

*Carbon Dioxide, Hydrographic, and Chemical Data  
Obtained During the R/V Meteor Cruise  
15/3 in the South Atlantic Ocean  
(WOCE Section A9, February - March 1991)*



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Upton, New York*

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Woods Hole, Massachusetts*

*Carbon Dioxide Information Analysis Center  
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Oak Ridge, Tennessee*

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DURING THE R/V METEOR CRUISE 15/3 IN THE SOUTH ATLANTIC OCEAN  
(WOCE SECTION A9, FEBRUARY-MARCH 1991)**

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**Environmental Sciences Division  
Publication No. 4416**

**Date Published: June 1995**

**Prepared for the  
Global Change Research Program  
Environmental Sciences Division  
Office of Health and Environmental Research  
U.S. Department of Energy  
Budget Activity Number KP 05 02 00 0**

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managed by  
MARTIN MARIETTA ENERGY SYSTEMS, INC.  
for the  
U.S. DEPARTMENT OF ENERGY  
under contract DE-AC05-84OR21400**

**This research was performed under the auspices of  
the United States Department of Energy under  
Contract No. DE-AC02-76CH00016.**





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## ABSTRACT

Johnson, K. M., D. W. R. Wallace, R. J. Wilke, and C. Goyet. 1995. Carbon Dioxide, Hydrographic, and Chemical Data Obtained During the R/V *Meteor* Cruise 15/3 in the South Atlantic Ocean (WOCE Section A9, February–March 1991). ORNL/CDIAC-82, NDP-051. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 54 pp. doi: 10.3334/CDIAC/otg.ndp051

This data documentation discusses the procedures and methods used to obtain data on total carbon dioxide ( $\text{TCO}_2$ ), total alkalinity (TALK), and discrete partial pressure of  $\text{CO}_2$  ( $\text{pCO}_2$ ) during the Research Vessel (R/V) *Meteor* Expedition 15/3 in the South Atlantic Ocean (Section A9). Conducted as part of the World Ocean Circulation Experiment (WOCE), the cruise began in Vitoria, Brazil, on February 10, 1991, and ended in Pointe-Noire, Congo, on March 23, 1991. WOCE zonal Section A9 began at  $\sim 38^\circ$  W and continued along the  $19^\circ$  S parallel until  $\sim 8^\circ$  E. Samples were collected for  $\text{TCO}_2$  from 28 stations along the 19th parallel and at 3 diversions north and south of the 19th parallel. The latter stations were occupied to track bottom water movements. Measurements made along WOCE Section A9 included pressure, temperature, salinity, and oxygen measured by conductivity, temperature and depth sensor (CTD); bottle salinity, oxygen, phosphate, nitrate, nitrite, silicate, CFC-113,  $\text{CCl}_4$ , CFC-12, CFC-11,  $\text{TCO}_2$ , TALK, and  $\text{pCO}_2$  measured at  $20^\circ\text{C}$ . Replicate samples from ten Niskin bottles at four stations were also collected for later shore-based reference analyses of  $\text{TCO}_2$  and TALK by vacuum extraction and manometry in the laboratory of Dr. Charles Keeling, Scripps Institution of Oceanography (SIO).

The  $\text{TCO}_2$  was measured using an automated sample processor (SOMMA) for extracting  $\text{CO}_2$  from seawater samples coupled to a Coulometer for detection of the extracted gas. The precision and accuracy of the system was  $\pm 1.0 \mu\text{mol/kg}$ . R/V *Meteor* Cruise 15/3 was an initial test of an experimental system for measuring  $\text{pCO}_2$  on discrete water samples: a batch equilibration technique was used followed by headspace gas chromatography with flame ionization detection. While the quality of some  $\text{pCO}_2$  data is poor compared with that collected more recently (i.e., precision and accuracy  $\sim 2\text{--}3\%$ ), all data have been included for completeness. Samples collected for TALK were measured using standard potentiometric techniques; precision was  $\pm 2.6 \mu\text{mol/kg}$ .

The R/V *Meteor* Cruise 15/3 data set is available free-of-charge as a numeric data package (NDP) from CDIAC. The NDP consists of five data files and this printed documentation, which describes the contents and format of all data files as well as the procedures and methods used to obtain the data.

**Keywords:** carbon dioxide; World Ocean Circulation Experiment; South Atlantic Ocean; hydrographic measurements; carbon cycle

**PART 1:**  
**OVERVIEW**

## 1. BACKGROUND INFORMATION

may | The increase in atmospheric carbon dioxide (CO<sub>2</sub>) concentrations (as well as in other radiatively active trace gases) because of human activity has produced serious concern regarding the heat balance of the global atmosphere (Moore and Braswell 1994). The increasing concentrations of these gases <sup>may</sup> intensify the earth's natural greenhouse effect, ~~shifting the balance will~~ <sup>and</sup> force the global climate system in ways that are not well understood. The oceans play a major role in global carbon cycle processes. Carbon in the oceans is unevenly distributed because of complex circulation patterns and biogeochemical cycles, neither of which <sup>is</sup> completely understood. ~~In addition to circulation patterns, biological processes (i.e., photosynthesis, respiration) play a crucial role in the carbon cycle.~~ | are

delete | To better understand the ocean's role in climate and climatic changes, several large experiments have been conducted in the past, and others are currently under way. The World Ocean Circulation Experiment (WOCE) is a major component of the World Climate Research Program. Although total carbon dioxide (TCO<sub>2</sub>) is not an official WOCE measurement, a coordinated effort, supported in the United States by the U.S. Department of Energy (DOE), is being made on WOCE cruises (through 1998) to measure the global, spatial, and temporal distributions of TCO<sub>2</sub> and other carbon-related parameters. The CO<sub>2</sub> survey goals include 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<sub>2</sub> between the atmosphere and the ocean, and preparation of a database suitable for carbon-cycle modeling and the subsequent assessment of anthropogenic CO<sub>2</sub> increase in the oceans. The CO<sub>2</sub> survey is taking advantage of the sampling opportunities provided by the WOCE cruises during this period. The final data set is expected to cover ~23,000 stations. | the

WOCE Expedition Code 064T15/3 | This document describes the first effort by chemical oceanographers from Brookhaven National Laboratory (BNL) to make high-quality CO<sub>2</sub> measurements during a 42-day expedition in the South Atlantic Ocean aboard the Research Vessel (R/V) *Meteor* in the austral summer of 1991. Designated Expedition 15/3, the cruise departed Vitoria, Brazil, on February 10, 1991, and arrived in Pointe-Noire, Congo, on March 23, 1991. The WOCE zonal Section is A9 (Fig. 1).

The CO<sub>2</sub> investigation during R/V *Meteor* Cruise 15/3 was supported by DOE grant DE-AC02-76CH00016.

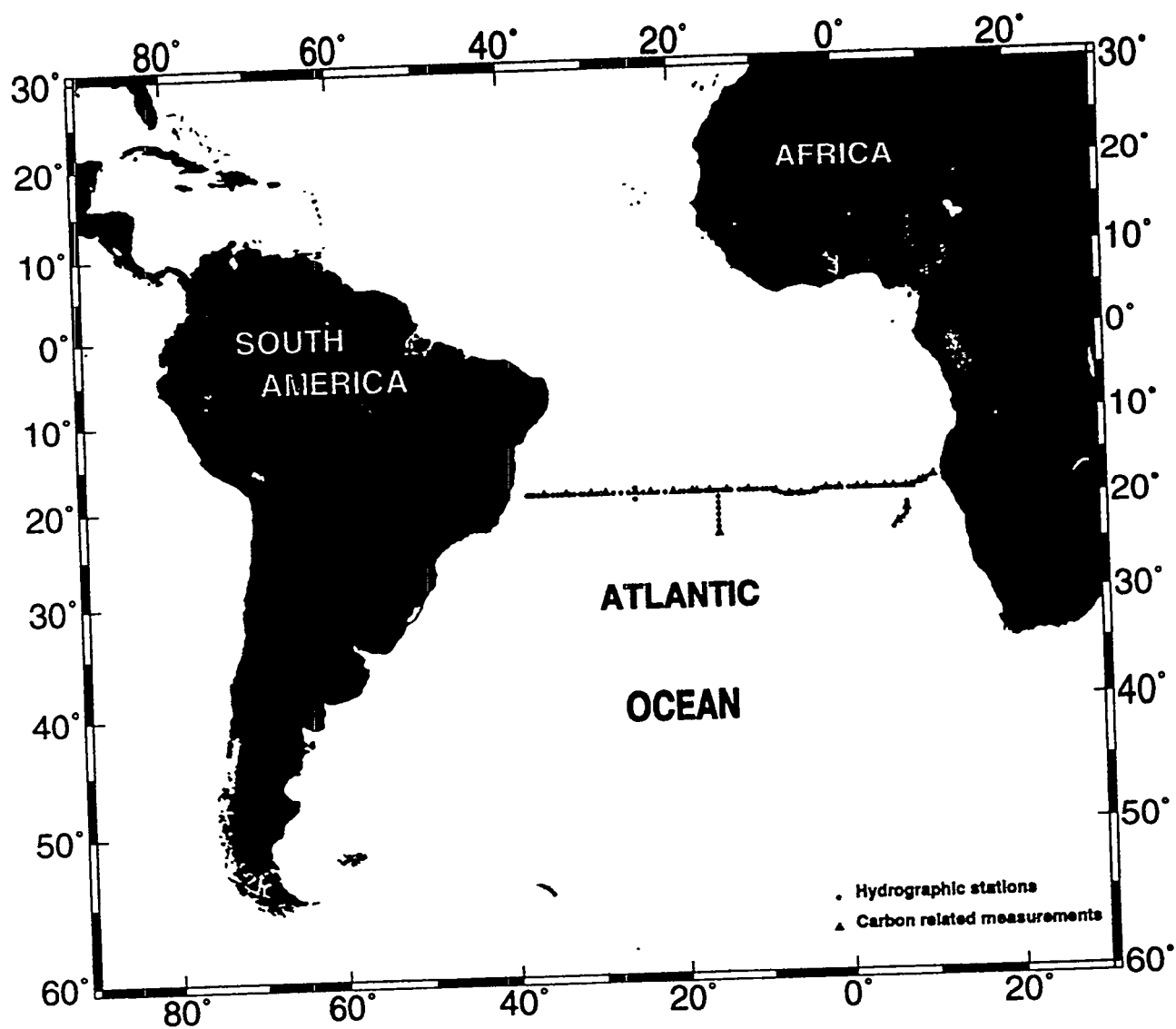


Figure 1. Station locations during R/V *Meteor* Cruise 15/3 (WOCE Section A9).

