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# Carbon Dioxide, Hydrographic, and Chemical Data Obtained During the R/V *Meteor* Cruise 22/5 in the South Atlantic Ocean

(WOCE Section A10, December 1992 - January 19[illegible])

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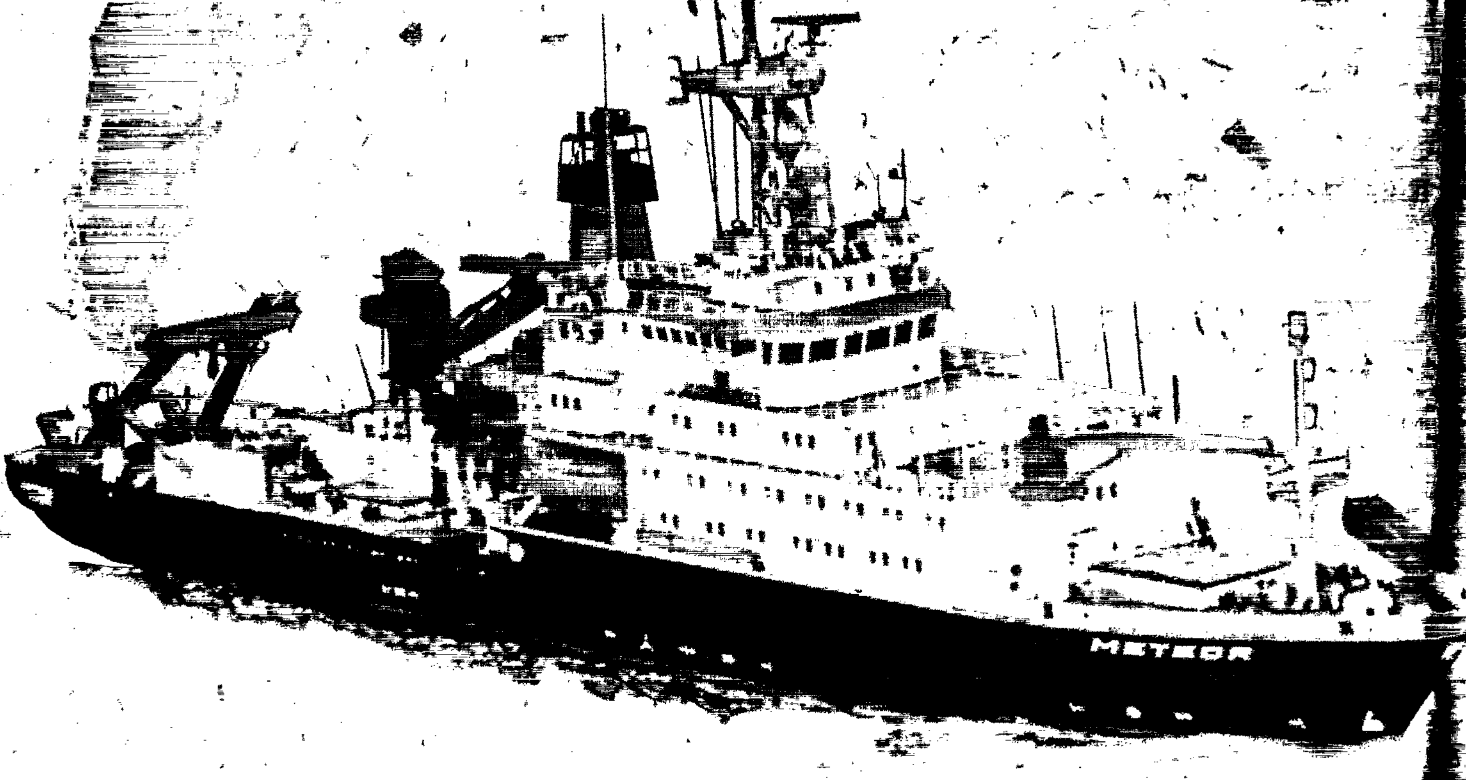


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# CARBON DIOXIDE, HYDROGRAPHIC, AND CHEMICAL DATA OBTAINED DURING THE R/V *METEOR* CRUISE 22/5 IN THE SOUTH ATLANTIC OCEAN (WOCE SECTION A10, DECEMBER 1992–JANUARY 1993)


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# ABSTRACT

Johnson, K. M., B. Schneider, L. Mintrop, D. W. R. Wallace, and A. Kozyr (ed.). 1998 Carbon Dioxide, Hydrographic, and Chemical Data Obtained During the R/V *Meteor* Cruise 22/5 in the South Atlantic Ocean (WOCE Section A10, December 1992–January 1993). ORNL/CDIAC-113, NDP-066. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee. 66 pp.

