108  351.879  2  346.264  361.523
 WOCE_P10  1993  313.183   35.127  140.832  22.9060  34.7265  23.3  1.0107  350.529  2  344.973  361.518
 WOCE_P10  1993  313.184   35.127  140.832  22.9086  34.7231  23.3  1.0108  350.694  2  345.173  361.515
 WOCE_P10  1993  313.184   35.128  140.832  22.9053  34.7244  23.3  1.0108  349.981  2  344.424  361.511
 WOCE_P10  1993  313.186   35.128  140.832  22.8965  34.7264  23.3  1.0108  349.948  2  344.398  361.504
 WOCE_P10  1993  313.189   35.126  140.832  22.8930  34.7219  23.3  1.0108  352.820  2  347.308  361.496
 WOCE_P10  1993  313.190   35.126  140.832  22.8878  34.7287  23.3  1.0108  352.819  2  347.232  361.491
```

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106. S. Murayama, National Institute for Resources and Environment, Environmental Assessment Department, 16-3 Onogawa, Tsukuba, Ibaraki 305, Japan
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