## 2. DESCRIPTION OF THE EXPEDITION

### 2.1 R/V *Meteor*, Technical Details and History

The R/V *Meteor* is owned by the Federal Republic of Germany through the Ministry of Research and Technology (BMFT), which financed its construction. It is operated by the German Research Foundation (DFG), which provides about 70% of its operating funds (the BMFT supplies the remainder). DFG also plans the scientific cruises and appoints the chief scientists. The Operations Control Office of the University of Hamburg is responsible for management, logistics, execution and supervision of ship operations. These functions are exercised by direct cooperation with expedition coordinators and the managing owners, the Reedereigemeinschaft Forschungsschiffahrt GmbH, located in Bremen, Germany. The latter is responsible for hiring, provisioning, and coordinating ship maintenance. Used for ocean research, primarily in the Atlantic and Indian Oceans, the R/V *Meteor* routinely carries scientists from many different countries. The *Meteor* was completed in 1986 in Travemünde, Germany. The basic features of the vessel follow:

<b>Port of registration</b>	Hamburg
<b>Call sign</b>	DBBH
<b>Classification</b>	GL+100A4E2+MC Auto
<b>Operator</b>	University of Hamburg, Institute for Ocean Research
<b>Built</b>	1985–1986 at Schlichting Werft, Travemünde
<b>Basic dimensions</b>	
gross registered tonnage	3990
net registered tonnage	1284
displacement	4780 t
length overall	97.50 m
beam	16.50 m
draught max.	5.60 m
service speed	12 kn
depth main deck	7.70 m
<b>Personnel</b>	Crew: 32; Scientists: 30
<b>Main engine</b>	4 × Mak6M 322 = 4 × 1000 kW at 750 rpm
<b>Propulsion</b>	Diesel-electrical, tandem-motor = 2 × 1150 kW
<b>Fuel consumption</b>	Approximately 12.0 t IFO-80 per day at service speed
<b>Maximum cruise duration</b>	60 days
<b>Nautical equipment</b>	Integrated navigation system with data transfer to position computer, echosounder synchronization and supervision, and data-processing facility
<b>Science quarters</b>	20 laboratories on the main deck with ~400 m <sup>2</sup> of working space for multidisciplinary research

*Meteor* (I) was constructed in 1925, the first research and survey vessel of that name. Owned by the German navy, it was based in Wilhelmshaven. One of its first expeditions was the German Atlantic Ocean Expedition of 1925–1927, which was organized by the Institute of Marine Research in Berlin. Thereafter, the vessel was used for German physical, chemical, and microbiological marine investigations and for navy surveying and fisheries protection duties.

*Meteor* (II) was planned after the 1950s; it was operated by the Deutsche Forschungsgemeinschaft (German Science Community) in Bad Godesberg and the Deutsches Hydrographisches Institut (German Hydrographic Institute) in Hamburg. Commissioned in 1964, *Meteor* (II) participated in the International Indian Ocean Expedition.

Multipurpose *Meteor* (III), used on the cruise described in this documentation, was completed in 1986, replacing *Meteor* (II). Based in Hamburg, it is used for German ocean research worldwide and for cooperative efforts with other nations in this field. The vessel serves scientists of all marine disciplines in all of the world's oceans.

## 2.2 R/V *Meteor* Cruise 15/3 Information

R/V *Meteor* 15/3 cruise information follows:

Ship name	<i>Meteor</i>
Cruise/leg	15/3
Location	Vitoria, Brazil, to Pointe-Niore, Congo
Dates	February 10–March 23, 1991
Funding	German Science Community, Federal Ministry of Research and Technology, Bonn, Germany, and U.S. DOE
Chief Scientist	Gerold Siedler <del>University of Bremen, Germany</del> IFMK
Master	H. Bruns

Parameters measured	Institution	Principal Investigators
CTD, salinity	IFMK	R. Onken, T. Müller
Nutrients	SIO, OSU	J. Swift, D. Bos, J. Jennings
Oxygen	IFMW	D. Nehring
CFC's   <del>CFM's</del>	UBT	W. Roether, P. Beining
alkalinity   Tritium and <sup>3</sup> He	UBT	W. Roether, P. Beining
TCO <sub>2</sub> and pCO <sub>2</sub>	BNL, WHOI	K. M. Johnson, D. Wallace, <del>GOYET</del>
CCl <sub>4</sub> and CFC's	BNL	D. Wallace, R. J. Wilke
XBT, ADCP and XCP	IFMK	R. Onken, T. Müller
Dimethyl sulfide	MPI	A. Andrae, T. Andrae
Aerosols and particles	MPI	A. Andrae, S. de Mora

### Participating Institutions

BNL	Brookhaven National Laboratory
IFMK	Institut fuer Meereskunde Kiel
IFMW	Institut fuer Meereskunde Warnemünde
MPI	Max Planck Institut Mainz
UBT	University of Bremen, Tracer Oceanography Laboratory
OSU	Oregon State University
SIO	Scripps Institution of Oceanography

## 2.3 Brief Cruise Summary

Gerold Siedler relieved Walter Zenk as chief scientist upon completion of the R/V *Meteor* Cruise 15/2 on February 8, 1991, in Vitoria, Brazil; the remaining participants were on board by February 9. Equipment setup began on February 8. The R/V *Meteor* departed Vitoria at 9 am on February 10, 1991, and steamed to its initial position of 19° S, 38° W. On February 11 the ship began a short zonal section across the Brazil Current characterized by closely spaced expendable bathythermograph (XBT) launches and acoustic Doppler current profiling (ADCP). A test station was made to check CTD operation and possible contamination of the 10-liter Niskin bottles for CFC's. From these results and the earlier profiles, a decision was made to run westward to the 500-m isobath where the Section A9 began with a set of eight closely spaced expendable current profiler (XCP) and CTD profiles including the standard measurements (nutrients, O<sub>2</sub>, CO<sub>2</sub>, tracers) as the ship steamed once again eastward across the Brazil Current and into the open ocean along 19° S. Neither tracer nor CO<sub>2</sub> samples could be taken on all CTD stations because of the time required for analysis. The density of the CO<sub>2</sub> sampling was gradually increased during the first week until at least one CO<sub>2</sub> station was completed each day. Initial delays were aggravated by high (+ 3 to 10 µmol/kg) TCO<sub>2</sub> results for the certified reference material (CRM) analyses with respect to the certified value. It was initially assumed that the problem lay with the SOMMA-Coulometer system or its software, and time was lost troubleshooting. After analyzing a limited number of samples from an earlier CRM batch (see Table 1 on page 13) over several days, it was found that the measurement system was operating properly and that the new CRM batch supplied especially for the cruise was at fault. This was confirmed by subsequent testing. Figure 1 (pg. 4) shows the station positions where CO<sub>2</sub> parameters were measured.

three / To compare these data with data from the earlier U.S. South Atlantic Ventilation Experiment (SAVE) Program, the normal station routine (i.e., every 30 nm) was interrupted at 25° W between February 19 and 20 for an additional ~~three~~ stations north and south of 19° S. To identify deep water movements on the western edge of the Mid-Atlantic Ridge, between February 25 and 27 a short meridional section comprising seven stations was carried out from 19° 00' S to 23° 40' S. Between March 3 and 6 the ship veered slightly southward to avoid the 200-mile commerce zone belonging to the island of St. Helena (United Kingdom). Between March 12 and 15 a diversion was made at 7° E to the Walvis Ridge, and eight CTD stations were taken along a track parallel to the ridge to study deep water movements in this region. The ship continued zonal section / the along 19° S until ~8° E where a course change to east-northeast was made. To adequately sample the eastern boundary current up to the continental shelf, the distance between stations at this point was reduced from 30 to 10 nm. On March 19, 1991 WOCE Zonal Section A9 was completed. The ship steamed to Pointe-Noire, Congo, arriving on March 23, 1991. Weather and sea conditions were excellent throughout the cruise.



### 3. DESCRIPTION OF VARIABLES AND METHODS

The data file **met153.dat** (see description in Part 2) in this numeric data package (NDP) contains the following variables: station numbers; cast numbers; sample numbers; bottle numbers; CTD pressures, temperatures, salinities, and oxygen; potential temperatures; bottle salinities; concentrations of dissolved oxygen, silicate, nitrate, nitrite, and phosphate;  $\text{TCO}_2$  and TALK concentrations; partial pressure of  $\text{CO}_2$  ( $\text{pCO}_2$ ) measured at  $20^\circ\text{C}$ ; CFC-113;  $\text{CCl}_4$ ; CFC-12; CFC-11; and quality flags. The station inventory file **m153sta.inv** (Part 2) contains expocodes, section numbers, station numbers, cast numbers, sampling dates (i.e., day, month, year), sampling times, latitude, longitude, and bottom depth for each station. 1.2

and Water samples were collected by a General Oceanics rosette equipped with 24 10-L bottles and mounted on a Neil Brown Mark III instrument (IFMK numbers NB3 and NB2) with an  $\text{O}_2$  sensor and bottom alarm. Using IFMK software by L. Bellach, pressure, temperature, conductivity, oxygen, and sensor temperature data were recorded on a PC at the full sampling rate of 32 Hz in binary form and at a reduced sampling rate of 3 Hz on a Micro Vax computer. Reversing thermometers were included on bottles 1 and 23 (deepest and mixed-layer sample); each rack consisted of ~~two~~ <sup>three</sup> thermometers. The CTD pressure, temperature, oxygen, and conductivity data were processed and corrected according to laboratory calibrations in 1990 and 1991, and *in situ* measurements, according to procedures written by Ruhsam (1994) and Siedler and Zenk (1992). Pressure values are expected to be accurate to  $\pm 3$  dbar; temperature to  $\pm 0.002^\circ\text{C}$ . Salinity for selected Niskin bottles (about one in every ~~two~~ <sup>three</sup>) was also determined on a Guildline Autosol model 8400A, that was standardized weekly with International Association for the Physical Sciences of the Ocean (IAPSO) water (batch P112). These data were also used to process the CTD data, and the final salinity data are expected to be accurate to  $\pm 0.002$  Practical Salinity Scale (PSS). Oxygen was determined on each Niskin bottle by the Winkler method as modified by Grasshoff et al. (1983). Duplicates were taken periodically to estimate the accuracy and precision of the entire sampling procedure, which was determined to be  $\pm 1 \mu\text{mol/kg}$ . The concentrations of nitrate, nitrite, phosphate, and silicate dissolved in seawater were determined on a continuous flow analyzer: the Alpkem Corporation RFA 300, which was used in conjunction with a data acquisition system supplied by Oregon State University. The analyses were completed within 24 h after sampling. CTD

three The  $\text{TCO}_2$  was determined using an automated coulometric system (SOMMA) (Johnson et al. 1985; Johnson et al. 1987; Johnson and Wallace 1992). Some 753 individual samples, along with 145 duplicates from 29 stations (Fig. 2), were collected in 300-mL precombusted ( $450^\circ\text{C}$  for 24 h) bottles and immediately poisoned with  $\text{HgCl}_2$  according to the DOE Handbook of Methods (DOE 1994). Before analysis, samples were kept in darkness until thermally equilibrated to the pipette temperature. CRM supplied by Andrew G. Dickson, of SIO (DOE 1994), were also analyzed. CRMs are filtered sterile salt solutions or seawater spiked with  $\text{Na}_2\text{CO}_3$ , analyzed for  $\text{TCO}_2$  concentration by vacuum-extraction/manometry in the laboratory of Charles D. Keeling at SIO. three on the

For analysis, seawater introduced from an automated "To Deliver" pipette into a stripping chamber was acidified, and the resultant  $\text{CO}_2$ , after drying, was coulometrically titrated on a model 5011 UIC coulometer. In the coulometer cell the hydroxyethylcarbamic acid, formed from the reaction of  $\text{CO}_2$  and ethanolamine, was titrated coulometrically (electrolytic generation of  $\text{OH}^-$ )