This data documentation discusses the procedures and methods used to measure total carbon dioxide ($TCO_2$) and total alkalinity (TALK) at hydrographic stations, as well as the underway partial pressure of $CO_2$ ($pCO_2$) during the R/V *Meteor* Cruise 22/5 in the South Atlantic Ocean (Section A10). Conducted as part of the World Ocean Circulation Experiment (WOCE), the cruise began in Rio de Janeiro on December 27, 1992, and ended after 36 days at sea in Capetown, South Africa, on January 31, 1993. Measurements made along WOCE Section A10 included pressure, temperature, and salinity [measured by conductivity, temperature, and depth (CTD) sensor], bottle salinity, bottle oxygen, phosphate, nitrate, nitrite, silicate, chlorofluorocarbons (CFC-11 , CFC-12), $TCO_2$, TALK, and underway $pCO_2$.

The $TCO_2$ was measured by using two Single-Operator Multiparameter Metabolic Analyzers (SOMMAs) for extracting $CO_2$ from seawater samples that were coupled to a coulometer for detection of the extracted $CO_2$. The overall precision and accuracy of the analyses was ±1.9 µmol/kg. Samples collected for TALK were measured by potentiometric titration; precision was ±2.0 µmol/kg. Underway $pCO_2$ was measured by infrared photometry with a precision of ±2.0 µatm. The work aboard the R/V *Meteor* was supported by the U.S. Department of Energy under contract DE-ACO2-76CH00016, and the Bundesministerium für Forschung und Technologie through grants 03F0545A and MFG 099/1.

The R/V *Meteor* Cruise 22/5 data set is available free of charge as a numeric data package (NDP) from the Carbon Dioxide Information Analysis Center. The NDP consists of three oceanographic data files, three FORTRAN 77 data-retrieval routines, a documentation file, and this printed documentation, 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; South Atlantic Ocean; hydrographic measurements; alkalinity; partial pressure of carbon dioxide; carbon cycle

# PART 1:

# OVERVIEW

# 1. BACKGROUND INFORMATION

The World Ocean Circulation Experiment (WOCE) Hydrographic Program (WHP) is a major component of the World Climate Research Programme (WCRP). The overall goal of the WCRP is to better understand the role of the ocean in climate and climatic changes resulting from both natural and anthropogenic causes. The need for this experiment arose from serious concern over the rising atmospheric concentration of carbon dioxide ($CO_2$) and its effect on the heat balance of the global atmosphere. The increasing concentration of this gas may intensify the earth's natural greenhouse effect and alter the global climate in ways that are not well understood. The complex and poorly understood circulation patterns and biogeochemical cycles of the ocean yield a complex and uneven distribution of $CO_2$. Although total $CO_2$ ($TCO_2$) 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 $TCO_2$ as well as other related parameters. Goals of the survey are to estimate the meridional transport of inorganic carbon in a manner analogous to the oceanic heat transport estimates (Bryden and Hall 1980; Brewer et al. 1989; Roemmich and Wunsch 1985) and to build a database suitable for carbon-cycle modeling and the subsequent estimation of anthropogenic $CO_2$ increase in the oceans. The $CO_2$ survey is taking advantage of the sampling opportunities provided by the WHP cruises during this period. The final data set is expected to cover ~23,000 stations.