# WOCE Section A9

Station Number

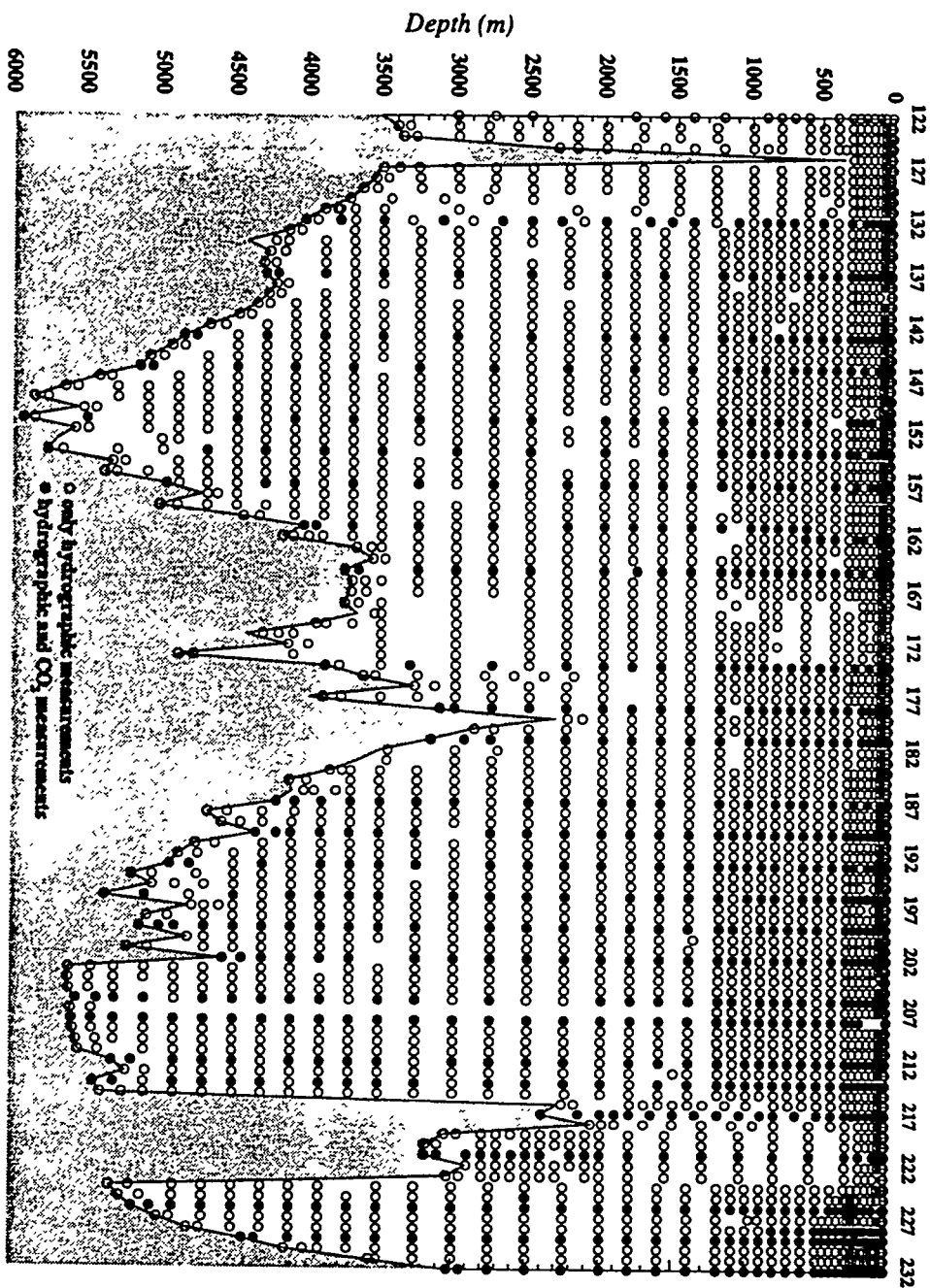


Figure 2. Sampling depths at all hydrographic stations occupied during R/V *Meteor* Cruise 15/3.

with photometric endpoint detection. The product of the <sup>time and the</sup> current passed through the cell during titration <sup>and time</sup> was related by Faraday's constant to the number of moles of OH<sup>-</sup> generated, and thus to the moles of CO<sub>2</sub> that reacted with ethanolamine to form the acid. For system calibration, a gas calibration procedure using pure CO<sub>2</sub> was built into the SOMMA. The hardware, located upstream of the stripper, consisted of an eight-port Gas Sampling Valve (GSV) with two sample loops connected to a source of pure CO<sub>2</sub> through an isolation valve; the vent side of the GSV <sup>was</sup> plumbed to a barometer. When a gas loop was filled with CO<sub>2</sub>, the mass (moles) of CO<sub>2</sub> contained therein was calculated by <sup>dividing</sup> multiplying the loop volume (V) by the <sup>molar volume</sup> density of CO<sub>2</sub> at the ambient T and P. <sup>was calculated</sup> Density was calculated from the molar volume of CO<sub>2</sub> [V(CO<sub>2</sub>)] <sup>obtained</sup> iteratively from an equation of state.

$$V(\text{CO}_2) = RT / P[1 + B(T) / V(\text{CO}_2)] ,$$

where P is the instantaneous barometric pressure, T is the loop temperature, and B(T) is the first virial coefficient for pure CO<sub>2</sub>. The ratio of the calculated mass to that determined coulometrically was the gas calibration factor (CALFAC) <sup>response</sup> used to correct the subsequent titrations for small departures from 100% theoretical. The volume of the loops was determined gravimetrically with deionized water by the method of Wilke et al. (1993).

The "to deliver" volume (TDV) of the SOMMA sample pipette was determined gravimetrically with milli-Q deionized water degassed with helium. The thermostatted sample pipette was filled with water at the same temperature and then discharged into preweighed 50-mL serum bottles that were reweighed on a model R300S (Sartorius, Göttingen, Germany) balance. The apparent weight (g) of water collected (W<sub>air</sub>) was corrected to the mass in vacuo (M<sub>vac</sub>) from

$$M_{\text{vac}} = W_{\text{air}} + W_{\text{air}} (0.0012/d - 0.0012/8.0) ,$$

where 0.0012 is the sea level density of air at 1 atm, d is the density of the calibration fluid at the pipette temperature and sample salinity, and 8.0 is the density of the stainless steel weights. The TDV was

$$\text{TDV} = M_{\text{vac}} / d .$$

The precruise calibrated TDV of the pipette was 28.7113 ± 0.003 mL (n = 8) at 20°C. During the cruise, 52 preweighed serum bottles were filled from the pipette. They were sealed and returned to the laboratory for reweighing. The mean volume from these bottles was 28.7172 ± 0.0096 at 20°C. The mean difference between the precruise and postcruise results was 0.0059 mL, which is less than the standard deviation of the 52 postcruise weighings; accordingly, ~~the~~ TCO<sub>2</sub> <sup>le</sup>

<sup>was</sup> calculated using the precruise volume of 28.7113 mL.

<sup>personal</sup> An IBM compatible <sup>personal</sup> computer with two RS232 serial, a 24-line digital input/output, and analog-to-digital ports was used to control the coulometer, barometer, solid state control relays, and temperature sensors, respectively. The temperature sensors (model LM34CH, National Semiconductor, Santa Clara, California) with a voltage output of 10 mV/°F were calibrated against thermistors certified to 0.01°C (PN CSP60BT103M, Thermometrics, Edison, New Jersey) with a certified mercury thermometer as a secondary standard. These sensors monitored the pipette, gas sample loop, and the coulometer cell temperatures. The barometer, model 216B-101 Digiquartz Transducer (Paroscientific, Inc., Redmond, Washington) was factory-calibrated for pressures between 11.5 and 16.0 psi. The SOMMA software was written in GWBASIC Version

3.20 (Microsoft Corp., Redmond, Washington), and the instrument was driven from an options menu appearing on the personal computer monitor.

Titration were done with the coulometer in the counts mode: the total charge passed during a titration was displayed as the total number of counts accumulated by the coulometer's voltage-to-frequency converter (VFC). From the factory calibration of the VFC [frequency =  $10^5$  pulses (counts) generated per second at 200 mA] and the value of a Faraday (96489 coulomb/mol), a scaling factor of  $4.82445 \times 10^3$  counts per micromole was derived, and the micromole titrated was

$$\mu\text{mol} = \text{counts}/4824.45 - (\text{blank} \times T_T),$$

where  $T_T$  was the length of the titration in minutes and blank was the system blank in micromoles per minute. The total carbon dioxide concentration in micromole per kilogram was calculated as follows:

$$\text{TCO}_2 = \mu\text{mol}(\text{CALFAC})(1000/\text{TDV}_c \times p) \times 1.00017,$$

where CALFAC is the gas calibration factor,  $\text{TDV}_c$  is the "to deliver" volume of the pipette in milliliters corrected for the thermal expansion of glass,  $p$  is the density of sea water in kilograms per liter from the equation of state (Millero and Poisson 1981), and 1.00017 corrects for the dilution of the sample by 100  $\mu\text{L}$  of  $\text{HgCl}_2$  solution. Precision for a set of analyzed samples was expressed as the square root of the pooled variance ( $S_p^2$ ) calculated according to Youden (1951):

$S_p^2 =$

$$\sqrt{\frac{\sum_{j=1}^k \left( \sum_{i=1}^{n_j} \{x_{ij} - \bar{x}_j\}^2 - \frac{\{\sum_{i=1}^{n_j} [x_{ij} - \bar{x}_j]\}^2}{n_j} \right)}{\sum_{j=1}^k n_j - k}}$$

where  $k$  is the number of samples analyzed, and  $\sum_{j=1}^k n_j - k$  is the degrees of freedom i.e., the total number of replicates analyzed minus the number of samples.

unstable and uncertifiable, data from this batch cannot be used to evaluate the performance of the  $\text{TCO}_2$  measurement system. Figure 3 summarizes the analytical results as a contour section plot of the  $\text{TCO}_2$  data from the A9 transect along  $19^\circ \text{S}$ .

Replicate samples from ten Niskin bottles at four stations were also collected for later shore-based reference analyses of  $\text{TCO}_2$  by vacuum extraction and manometry by Charles D. Keeling, SIO. The results (Table 2), extracted from Guenther et al. (1994), were obtained very early in the program for comparing shipboard analyses by coulometry with shore-based analyses of duplicate

# R/V Meteor Cruise 15/3 WOCE Section A9

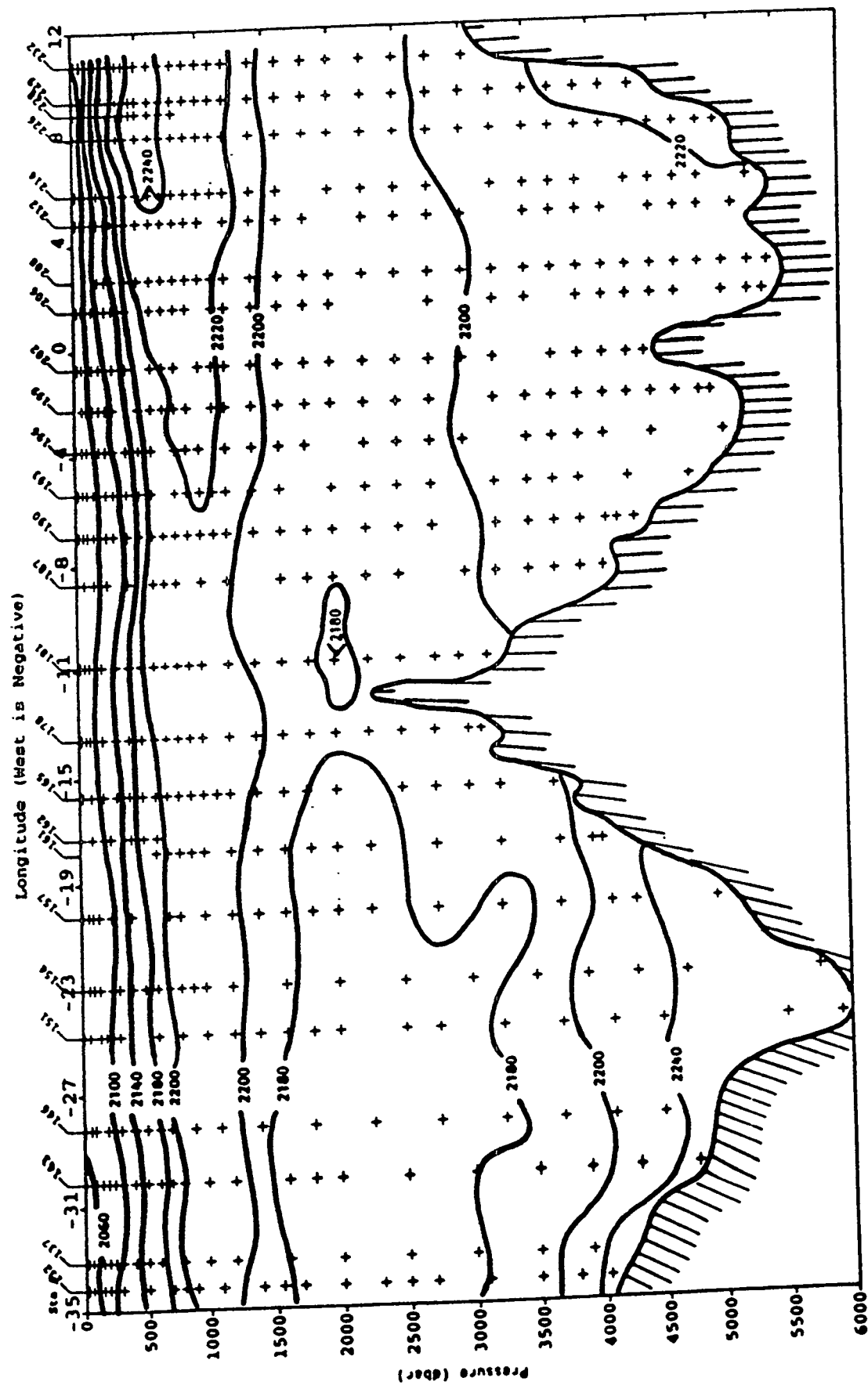


Figure 3. Distribution of the total CO<sub>2</sub> in seawater along WOCE Section A9.

made

samples, and many mistakes and false starts were <sup>made</sup> ~~noted~~. For example, experimentation with the most suitable sample bottle for this purpose was not yet completed, nor had storage precautions

**Table 1. Results of the certified reference material (batch 2) shipboard analyses during R/V Meteor Cruise 15/3 February–March 1991.**

The CRM had a certified  $\text{TCO}_2$  of  $1978.8 \mu\text{mol/kg}$  and salinity of 33.361 PSS.

CRM bottle No	Date analyzed	System Blank $\mu\text{gC/min}$	CALFAC	Total $\text{CO}_2$ $\mu\text{mol/kg}$
206	13.02.91	0.050	1.004596	1977.1
213	15.02.91	0.058	1.004005	1977.8
297	15.02.91	0.058	1.004005	1976.9
4	16.02.91	0.034	1.009080	1979.6
308	17.02.91	0.018	1.003203	1977.8
181	19.02.91	0.034	1.003736	1977.6
155	23.02.91	0.036	1.002476	1977.6
259	27.02.91	0.038	1.004088	1979.2
292	06.03.91	0.031	1.004465	1978.3
237	12.03.91	0.030	1.003876	1978.3
156	20.03.91	0.039	1.003915	1978.4
Mean standard deviation				$1978.1 \pm 0.82$

or expedited shipping procedures been worked out. Therefore, some of the differences in the seven completed comparisons listed in Table 2 probably resulted from unfamiliarity with the new RODAVISS glass bottle stoppers: some breakage was caused by overtightening; some loss of  $\text{CO}_2$ , by undertightening of the stoppers. Nor were the storage conditions optimal for the data quality of the surviving samples: they were kept in a non-air-conditioned cargo hold for the remainder of R/V Meteor Cruise 15/3 and then transported to Brazil before they could be shipped to SIO. Temperature sensors were not included in the shipping crates, as is now standard operating procedure; however, temperatures likely exceeded an unacceptable  $30^\circ\text{C}$  in either the cargo hold during the R/V Meteor's return voyage to Brazil or in Brazil prior to shipment to SIO.

TALK samples were collected and poisoned with  $50 \mu\text{L}$  of saturated solution of  $\text{HgCl}_2$  in 250-mL, standard borosilicate glass, screw-cap bottles. They were stored at room temperature and returned to Woods Hole for TALK analysis. TALK was determined by potentiometric titration; a method derived from one first described by Dyrssen (1965) and later modified by Bradshaw et al. (1981) was used. The automated titration was performed in a closed cell maintained at constant temperature ( $25 \pm 0.1^\circ\text{C}$ ); to be similar to seawater, the ionic strength of the hydrochloric

acid solution (0.1 N) was adjusted with NaCl. The ratio of the acid normality over the cell volume was calibrated before and after the sample analysis. The calibration consisted of preparing solutions of known TALK concentration and measuring them as described by Brewer et al. (1986). The precision of the measurements was estimated to be better than 0.1%. The samples were likely exposed to relatively high temperatures during shipment from Brazil to Woods Hole. Some sample bottles | ~~sample bottles~~ were also broken during shipment. Overall precision of the data set was therefore slightly degraded from that expected from measurement error alone. The pooled standard deviation for ten replicate samples was ~0.12%.

**Table 2. Comparison of shipboard analyses of total carbon dioxide by coulometry (BNL) during R/V *Meteor* Cruise 15/3 with the shore-based reference analyses by manometry on duplicate samples by C. D. Keeling, Scripps Institution of Oceanography (SIO).**

Station No	Sample date	Niskin No	Depth m	TCO <sub>2</sub> BNL $\mu\text{mol/kg}$	TCO <sub>2</sub> SIO $\mu\text{mol/kg}$	Diff. BNL-SIO $\mu\text{mol/kg}$	Sal. Diff. BNL-SIO PSS
143	16.02.91	318	1593	2174.21	2171.58	+2.65	+0.014
143	16.02.91	312	2995	2180.38	2183.44	-3.06	+0.020
154	21.02.91	224	8	2084.12	2095.58	-11.46	+0.045
187	03.03.91	224	7	2073.05	2075.58	-2.53	+0.013
187	03.03.91	318	1194	2212.87	2217.78	-4.91	+0.023
187	03.03.91	312	2492	2188.71	2183.74	+4.97	+0.034
199	07.03.91	202	898	2220.60	2228.38	-7.78	+0.007
Mean						-3.16	+0.022

pCO<sub>2</sub> was measured using an experimental analytical system employing a batch-equilibration, static headspace analysis technique, with detection by gas chromatography and a flame ionization detector. Subsequently, this technique has been greatly improved and a full description is presented by Neill et al. (1995). During the R/V *Meteor* Cruise 15/3, the developing technique gave less than optimum data quality for this parameter because not all sources of error were known. The data are presented primarily for completeness, and caution must be exercised in their quantitative interpretation.

Briefly, the technique used was based on the static headspace methane method of Johnson et al. (1990). Samples were collected in 60-mL serum bottles rinsed and filled to overflowing at the Niskin bottle. These samples were transported to a box that was purged with a flow of 350 ppm CO<sub>2</sub> in argon. A headspace of ~ 5-mL was introduced using a disposable pipette-tip attached to a special tool (Johnson et al. 1990). The headspace was purged briefly with the argon-CO<sub>2</sub> mixture, and a septum was placed over the serum bottle neck and crimped tightly with an aluminum cap. Headspace overpressure from crimping was relieved by piercing the septum with a needle for 3 to 4 seconds. The samples were equilibrated for 4 to 6 hours in the dark in a shaking water bath at 20°C. The experiments performed at sea indicated that there was no significant difference in the measured pCO<sub>2</sub> of replicate samples equilibrated for periods from 2



to 9 hours. Following equilibration, the septum was pierced with two needles. The longer needle was inserted to the bottom of the serum bottle to dispense a brine solution, while the shorter one penetrated just below the septum into the headspace. Approximately 4 mL of brine solution was injected into the bottle through the longer needle displacing the headspace through the shorter one to purge and fill a small (400  $\mu$ L) gas sample loop attached to the gas chromatograph. After filling, the loop was allowed to come to atmospheric pressure, temperature and pressure were recorded, and the contents were injected onto a 6 ft  $\times$  1/8 in. stainless steel chromatographic column packed with Porapak N. A methanizer column containing a nickel catalyst (Varian Inc.) mounted in the injector block of the gas chromatograph at 325°C on the terminal end of the column was used to quantitatively convert CO<sub>2</sub> to CH<sub>4</sub> for detection by flame ionization. Carrier gas flow rate was 30 mL/min of ultra high purity nitrogen; the methanizer was supplied with hydrogen from a hydrogen generator at 30 mL/min. The flame ionization detector was supplied with compressed air and hydrogen at 300 and 30 mL/min, respectively.

The variety of septa used were found to leak during equilibration, after they had been pierced with needles. To calculate the partial pressure of CO<sub>2</sub> after equilibration, it is usually necessary to measure or calculate the pressure of equilibration because of the phase redistribution of gases dissolved in seawater. Subsequent testing with a wide variety of septa and improved technique showed that the pressure of equilibration can be calculated or measured accurately when the septa do not leak. However, septa used during R/V *Meteor* Cruise 15/3 consistently leaked, so that the pressure of equilibration was the same as the ambient atmospheric pressure.

To calculate the pCO<sub>2</sub> of the equilibrated samples, the area of the CO<sub>2</sub> peak was converted to a mole fraction of CO<sub>2</sub> within the headspace from temperature and pressure measurements, and a calibration curve was obtained from injections of gas-phase CO<sub>2</sub> standards at nominal levels of 250, 350, 750, and 1500 ppmv. Subsequently, these standards were intercalibrated against primary standards maintained at the Lamont-Doherty Earth Observatory. The mole fraction of CO<sub>2</sub> at the measured atmospheric pressure was converted to the partial pressure of CO<sub>2</sub> after equilibration. From the measured (unequilibrated) sample TCO<sub>2</sub> (SOMMA), the original CO<sub>2</sub> content of the introduced headspace, and the CO<sub>2</sub> content after equilibration, the mass of CO<sub>2</sub> transferred from the liquid to the gas phase, or vice versa, was calculated and used to <sup>calculate</sup> ~~measure~~ the sample TCO<sub>2</sub> after equilibration. From TCO<sub>2</sub> and the measured pCO<sub>2</sub>, the TALK was calculated. TALK was assumed to be conservative, and from the TALK-TCO<sub>2</sub> pair the pCO<sub>2</sub> of the water sample at 20°C prior to equilibration was calculated by using the thermodynamic constants of Roy et al. (1993), Weiss (1974) and published procedures (DOE, 1994). In the data files pCO<sub>2</sub> is reported at a standard temperature of 20°C <sup>and refers to the pCO<sub>2</sub> in water-saturated air</sup>. Actual equilibration temperatures generally ranged from 19.9°C to 20.2°C.

Precision varied throughout the cruise, depending primarily on the status of the catalyst, that had to be reconditioned periodically. Precision on multiple (>3) replicates varied from 0.4 to ~6% and averaged 2%. Accuracy was judged in three ways. First, throughout the cruise the mole fraction of CO<sub>2</sub> in air was measured; air was collected in syringes at the bow of the ship during steaming between stations. The mean pCO<sub>2</sub> of the air, expressed as a dry air mole fraction, was 353.6 ( $\pm$  9.74); this compares well with contemporary measurements of 353.5 and 352.9 made by the National Oceanic and Atmospheric Administration-Climate Monitoring and Diagnostics Laboratory air sampling network in February and March 1991 on air samples collected at Ascension Island (7° 55' S and 14° 25' W) (Conway et al. 1994). This agreement suggested that although instrument imprecision was high, the overall accuracy of the measurements was consistent with a completely independent set of measurements. Second, assessment of accuracy arose from samples overdetermined for the carbonate system. In this case, the TALK by potentiometric titration for samples from two stations was compared with the TALK calculated from the measured pCO<sub>2</sub>-TCO<sub>2</sub> pair. TALK calculated from the pCO<sub>2</sub>-TCO<sub>2</sub> pair was 4  $\mu$ mol/kg

( $\pm 12$ ) lower than the measured TALK for these stations. Once again, this suggested relatively good accuracy but poor precision. Third, overall assessment of accuracy was made by comparing the discrete- $p\text{CO}_2$  measurements with measurements made by Lamont-Doherty Earth Observatory (LDEO). Station 199 ( $19^\circ \text{ S}$ ,  $2^\circ \text{ W}$ ) of *Meteor* Cruise 15/3 was compared with Station 144 ( $20^\circ \text{ S}$ ,  $1^\circ \text{ W}$ ) of the SAVE expedition, at which a discrete- $p\text{CO}_2$  profile had been collected during February 1988 by D. Chipman and T. Takahashi of LDEO. The respective profiles show very good agreement within the Angola Basin Deep Waters ( $>2000 \text{ m}$ ) (Fig. 4). For this depth range, the R/V *Meteor* 15/3 mean value of  $p\text{CO}_2$  at  $20^\circ \text{ C}$  was  $801 (\pm 10)$  compared with a SAVE value of  $786 (\pm 11)$ . In the upper waters, systematic differences were noted between the two profiles; however, these can be seen in the  $\text{TCO}_2$  data as well.