This report discusses the results of the research vessel (R/V) *Meteor* Cruise 22/5 along the WOCE zonal section A10 (along ~30° S) (Fig. 1). The expedition started in Rio de Janeiro, Brazil, on December 27, 1992, and ended in Capetown, South Africa, on January 31, 1993. This section is one of four zonal sections (A8, A9, A10, and A11) completed in the South Atlantic Ocean during the WOCE survey. The large-scale three-dimensional distribution of temperature, salinity, and chemical constituents, including the carbonate system parameters, will be plotted using the data from these sections. Knowledge of these parameters and their initial conditions will enable researchers to determine heat and water transport as well as carbon transport. An understanding of this transport will contribute to the understanding of processes that are relevant to climate change. This section in the South Atlantic subtropical gyre is especially relevant to understanding $CO_2$ transport because it crosses both the Brazil and the Benguela boundary currents.

This data documentation is the result of the cooperative efforts of chemical oceanographers from Brookhaven National Laboratory (BNL), U.S.A; Baltic Sea Research Institute [Institut für Ostseeforschung (IOW)], Germany; and the Institute for Marine Sciences of University of Kiel [Institut für Meereskunde Kiel (IfMK)], Germany.

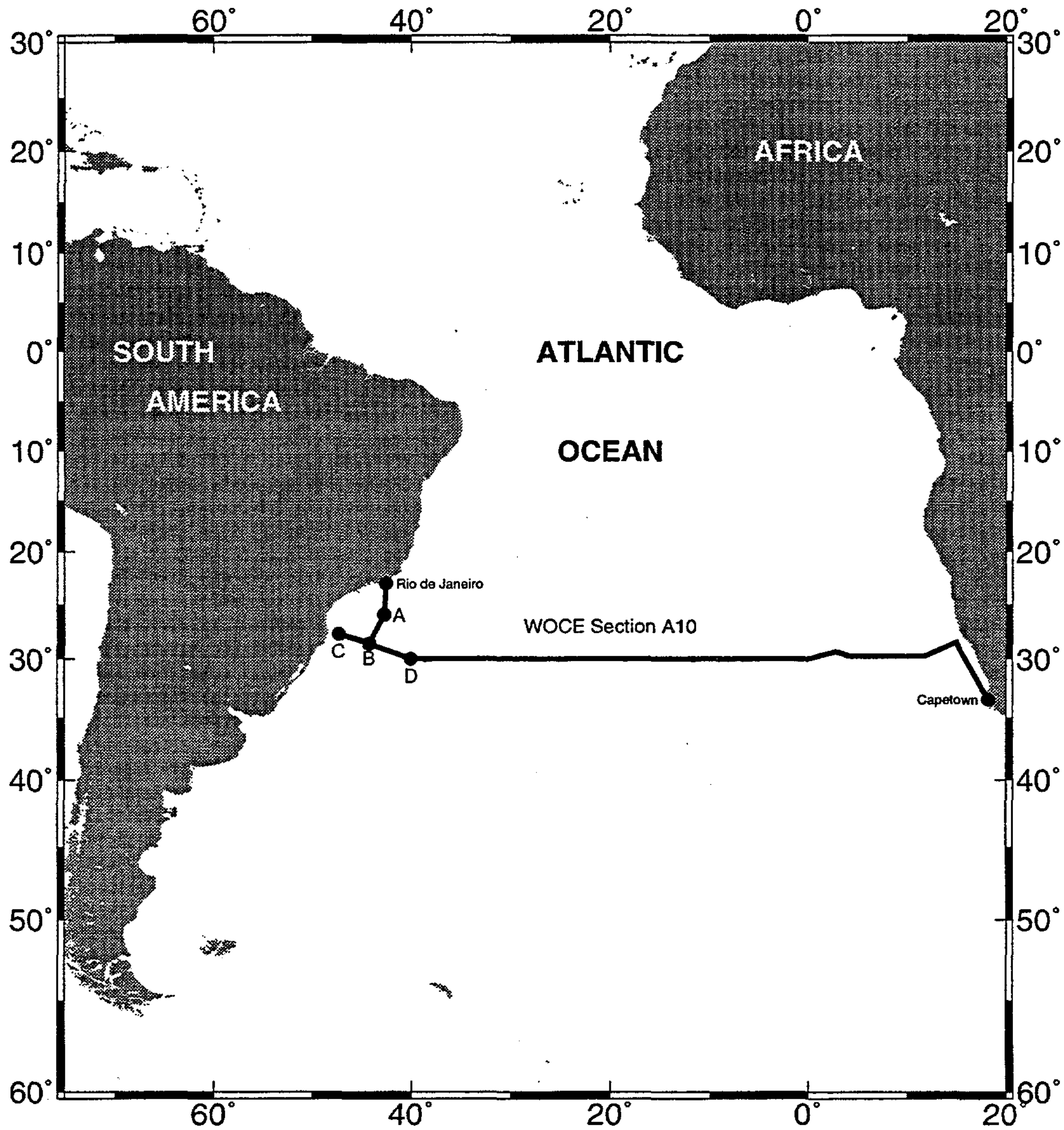


**Figure 1. The cruise track during R/V *Meteor* Cruise 22/5 (WOCE Section A10).** A, B, C, and D on the map designate waypoints, which are described in Section 2.3.

# 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:

| | |
|---|---|
| **Port of registration** | Hamburg |
| **Call sign** | DBBH |
| **Classification** | GL+100A4E2+MC Auto |
| **Operator** | University of Hamburg, Institute for Ocean Research |
| **Built** | 1985–1986 at Schlichting Werft, Travemünde |
| **Basic dimensions:** | |
| ***Gross registered tonnage*** | 3990 t |
| ***Net registered tonnage*** | 1284 t |
| ***Displacement*** | 4780 t |