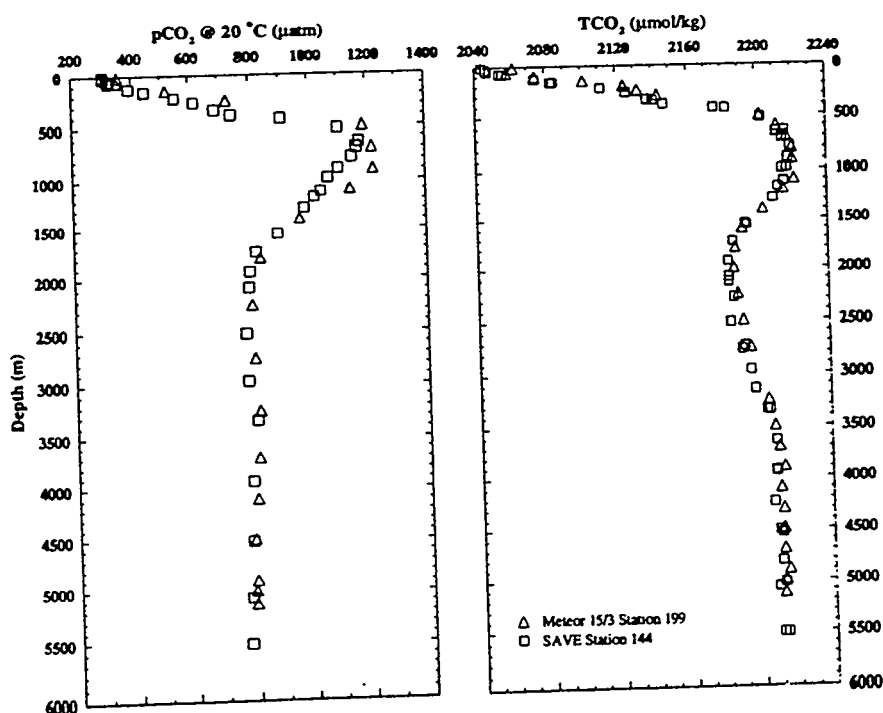


Figure 4. Comparison of discrete partial pressure of carbon dioxide and total carbon dioxide profiles at Station 199 of R/V *Meteor* Cruise 15/3 (March 1991) to those from South Atlantic Ventilation Experiment Station 144 (February 1988).

Exploratory measurements of anthropogenic halocarbon compounds [ $\text{CCl}_4$ ,  $\text{CCl}_2\text{FCClF}_2$  (CFC-113),  $\text{CCl}_3\text{F}$  (CFC-11), and  $\text{CCl}_2\text{F}_2$  (CFC-12)] were made using a new analytical technique on R/V *Meteor* Cruise 15/3 (Wallace et al. 1994). The new method was jointly developed by BNL, Bedford Institute of Oceanography (Canada), and Chalmers University of Technology (Sweden). Briefly, it employs a purge-and-trap extraction technique similar to that used in previous CFC analysis systems (Gammon et al. 1982; Wallace and Moore 1985; Bullister and Weiss 1988). The most significant differences were:

from the earlier technique

1. The chromatographic column used was a wide-bore DB-624 glass capillary (J&W; 70 m x 0.53 mm OD; 3- $\mu$ m film) which gives baseline resolution between the tracer compounds of interest and a variety of natural and anthropogenic halocarbons.

by a group from the University of Bremen

2. The purged volatile compounds were trapped on a short Porapak N column kept at ambient temperature ( $\sim 20^{\circ}\text{C}$ ). This eliminated the need for taking cryogenic systems to sea. Because CFC-11 and CFC-12 were measured separately, the system was optimized for measuring low levels of  $\text{CCl}_4$ ,  $\text{CH}_2\text{Cl}_2$ , and CFC-113 by using a 20-mL water sample and increasing the purge-gas flow to 5 min at 60 mL/min. Extraction efficiency was  $> 99\%$  for all compounds except  $\text{CH}_2\text{Cl}_2$  ( $\sim 85\%$ ). These conditions caused CFC-12 to approach breakthrough on the trap, decreasing precision and accuracy for this compound. Hence, all CFC-12 (and most CFC-11) data in this NDP are based on measurements obtained by using the separate packed column system, which employed low-temperature trapping.

BNL

Two unexpected problems were encountered: a partial chromatographic interference for CFC-113 due to extremely high levels of  $\text{CH}_3\text{I}$  in tropical near-surface waters and a second, more serious problem, arising from a buildup of water on the column, which caused large negative peaks and an interfering baseline shift in the vicinity of the CFC-113 peak. Both of these problems were corrected; however, they greatly reduced the number of samples that could be obtained.

have subsequently been

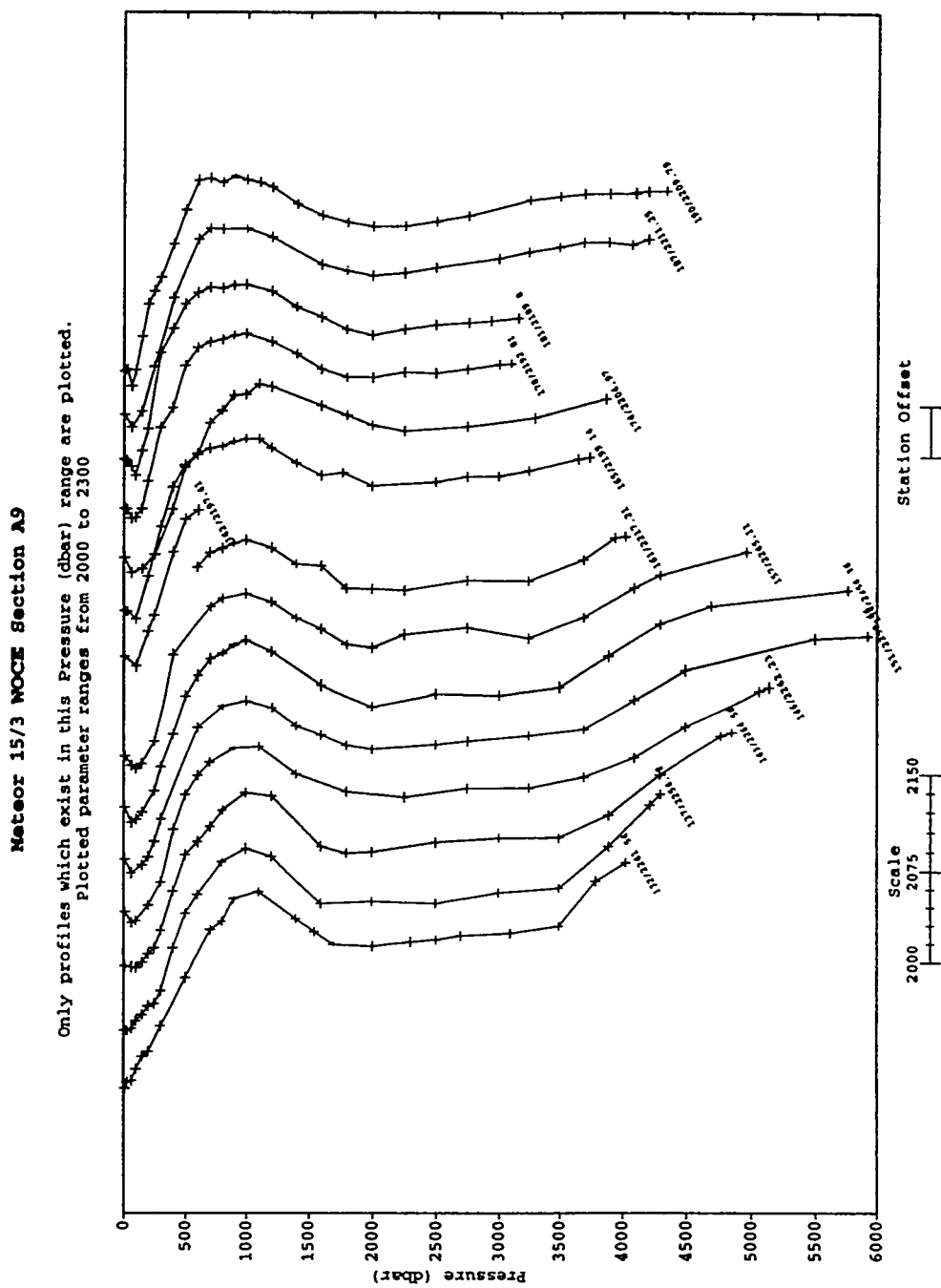
have subsequently been

#### 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. Although they have common objectives, these reviews are tailored to each data set, often requiring extensive programming efforts. In short, the QA process is a critical component in the value-added concept of supplying accurate, usable data for researchers.

The following summarizes the data-processing and QA checks performed by CDIAC on the data obtained during the R/V *Meteor* Expedition 15/3 in the South Atlantic Ocean.

1. Carbon-related data and preliminary hydrographic measurements were provided to CDIAC by K. M. Johnson and D. W. R. Wallace of BNL. 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 77 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 (LDEO). 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. 5 and 6). Several outliers were identified and removed after consultation with the principal investigators.
3. To identify "noisy" data and possible systematic, methodological errors, property-property plots for all parameters were generated (Fig. 7), carefully examined, and compared with plots from previous expeditions in the South Atlantic 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 > 1991; TIME < 0000 or > 2400; LAT < -25.000 or > 17.000; and LONG < -40.000 or > 12.000).
6. Station locations (latitudes and longitudes) and sampling times were examined for consistency with maps and with cruise information supplied by K. M. Johnson and D. W. R. Wallace, BNL.
7. The designation for missing values, given as -9.0 in the original files, was changed to -999.9.