| ***Length overall*** | 97.50 m |
| ***Beam*** | 16.50 m |
| ***Draught maximum*** | 5.60 m |
| ***Service speed*** | 12 kn |
| ***Depth main deck*** | 7.70 m |
| **Personnel** | Crew: 32; scientists: 30 |
| **Main engine** | 4 × Mak6M 322 = 4 × 1000 kW at 750 rpm |
| **Propulsion** | Diesel-electrical, tandem-motor = 2 × 1150 kW |
| **Fuel consumption** | Approximately 12.0 t IFO-80 per day at service speed |
| **Maximum cruise duration** | 60 days |
| **Nautical equipment** | Integrated navigation system with data transfer to position computer, echo sounder synchronization and supervision, and data-processing facility |
| **Science quarters** | 20 laboratories on the main deck with ~400 m$^2$ 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 for 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 22/5 Information

R/V *Meteor* Cruise 22/5 information follows:

| | |
|---|---|
| **Ship name** | *Meteor* |
| **Cruise/leg** | 22/5 |
| **WOCE Section** | A10 |
| **Location** | Rio de Janeiro, Brazil, to Capetown, South Africa |
| **Dates** | December 27, 1992, to January 31, 1993 |
| **Funding** | German Science Community;<br>Federal Ministry of Research and Technology, Bonn, Germany; and U.S. DOE |
| **Chief Scientist** | Dr. Reiner Onken, IfMK |
| **Master** | Martin Kull |

| **Parameters measured** | **Institution** | **Principal investigators** |
|---|---|---|
| CTD[1], salinity, XBT[2], and XCP[3] | IfMK | R. Onken |
| Nutrients | IOW, IfMK | B. Schneider, and H. Johannsen |
| Oxygen | IOW, IfMK | B. Schneider, and H. Johannsen |
| Chlorofluorocarbons (CFCs) | UBT[4] | W. Roether, and A. Putzka |
| Tritium, helium, and radiocarbon | UBT | W. Roether, and A. Putzka |
| $TCO_2$ | BNL, IOW | K. Johnson, and B. Schneider |
| TALK | IfMK | L. Mintrop |
| Underway $pCO_2$ | IOW | B. Schneider |
| ADCP[5] | IfMK | R. Onken |

[1]Conductivity, temperature, and depth sensor.
[2]Expendable bathythermograph.
[3]Expendable current profiler.
[4]University of Bremen, Tracer Oceanography Laboratory.
[5]Acoustic Doppler current profiler.

## 2.3 Brief Cruise Summary

On December 26, 1992, K. Johnson of BNL arrived in Rio de Janeiro, where he joined Drs. B. Schneider and L. Mintrop and their $CO_2$ group consisting of A. Morak, U. Karbach, A. Korves, and J. Morlang who were already onboard the R/V *Meteor.* Setting up of the equipment began immediately by locating the coulometry systems in the Universal Laboratory, the underway $pCO_2$ system in the Geo-Laboratory, and the alkalinity system in one of the ship's chemistry laboratories. The R/V *Meteor* departed Rio de Janeiro at 6 p.m. on December 27, 1992. Work began almost immediately with ADCP and XBT measurements across the Brazil Current and the occupation of test station no. 620 (waypoint A). Then R/V *Meteor* headed to waypoint B and once again crossed the Brazil Current, where additional ADCP and XBT measurements were made (see Fig. 1). After R/V *Meteor* crossed the Brazil Current for the second time, the ship began the hydrographic stations at waypoint C. Between waypoints C and B the interval between stations was ~10 nautical miles (nm), and after waypoint B it rose to ~30 nm. The $CO_2$ sampling began at test station no. 620. The 30° S parallel was reached at waypoint D, and for the next few weeks the R/V *Meteor* sailed eastward along the 30° S parallel, passing over portions of the Vema Channel, the eastern part of the Rio Grande Rise, the Argentine Basin, the southern Brazil Basin, the Mid-Atlantic Ridge, the Angola Basin, the Walvis Ridge, and the Cape Basin. There was a small interruption in the work schedule to allow a New Year's Eve celebration. On January 8, nets laid by Spanish fishing boats on the western edge of the Rio Grande Rise caused the R/V *Meteor* to make a detour. (However, this meeting with the fishing boats also resulted in a trade between captains in which the R/V *Meteor* received fresh swordfish and tuna.) A small northward jog was made over the Walvis Ridge in order to sample around topographical features. The intervals between stations as the ship steamed eastward varied between 9 and 45 nm to limit the difference between the bottom depth at consecutive station depths to ≤1000 m. At 11° 30' E, the ship veered slightly to the east-northeast in order to avoid the South African 200-nm exclusion zone because permission to sample in these waters had not been obtained. After this turn, the station resolution was reduced to 20 nm until the last station on the African shelf at a depth of ~200 m. The measurement phase concluded on January 28, 1993, and the R/V *Meteor* steamed to Capetown, where it arrived on the afternoon of January 30. Aside from some light rain and intermittent cloudiness at the beginning of the cruise, the weather remained mostly sunny with summer temperatures and calm seas throughout. Closer to the coast of Africa, swells of ~5 m originating from subantarctic low-pressure areas were experienced but without any loss of work time.

Two Single-Operator Multiparameter Metabolic Analyzers (SOMMAs) were used for measuring $TCO_2$ concentration during this cruise. One was supplied by BNL and another by the IfMK. In addition, two potentiometric alkalinity titrators from IfMK were run in parallel, and an infrared (IR)-based system belonging to IfMK was deployed to measure underway $pCO_2$. The $TCO_2$ concentration was analyzed in 1425 samples from 57 of 100 CTD stations (57%) occupied during the cruise (Fig. 2). In addition, 116 coulometric measurements for the Certified Reference Material (CRM) and duplicate analyses were made during the cruise. The TALK concentration in 665 samples was determined by potentiometric titration during the cruise. Not all stations could be sampled for $TCO_2$ and TALK because of the time required for analysis; however, the goal of 50% station coverage for $CO_2$ samples was surpassed, and on average 1.5 stations were sampled per day by the $CO_2$ group. The standard WOCE parameters (oxygen, nutrients, and salinity) were analyzed on all samples, and the tracer samples included CFC's, helium, tritium, and radiocarbon. The underway $pCO_2$ system operated continuously.