**Figure 5. Nested profiles: total carbon ( $\mu\text{mol/kg}$ ) vs pressure (dbar) for Stations 132-190.**

# Meteor 15/3 WOCE Section A9

Only profiles which exist in this Pressure (dbar) range are plotted.  
Plotted parameter ranges from 2000 to 2300

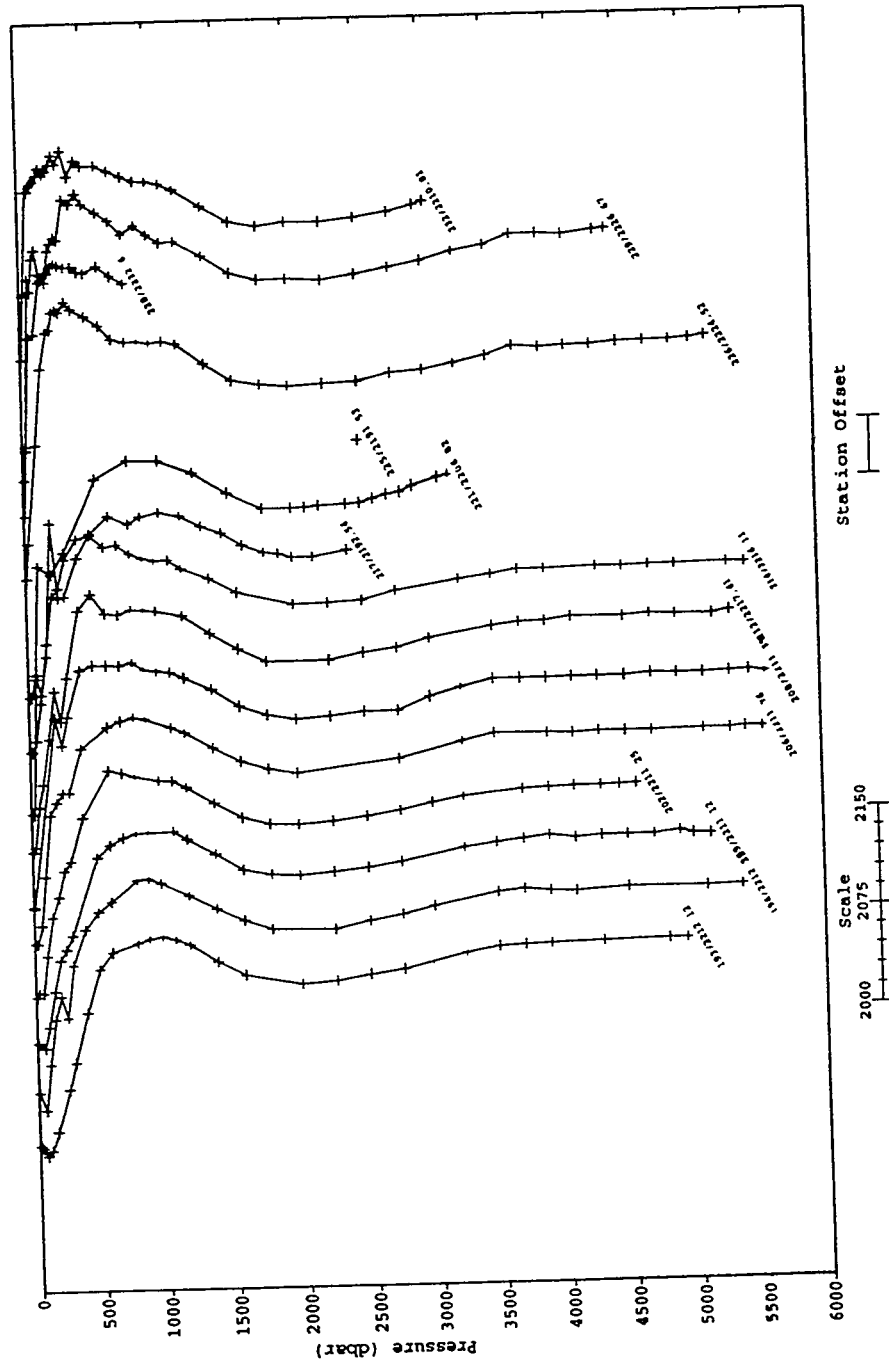


Figure 6. Nested profiles: total carbon ( $\mu\text{mol/kg}$ ) vs pressure (dbar) for Stations 193-232.

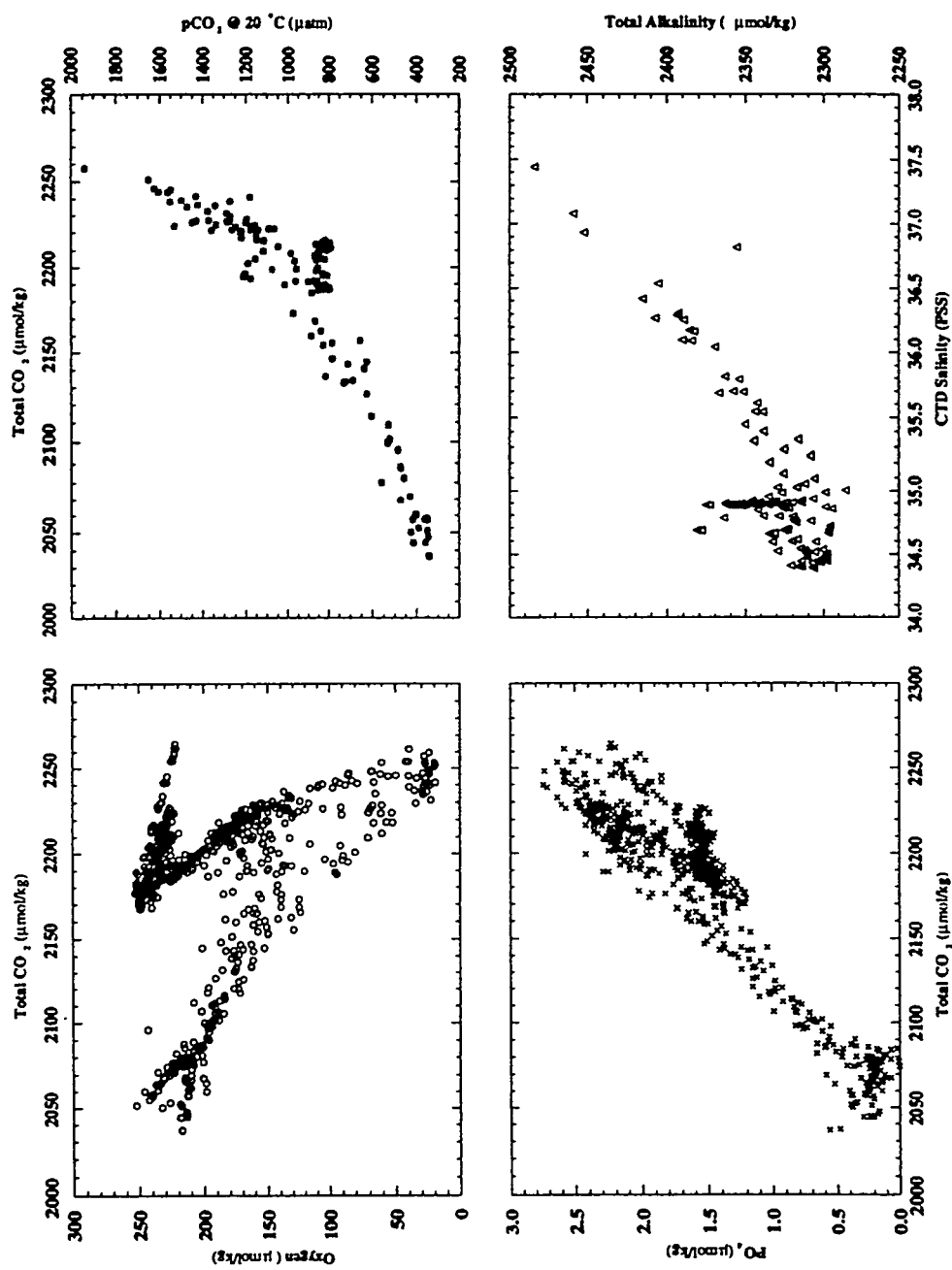


Figure 7. Property-property plots for all stations occupied during R/V Meteor Cruise 15/3.



## 5. HOW TO OBTAIN THE DATA AND DOCUMENTATION

This database is available on request in machine-readable form, without charge, from CDIAC. CDIAC will also distribute subsets of the database as needed. It can be acquired on 9-track magnetic tape; 8-mm tape; 150-mB, quarter-inch tape cartridge; IBM-formatted floppy diskettes; or from CDIAC's anonymous File Transfer Protocol (FTP) area via Internet (see FTP address below). Requests should include any specific media instructions (e.g., 1600 or 6250 BPI, labeled or nonlabeled, ASCII or EBCDIC characters, and variable- or fixed-length records; 3.5- or 5.25-inch floppy diskettes, high or low density; and 8200 or 8500 format, 8-mm tape) required by the user to access the data. Magnetic tape requests not accompanied by specific instructions will be filled on 9-track, 6250-BPI, standard-labeled tapes with EBCDIC characters. Requests should be addressed to

Carbon Dioxide Information Analysis Center  
Oak Ridge National Laboratory  
Post Office Box 2008  
Oak Ridge, Tennessee 37831-6335  
U.S.A.

Telephone: (615) 574-0390 or (615) 574-3645  
Fax: (615) 574-2232

Electronic Mail: INTERNET: CDIAC@ORNL.GOV

The data files can also be acquired from CDIAC's anonymous FTP account via Internet:

- FTP to `cdiac.esd.ornl.gov` (128.219.24.36),
- Enter "ftp" or "anonymous" as the user ID,
- Enter your electronic mail address as the password (e.g., "alex@.esd.ornl.gov")<sup>1</sup>,
- Change to the directory "/pub/ndp051", and
- Acquire the files using the FTP "get" or "mget" command.

---

<sup>1</sup>Please enter your correct address. This address is used by CDIAC to inform data recipients of data revisions and updates.

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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 five files that comprise this NDP (see Table 3). Because CDIAC distributes the data set in several ways (e.g., via anonymous FTP, floppy diskette, and on 9-track magnetic tape), each of the five files is referenced by both an ASCII file name, which is given in lower-case, bold-faced type (e.g., **readme**) and a file number. The remainder of this section describes (or lists, where appropriate) the contents of each file. The files are discussed in the order in which they appear on the magnetic tape.

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

File number, name, and description	Logical records	File size in bytes	Block size	Record length
1. <b>readme</b> : a detailed description of the cruise network, the two FORTRAN 77 data retrieval routines, and the two oceanographic data files	450	48,004	8,000	80
2. <b>stainv.for</b> : a FORTRAN 77 data retrieval routine to read and print <b>m153sta.inv</b> (File 4)	33	1,195	8,000	80
3. <b>m153dat.for</b> : a FORTRAN 77 data retrieval routine to read and print <b>met153.dat</b> (File 5)	49	2,278	8,000	80
4. <b>m153sta.inv</b> : a listing of the station locations, sampling dates, and sounding bottom depths for each of the 111 stations	195	15,405	4,100	41
5. <b>met153.dat</b> : hydrographic, carbon dioxide, and chemical data from 111 stations	3,706	811,614	16,000	160
Total	4,433	878,496		

## readme (File 1)

This file contains a detailed description of the data set, the two FORTRAN 77 data retrieval routines, and the two oceanographic data files. It exists primarily for the benefit of individuals who acquire this database as machine-readable data files from CDIAC.