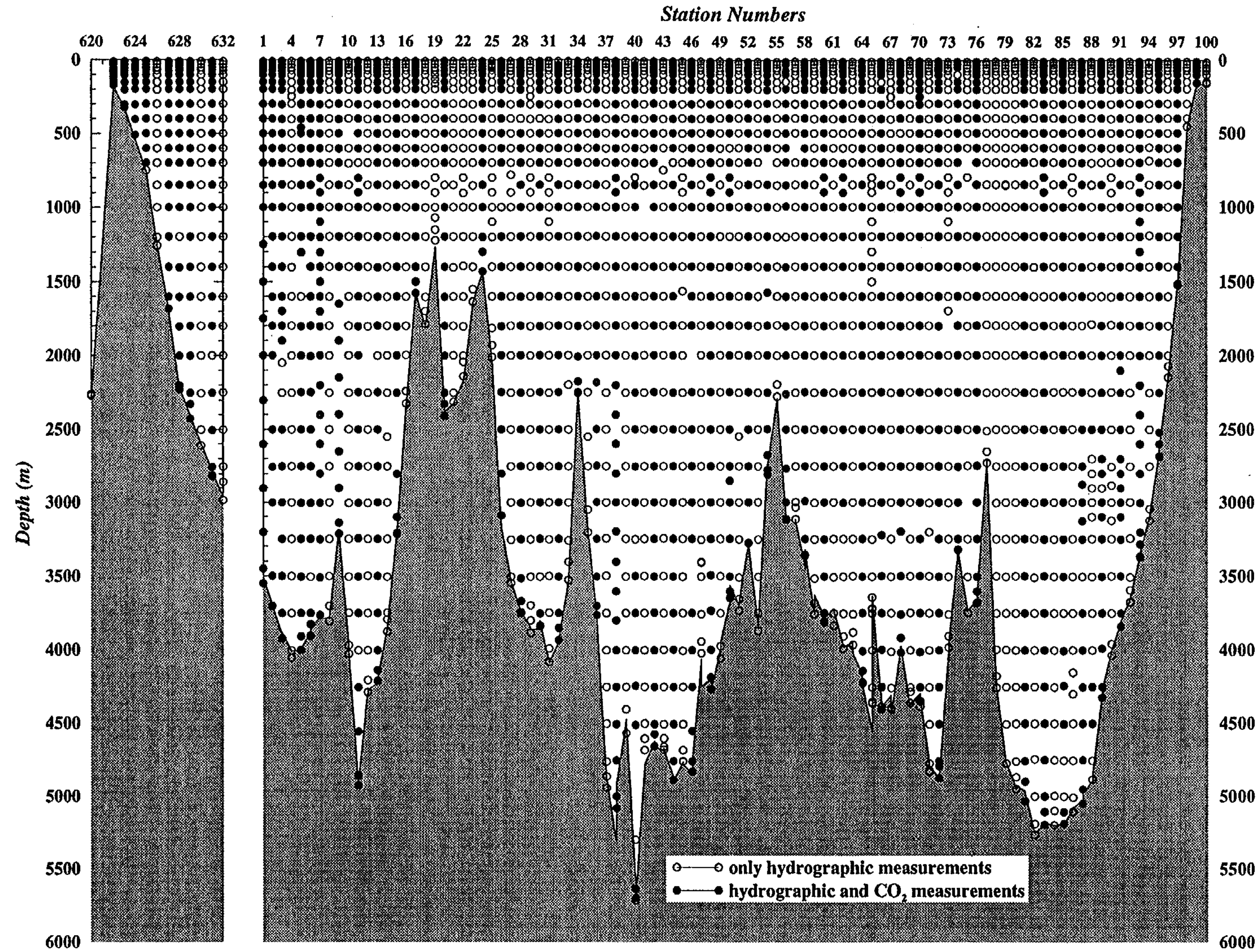


**Figure 2. Sampling depths at all hydrographic stations occupied during R/V *Meteor* expedition along WOCE Section A10.**

# 3. DESCRIPTION OF VARIABLES AND METHODS

## 3.1 Hydrographic Measurements

Water samples were collected with a General Oceanics rosette equipped with twenty-four 10-L Niskin bottles mounted on a Neil Brown Mark III CTD instrument provided by the IfMK. For stations deeper than 3500 m, two separate CTD/rosette casts were launched. For stations with a depth less then 3500 m, one CTD/rosette cast of up to 24 bottles was lowered. Surface currents down to 300 m, surface temperature, and surface salinity were measured continuously during the cruise with a hull-mounted ADCP and a thermosalinograph. In between CTD stations, XBTs were routinely launched. Over the boundary currents, XBTs were launched every half hour, and over the Benguela Current, the XBT launches were supplemented with free-falling XCPs.