## stainv.for (File 2)

This file contains a FORTRAN 77 data retrieval routine to read and print m153sta.inv (File 4). 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 m153sta.inv.

```
c*****
c* FORTRAN 77 data retrieval routine to read and print the      *
c* file named "m153sta.inv" (File 4)                          *
c*****

      INTEGER stat, cast, depth
      CHARACTER date*7, expo*8, sect*2, time*4
      REAL latdcm, londcm
      OPEN (unit=1, file='m153sta.inv')
      OPEN (unit=2, file='m153stat.inv')
      write (2, 5)

5      format (20X, 'METEOR CRUISE 15 LEG 3', 5X, 'WOCE LINE A9', /,
1 2X, 'EXPOCODE', 2X, 'SECT', 2X, 'STNNBR', 2X, 'CASTNO', 5X, 'DATE',
2 3X, 'TIME', 5X, 'LATDCM', 5X, 'LONDCM', 3X, 'DEPTH', /)

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

10     format (2X, A8, 2X, A2, 7X, I3, 7X, I1, 2X, A7, 3X, A4, 4X,
1 F7.3, 4X, F7.3, 4X, I4)

      write (2, 20) expo, sect, stat, cast, date, time, latdcm,
1 londcm, depth

20     format (2X, A8, 2X, A2, 7X, I3, 7X, I1, 2X, A7, 3X, A4, 4X,
1 F7.3, 4X, F7.3, 4X, I4)

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



## m153sta.inv (File 4)

This file provides station inventory information for each of the 111 stations occupied during R/V Meteor Cruise 15/3. Each line of the file contains an expocode, section number, station number, cast number, sampling date, sampling time, latitude, longitude, and sounding depth. The file is sorted by station number and can be read by using the following FORTRAN 77 code (contained in stainv.for, File 2):

```

      INTEGER stat, cast, depth
      CHARACTER date*7, expo*8, sect*2, time*4
      REAL latdcm, londcm

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

10  format (2X, A8, 2X, A2, 7X, I3, 7X, I1, 2X, A7, 3X, A4, 4X,
1 F7.3, 4X, F7.3, 4X, I4)

```

Stated in tabular form, the contents include the following:

Variable	Variable type	Variable width	Starting column	Ending column
expo	Character	8	3	10
sect	Character	2	13	14
stat	Numeric	3	22	24
cast	Numeric	1	32	32
date	Character	7	35	41
time	Character	4	45	48
latdcm	Numeric	7	53	59
londcm	Numeric	7	64	70
depth	Numeric	4	75	78

where

expo is the expocode of the cruise;  
 sect is the WOCE section number;  
 stat is the station number (values range from 122 to 232);  
 cast is the cast number;  
 date is the sampling date (includes: month/day/year);

time is the sampling 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).

### met153.dat (File 5)

This file provides hydrographic, carbon dioxide, and chemical data for the 111 stations occupied during R/V *Meteor* Cruise 15/3. Each line consists of a station number; cast number; sample number; bottle number; CTD pressure, temperature, salinity, and oxygen; potential temperature; bottle salinity; concentrations of oxygen, silicate, nitrate, nitrite, phosphate, total carbon dioxide, and total alkalinity; pCO<sub>2</sub>; pCO<sub>2</sub> temperature; CFC-113; CCl<sub>4</sub>; CFC-12; CFC-11; and data quality flags. The file is sorted by station number and pressure and can be read by using the following FORTRAN 77 code (contained in *m153dat.for*, File 3):

```

CHARACTER qual*16
INTEGER sta, cast, samp, bot
REAL pre, ctdtmp, ctdsal, ctdoxy, theta, sal, oxy, silca
REAL nitrat, nitrit, phspht, tcarb, talk, pco2, pco2tmp
REAL cfc113, ccl4, cfc12, cfc11

      read (1, 10, end=999) sta, cast, samp, bot, pre, ctdtmp,
1 ctdsal, ctdoxy, theta, sal, oxy, silca, nitrat, nitrit,
2 phspht, tcarb, talk, pco2, pco2tmp, cfc113, ccl4, cfc12,
3 cfc11, qual