No serious problems were experienced with the CTD/rosette systems during the cruise. Repeated checks on board and several careful verifications using the complete bottle data sets have been carried out, and the sampling pressures have been assigned to each sample. Reversing thermometers of both the electronic (SIS, Kiel) and the mechanical (Gohla Precision, Kiel) types were also read at the completion of each cast. The processing and quality control of CTD and bottle data followed the published guidelines in the *WOCE Operations Manual* (WHPO 91-1, 1991).

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. Salinity for selected Niskin bottles (about one in every three) was also determined on a Guildline Autosal model 8400A that was standardized weekly with International Association for the Physical Sciences of the Ocean (IAPSO) water. These data were also used to process the CTD data, and the final salinity data are expected to be accurate to ±0.002. Bottle oxygen was determined by Winkler titration after the technique of Carpenter (1965) with the modifications of Culberson et al. (1991), using standards and blanks run in seawater. The precision of the analyses determined from parallel analyses ($n = 10$) of samples at and well below saturation is ±0.4%. The concentrations of nitrate, nitrite, phosphate, and silicate dissolved in seawater were determined for samples collected in high-density polyethylene screw-capped bottles by a continuous-flow method with an autoanalyzer. Precision was as follows: silicate, ±1.3%; phosphate, ±1.5%; and nitrite/nitrate, ±1.1%. Preweighed standards were used to prepare the nutrient working standards aboard the ship.

## 3.2 $TCO_2$ Measurements

The $TCO_2$ was determined by using two automated dynamic headspace sample SOMMA processors with coulometric detection of the $CO_2$ extracted from acidified samples. A description of the SOMMA-coulometry system and its calibration can be found in Johnson et al. (1987), Johnson and Wallace (1992), and Johnson et al. (1993). Details concerning the coulometric titration procedure can be found in Huffman (1977) and Johnson et al. (1985). Samples were collected in 300-mL precombusted (450°C for 24 h) glass standard Biological Oxygen Demand (BOD) bottles and analyzed for $TCO_2$ during the cruise. During the cruise the samples were not poisoned with $HgCl_2$ as per normal operating procedure (DOE 1994), but they were analyzed within 24 h of collection. Before analysis, samples were kept in darkness in a cold room and subsequently thermally equilibrated for at least 3 h to the analytical temperature. Analyses of duplicate samples separated in time by up to 8 h showed no evidence of any significant biological consumption or production of $CO_2$ during storage. The CRMs were supplied by Dr. A. Dickson of Scripps Institution of Oceanography (SIO) (DOE 1994) and were also routinely analyzed. CRMs from batches 7 and 11 were available for this work (batch 7: S = 37.120, $TCO_2$ = 1926.41 ± 0.82 μmol/kg; batch 11: S = 38.5, $TCO_2$ = 2188.77 μmol/kg). The CRMs were made from filtered sterile salt solutions spiked with $Na_2CO_3$, and their $TCO_2$ concentrations were determined by vacuum-extraction/manometry in the laboratory of Dr. C. D. Keeling at SIO.

Seawater introduced from an automated "to deliver" (TD) pipette into a stripping chamber was acidified, and the resultant $CO_2$ from continuous gas extraction was dried and coulometrically titrated on a model 5011 UIC coulometer. The coulometers were adjusted to give a maximum titration current of 50 mA, and they were run in the counts mode [the number of pulses or counts generated by the coulometer's voltage-to-frequency converter (VFC) during the titration was displayed]. In the coulometer cell, the hydroxyethylcarbamic acid formed from the reaction of $CO_2$ and ethanolamine was titrated coulometrically (electrolytic generation of $OH^-$) with photometric endpoint detection. The product of the time and the current passed through the cell during the titration (charge in Coulombs) is related by Faraday's constant to the number of moles of $OH^-$ generated and thus to the moles of $CO_2$ that reacted with ethanolamine from the acid.