10  format (5X, I3, 7X, I1, 6X, I2, 5X, I3, 2X, F6.1, 1X, F7.4,
1 3X, F9.4, 1X, F7.1, 1X, F7.4, 3X, F9.4, 1X, F7.1, 1X, F7.2,
2 1X, F7.2, 1X, F7.2, 1X, F7.2, 2X, F6.1, 1X, F7.1, 1X, F7.1,
3 1X, F7.2, 2X, F8.3, 2X, F8.3, 2X, F8.3, 2X, F8.3, 2X, A16)

```

Stated in tabular form, the contents include the following:

Variable	Variable type	Variable width	Starting column	Ending column
sta	Numeric	3	6	8
cast	Numeric	1	16	16
samp	Numeric	2	23	24
bot	Numeric	3	30	32
pre	Numeric	6	35	40
ctdtmp	Numeric	7	42	48

<b>ctdsal</b>	Numeric	9	52	60
<b>ctdoxy</b>	Numeric	7	62	68
<b>theta</b>	Numeric	7	70	76
<b>sal</b>	Numeric	9	80	88
<b>oxy</b>	Numeric	7	90	96
<b>silca</b>	Numeric	7	98	104
<b>nitrat</b>	Numeric	7	106	112
<b>nitrit</b>	Numeric	7	114	120
<b>phspht</b>	Numeric	7	122	128
<b>tcarb</b>	Numeric	6	131	136
<b>talk</b>	Numeric	7	138	144
<b>pco2</b>	Numeric	7	146	152
<b>pco2tmp</b>	Numeric	7	154	160
<b>cfc113</b>	Numeric	8	163	170
<b>ccl4</b>	Numeric	8	173	180
<b>cfc12</b>	Numeric	8	183	190
<b>cfc11</b>	Numeric	8	193	200
<b>qualt</b>	Character	16	203	218

---

where

<b>sta</b>	is the station number;
<b>cast</b>	is the cast number;
<b>samp</b>	is the sample number;
<b>bot*</b>	is the bottle number;
<b>pre</b>	is the CTD pressure (in dbar);
<b>ctdtmp</b>	is the CTD temperature (in °C);
<b>ctdsal*</b>	is the CTD salinity [in Practical Salinity Scale (PSS)];
<b>ctdoxy*</b>	is the CTD oxygen (in $\mu\text{mol/kg}$ );
<b>theta</b>	is the potential temperature (in °C);
<b>sal*</b>	is the bottle salinity (in PSS);
<b>oxy*</b>	is the oxygen concentration (in $\mu\text{mol/kg}$ );
<b>silca*</b>	is the silicate concentration (in $\mu\text{mol/kg}$ );
<b>nitrat*</b>	is the nitrate concentration (in $\mu\text{mol/kg}$ );

nitrit*	is the nitrite concentration (in $\mu\text{mol/kg}$ );
phspht*	is the phosphate concentration (in $\mu\text{mol/kg}$ );
tcarb*	is the total carbon dioxide concentration (in $\mu\text{mol/kg}$ );
talk*	is the total alkalinity (in $\mu\text{mol/kg}$ );
pco2*	is the partial pressure of $\text{CO}_2$ (in $\mu\text{atm}$ and measured at $20^\circ\text{C}$ );
pco2tmp	is the temperature of the $\text{pCO}_2$ samples <sup>equilibration of</sup> <del>in equilibrator</del> (in $^\circ\text{C}$ ); <sup>; water-saturated air</sup>
cfc113*	is the trichlorotrifluoroethane concentration ( $\text{CCl}_2\text{FCClF}_2$ ) (in $\text{pmol/kg}$ );
ccl4*	is the carbon tetrachloride concentration (in $\text{pmol/kg}$ );
h   cfc12*	is the <sup>h</sup> dichlorodifluoromethane-12 concentration ( $\text{CCl}_2\text{F}_2$ ) (in $\text{pmol/kg}$ );
h   cfc11*	is the <sup>h</sup> trichlorofluoromethane-11 concentration ( $\text{CCl}_3\text{F}$ ) (in $\text{pmol/kg}$ );
qualt	is a 16-digit character variable that contains data quality flag codes for parameters flagged by an asterisk (*) in the output file. Quality flags definitions:

- 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.

## **8. VERIFICATION OF DATA TRANSPORT**

The data files contained in this numeric data package can be read by using the FORTRAN 77 data retrieval programs provided. Users should visually examine each data file to verify that the data were correctly transported to their systems. To facilitate the visual inspection process, partial listings of each data file are provided in Tables 4 and 5. Each of these tables contains the first and last five lines of a data file.

**Table 4. Partial listing of "m153sta.inv" (File 4)**

---

*First five lines of the file:*

06MT15/3	A9	122	1	2/11/91	1021	-19.000	-37.423	3514
06MT15/3	A9	122	2	2/11/91	1339	-19.005	-37.430	3510
06MT15/3	A9	123	1	2/11/91	1813	-19.005	-37.590	3370
06MT15/3	A9	124	1	2/11/91	2158	-19.000	-37.672	3376
06MT15/3	A9	125	1	2/12/91	0217	-19.002	-37.750	2354

*Last five lines of the file:*

06MT15/3	A9	230	2	3/18/91	0532	-18.072	10.007	4124
06MT15/3	A9	231	1	3/18/91	1056	-17.018	10.483	3590
06MT15/3	A9	231	2	3/18/91	1218	-17.018	10.483	3598
06MT15/3	A9	232	1	3/18/91	1931	-17.025	10.807	3047
06MT15/3	A9	232	2	3/18/91	2051	-17.025	10.805	3045

---

Table 5. Partial listing of "met153.dat" (File 5)

*First five lines of the file:*

122	1	1	324	2998.0	2.6299	34.9159	254.2	2.3874	34.9150	253.5	-999.90	-999.90
-999.90	-999.90	-999.9	-999.9	-999.9	-999.90	-999.900	-999.900	0.000	0.088	222229999999923		
122	1	2	323	2998.0	2.6299	34.9159	-999.9	2.3874	34.9140	254.5	-999.90	-999.90
-999.90	-999.90	-999.9	-999.9	-999.9	-999.90	-999.900	-999.900	0.001	0.017	229229999999923		
122	1	3	322	2998.0	2.6299	34.9159	254.2	2.3874	34.9150	253.0	-999.90	-999.90
-999.90	-999.90	-999.9	-999.9	-999.9	-999.90	-999.900	-999.900	-0.004	0.112	222229999999923		
122	1	4	321	2998.0	2.6299	34.9159	-999.9	2.3874	34.9150	254.0	-999.90	-999.90
-999.90	-999.90	-999.9	-999.9	-999.9	-999.90	-999.900	-999.900	-0.004	0.008	229229999999922		
122	1	5	320	2998.0	2.6299	34.9159	254.2	2.3874	34.9160	254.3	-999.90	-999.90
-999.90	-999.90	-999.9	-999.9	-999.9	-999.90	-999.900	-999.900	-0.001	0.007	222229999999922		

*Last five lines of the file:*

232	2	20	305	2743.0	2.7420	34.9073	226.2	2.5231	34.9060	226.4	43.31	22.98
0.00	1.53	2203.1	-999.9	-999.9	-999.90	-999.900	-999.900	0.001	0.007	222222222299922		
232	2	21	304	2943.0	2.6531	34.9052	-999.9	2.4158	-999.9000	224.8	46.05	23.17
0.00	1.56	-999.9	-999.9	-999.9	-999.90	-999.900	-999.900	0.002	0.014	229922222299923		
232	2	22	303	2943.0	2.6531	34.9052	224.3	2.4158	34.9040	224.6	46.54	23.27
0.00	1.53	2208.1	-999.9	-999.9	-999.90	-999.900	-999.900	0.000	0.000	222222222299922		
232	2	23	302	3023.0	2.5782	34.9023	-999.9	2.3344	34.9010	223.2	49.08	23.37
0.00	1.56	-999.9	-999.9	-999.9	-999.90	-999.900	-999.900	-0.001	0.005	229222222299922		
232	2	24	301	3023.0	2.5782	34.9023	217.6	2.3344	-999.9000	223.0	48.98	23.37
0.00	1.61	2210.8	-999.9	-999.9	-999.90	-999.900	-999.900	0.002	0.000	222922222299922		

**APPENDIX A**  
**STATION INVENTORY**



## APPENDIX A STATION INVENTORY

This appendix lists station inventory information for the 111 sites occupied during R/V *Meteor* Cruise 15/3 in the South Atlantic Ocean . The meanings of the column headings in Table A-1 are as follows.

<b>EXPCODE</b>	is the expocode of the cruise;
<b>STNNBR</b>	is the station number;
<b>SECT</b>	is the WOCE section number;
<b>CASTNO</b>	is the cast number;
<b>DATE</b>	is the sampling date (month/day/year);
<b>TIME</b>	is the sampling time (GMT);
<b>LATDCM</b>	is the latitude of the station (in decimal degrees). Stations in the Southern Hemisphere have negative latitudes;
<b>LONDCM</b>	is the longitude of the station (in decimal degrees). Stations in the Western Hemisphere have negative longitudes;
<b>DEPTH</b>	is the sounding bottom depth of each station (in meters).

Table A.1 Station inventory information for the 111 sites occupied during  
R/V Meteor Cruise 15/3.

EXPOCODE	SECT	STNNBR	CASSTNO	DATE	TIME	LATDCM	LONGDCM	DEPTH
06MT15/3	A9	122	1	2/11/91	1021	-19.000	-37.423	3514
06MT15/3	A9	122	2	2/11/91	1339	-19.005	-37.430	3510
06MT15/3	A9	123	1	2/11/91	1813	-19.005	-37.590	3370
06MT15/3	A9	124	1	2/11/91	2158	-19.000	-37.672	3376
06MT15/3	A9	125	1	2/12/91	0217	-19.002	-37.750	2354
06MT15/3	A9	126	1	2/12/91	0616	-19.002	-37.818	349
06MT15/3	A9	127	1	2/12/91	1008	-18.160	-37.440	3477
06MT15/3	A9	127	2	2/12/91	1305	-19.000	-37.452	3522
06MT15/3	A9	128	1	2/12/91	1636	-19.002	-37.260	3522
06MT15/3	A9	129	1	2/12/91	2132	-18.157	-37.088	3627
06MT15/3	A9	130	1	2/13/91	0233	-19.003	-36.905	3707
06MT15/3	A9	131	1	2/13/91	0847	-18.162	-36.385	3872
06MT15/3	A9	132	1	2/13/91	1425	-19.000	-35.843	4002
06MT15/3	A9	132	2	2/13/91	1622	-19.000	-35.842	4000
06MT15/3	A9	133	1	2/13/91	2148	-19.000	-35.312	4115
06MT15/3	A9	133	2	2/13/91	2327	-19.000	-35.313	4111
06MT15/3	A9	134	1	2/14/91	0440	-19.000	-34.782	4420
06MT15/3	A9	134	2	2/14/91	0621	-19.000	-34.785	4221
06MT15/3	A9	135	1	2/14/91	1126	-19.002	-34.255	4257
06MT15/3	A9	135	2	2/14/91	1312	-18.165	-34.255	4274
06MT15/3	A9	136	1	2/14/91	1816	-18.165	-33.718	4307
06MT15/3	A9	136	2	2/14/91	1951	-18.162	-33.723	4304
06MT15/3	A9	137	1	2/15/91	0106	-19.000	-33.193	4292
06MT15/3	A9	137	2	2/15/91	0245	-18.165	-33.192	4288
06MT15/3	A9	138	1	2/15/91	0808	-18.165	-32.668	4190
06MT15/3	A9	138	2	2/15/91	0935	-18.165	-32.665	4190
06MT15/3	A9	139	1	2/15/91	1440	-19.000	-32.140	4272
06MT15/3	A9	139	2	2/15/91	1622	-19.002	-32.140	4365
06MT15/3	A9	140	1	2/15/91	2152	-18.162	-31.605	4337
06MT15/3	A9	140	2	2/15/91	2333	-18.158	-31.605	4352
06MT15/3	A9	141	1	2/16/91	0445	-19.000	-31.080	4457
06MT15/3	A9	141	2	2/16/91	0643	-18.163	-31.080	4454
06MT15/3	A9	142	1	2/16/91	1201	-18.165	-30.552	4648
06MT15/3	A9	142	2	2/16/91	1352	-19.002	-30.553	4645
06MT15/3	A9	143	1	2/16/91	1916	-19.000	-30.023	4796
06MT15/3	A9	143	2	2/16/91	2100	-18.160	-30.020	4793
06MT15/3	A9	144	1	2/17/91	0221	-19.002	-29.495	4868
06MT15/3	A9	144	2	2/17/91	0433	-19.000	-29.495	4869
06MT15/3	A9	145	1	2/17/91	1004	-18.163	-28.965	5029
06MT15/3	A9	145	2	2/17/91	1154	-18.160	-28.967	5013
06MT15/3	A9	146	1	2/17/91	1716	-19.002	-28.437	5079
06MT15/3	A9	146	2	2/17/91	1918	-18.165	-28.438	5084
06MT15/3	A9	147	1	2/18/91	0238	-19.000	-27.562	5343
06MT15/3	A9	147	2	2/18/91	0451	-19.000	-27.558	5345
06MT15/3	A9	148	1	2/18/91	1232	-18.165	-26.688	5568
06MT15/3	A9	148	2	2/18/91	1432	-18.165	-26.685	5562
06MT15/3	A9	149	1	2/19/91	0011	-18.165	-25.812	5774
06MT15/3	A9	149	2	2/19/91	0220	-19.003	-25.807	5771
06MT15/3	A9	150	1	2/19/91	1239	-19.085	-24.998	5548
06MT15/3	A9	150	2	2/19/91	1435	-19.085	-24.998	5516
06MT15/3	A9	151	1	2/19/91	2153	-18.165	-24.998	5861
06MT15/3	A9	151	2	2/19/91	2358	-18.162	-24.995	5874
06MT15/3	A9	152	1	2/20/91	0520	-18.032	-25.002	5462
06MT15/3	A9	152	2	2/20/91	0733	-18.032	-25.002	5488
06MT15/3	A9	153	1	2/20/91	1623	-19.017	-24.120	5687
06MT15/3	A9	153	2	2/20/91	1820	-19.015	-24.123	5692
06MT15/3	A9	154	1	2/21/91	0129	-19.002	-23.248	5724
06MT15/3	A9	154	2	2/21/91	0327	-19.002	-23.248	5728
06MT15/3	A9	155	1	2/21/91	1120	-18.165	-22.375	5318
06MT15/3	A9	155	2	2/21/91	1310	-18.165	-22.375	5301
06MT15/3	A9	156	1	2/21/91	2018	-18.165	-21.497	5356
06MT15/3	A9	156	2	2/21/91	2212	-18.163	-21.500	5281

Table A.1 (continued)

EXPCODE	SECT	STNNR	CASTNO	DATE	TIME	LATDCM	LONDCM	DEPTH
06MT15/3	A9	157	1	2/22/91	0527	-19.000	-20.625	4916
06MT15/3	A9	157	2	2/22/91	0720	-19.002	-20.625	4910
06MT15/3	A9	158	1	2/22/91	1432	-19.002	-19.750	4718
06MT15/3	A9	158	2	2/22/91	1612	-19.000	-19.750	4724
06MT15/3	A9	159	1	2/22/91	2145	-18.165	-19.223	5015
06MT15/3	A9	159	2	2/22/91	2327	-18.165	-19.223	5016
06MT15/3	A9	160	1	2/23/91	0436	-19.000	-18.698	4457
06MT15/3	A9	160	2	2/23/91	0622	-19.000	-18.700	4444
06MT15/3	A9	161	1	2/23/91	1230	-19.002	-18.178	3987
06MT15/3	A9	161	2	2/23/91	1408	-19.002	-18.182	3938
06MT15/3	A9	162	1	2/23/91	1755	-19.000	-17.650	4164
06MT15/3	A9	162	2	2/23/91	1929	-19.000	-17.650	4164
06MT15/3	A9	163	1	2/24/91	0052	-19.000	-17.127	3663
06MT15/3	A9	163	2	2/24/91	0223	-19.000	-17.127	3672
06MT15/3	A9	164	1	2/24/91	0720	-19.000	-16.600	3514
06MT15/3	A9	164	2	2/24/91	0843	-19.000	-16.600	3516
06MT15/3	A9	165	1	2/24/91	1339	-19.002	-16.078	3701
06MT15/3	A9	165	2	2/24/91	1454	-19.000	-16.080	3706
06MT15/3	A9	166	1	2/24/91	1932	-19.000	-15.548	3678
06MT15/3	A9	166	2	2/24/91	2047	-18.165	-15.548	3672
06MT15/3	A9	167	1	2/25/91	0155	-19.000	-15.027	3715
06MT15/3	A9	167	2	2/25/91	0315	-18.162	-15.025	3676
06MT15/3	A9	168	1	2/25/91	1014	-19.000	-14.998	3723
06MT15/3	A9	169	1	2/25/91	1645	-20.000	-14.997	3656
06MT15/3	A9	170	1	2/25/91	2337	-21.002	-15.008	3892
06MT15/3	A9	171	1	2/26/91	0617	-21.000	-15.000	4277
06MT15/3	A9	172	1	2/26/91	1311	-22.000	-15.002	4113
06MT15/3	A9	173	1	2/26/91	1950	-23.002	-15.000	4738
06MT15/3	A9	174	1	2/27/91	0208	-23.000	-15.000	3875
06MT15/3	A9	174	2	2/27/91	0329	-23.163	-14.995	3876
06MT15/3	A9	175	1	2/28/91	1029	-18.165	-14.498	3581
06MT15/3	A9	175	2	2/28/91	1140	-18.165	-14.502	3575
06MT15/3	A9	176	1	2/28/91	1637	-18.165	-13.977	3271
06MT15/3	A9	176	2	2/28/91	1755	-19.000	-13.983	3231
06MT15/3	A9	177	1	2/28/91	2303	-19.000	-13.450	3981
06MT15/3	A9	177	2	3/01/91	0027	-18.163	-13.447	3863
06MT15/3	A9	178	1	3/01/91	0922	-18.162	-12.915	3197
06MT15/3	A9	179	1	3/01/91	1452	-19.000	-12.403	2329
06MT15/3	A9	180	1	3/01/91	2005	-19.000	-11.875	2879
06MT15/3	A9	181	1	3/02/91	0144	-19.000	-11.348	3122
06MT15/3	A9	182	1	3/02/91	0730	-18.165	-10.825	3499
06MT15/3	A9	183	1	3/02/91	1349	-18.163	-10.300	3644
06MT15/3	A9	184	1	3/02/91	1856	-19.000	-9.775	3829
06MT15/3	A9	184	2	3/02/91	2023	-18.165	-9.775	3836
06MT15/3	A9	185	1	3/03/91	0142	-18.155	-9.240	4055
06MT15/3	A9	185	2	3/03/91	0311	-18.160	-9.227	4082
06MT15/3	A9	186	1	3/03/91	0840	-18.165	-8.723	3997
06MT15/3	A9	186	2	3/03/91	1009	-18.158	-8.722	4093
06MT15/3	A9	187	1	3/03/91	1542	-19.033	-8.198	4166
06MT15/3	A9	187	2	3/03/91	1718	-19.027	-8.197	4181
06MT15/3	A9	188	1	3/03/91	2254	-19.068	-7.675	4622
06MT15/3	A9	188	2	3/04/91	0036	-19.063	-7.670	4619
06MT15/3	A9	189	1	3/04/91	0626	-19.100	-7.152	4540
06MT15/3	A9	189	2	3/04/91	0814	-19.098	-7.152	4542
06MT15/3	A9	190	1	3/04/91	1341	-19.098	-6.627	4323
06MT15/3	A9	190	2	3/04/91	1513	-19.103	-6.622	4327
06MT15/3	A9	191	1	3/04/91	2008	-19.102	-6.097	4676
06MT15/3	A9	191	2	3/04/91	2151	-19.093	-6.103	4656
06MT15/3	A9	192	1	3/05/91	0330	-19.090	-5.580	4792
06MT15/3	A9	192	2	3/05/91	0530	-19.092	-5.582	4795
06MT15/3	A9	193	1	3/05/91	1125	-19.098	-5.050	4791
06MT15/3	A9	193	2	3/05/91	1314	-19.092	-5.050	4891
06MT15/3	A9	194	1	3/05/91	1858	-19.098	-4.522	5079
06MT15/3	A9	194	2	3/05/91	2050	-19.097	-4.525	5077

Table A.1 (continued)

EXPOCODE	SECT	STNNBR	CASTNO	DATE	TIME	LATDCM	LONDCM	DEPTH
06MT15/3	A9	230	2	3/18/91	0532	-18.072	10.007	4124
06MT15/3	A9	231	1	3/18/91	1056	-17.018	10.483	3590
06MT15/3	A9	231	2	3/18/91	1218	-17.018	10.483	3598
06MT15/3	A9	232	1	3/18/91	1931	-17.025	10.807	3047
06MT15/3	A9	232	2	3/18/91	2051	-17.025	10.805	3045