Each system was controlled with an IBM-compatible personal computer equipped with two RS232 serial ports, a 24-line digital input/output card, and an analog-to-digital card. The latter were manufactured by Real Time Devices (State College, Pa.). These were used to control the coulometer, barometer (BNL system only), solid-state control relays, and temperature sensors, respectively. The temperature sensors (model LM34CH, National Semiconductor, Santa Clara, Calif.), with a voltage output of 10 mV/°F built into the SOMMA, were calibrated against thermistors certified to 0.01°C (PN CSP60BT103M, Thermometrics, Edison, N.J.) using a certified mercury thermometer as a secondary standard. These sensors monitored the temperature of SOMMA components, including the pipette, gas sample loops, and the coulometer cell. The SOMMA software was written in GWBASIC Version 3.20 (Microsoft Corp., Redmond, Wash.), and the instruments were driven from an options menu appearing on the personal computer (PC) monitor. With the coulometers operated in the counts mode, conversions and calculations were made by using the SOMMA software rather than the programs and the constants hardwired into the coulometer circuitry.

The BNL SOMMA-coulometry system was calibrated with pure $CO_2$ by using hardware that consisted of an 8-port gas sampling valve (GSV) with two sample loops of known volume [determined gravimetrically by the method of Wilke et al. (1993)]. This GCV was connected to a source of pure $CO_2$ through an isolation valve with the vent side of the GSV plumbed to a barometer. When a gas loop was filled with $CO_2$, the mass (moles) of $CO_2$ contained therein was calculated by dividing the loop volume ($V$) by the molar volume of $CO_2$ at the ambient temperature and pressure. The molar volume of $CO_2$ [$V(CO_2)$] was calculated iteratively from an expression using the instantaneous barometric pressure ($P$), loop temperature ($T$), gas constant (R), and the first virial coefficient B($T$) for pure $CO_2$:

$$V(CO_2) = RT / P[1 + B(T) / V(CO_2)] \ . \qquad (1)$$

The gas calibration factor (CALFAC)—the ratio of the calculated mass to that determined coulometrically—was used to correct the subsequent titrations for small departures from 100% recoveries (DOE 1994). Pressure was measured with a barometer, model 216B-101 Digiquartz Transducer (Paroscientific, Inc., Redmond, Wash.), which is factory-calibrated for pressures between 11.5 and 16.0 psia. The standard operating procedure was to make gas calibrations daily for each newly prepared titration cell (normally, one cell per day and three sequential calibrations per cell).

The "to deliver" volume ($V_{cal}$) of the BNL SOMMA sample pipette was determined (calibrated) gravimetrically during the cruise by periodically collecting aliquots of deionized water dispensed from the pipette into preweighed serum bottles. The serum bottles were crimp sealed and returned to shore, where they were reweighed on a model R300S (Sartorius, Göttingen, Germany) balance. The apparent weight (g) of water collected ($W_{air}$) was corrected to the mass in vacuo ($M_{vac}$) from

$$M_{vac} = W_{air} + W_{air} (0.0012/d - 0.0012/8.0) , \quad (2)$$

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. $V_{cal}$ was calculated by using the following equation:

$$V_{cal} = M_{vac}/d . \quad (3)$$

The $V_{cal}$ of the pipette for the BNL system was 20.6114 ± 0.0024 mL ($n$ = 23) at a mean temperature of 14.67°C (hereafter the calibration temperature $t_{cal}$). During the cruise, the mean pipette temperature was 14.95 ± 0.97°C, and the vast majority of samples were analyzed at a measurement temperature ($t$) that was within 1°C of this calibration temperature. The sample volume ($V_t$) at the measured pipette temperature was calculated from the expression

$$V_t = V_{cal} [1 + a_v (t - t_{cal})] , \quad (4)$$

where $a_v$ is the coefficient of volumetric expansion for pyrex-type glass ( $1 \times 10^{-5}\,°C^{-1}$) and $t$ is the temperature of the pipette at the time of a measurement.

The BNL coulometer was periodically electronically calibrated as described in Johnson et al. (1993, 1996) and the DOE *Handbook of Methods* (1994). Briefly, at least two levels of current (usually 50 and 2 mA) were passed through an independent and very precisely known resistance (R) for a fixed time. The voltage ($V$) across the resistance was continuously measured and the instantaneous current ($I$) across the resistance was calculated from Ohm's law and integrated over the calibration time. Then, the number of pulses (counts) accumulated by the VFC during this time was compared to the theoretical number computed from the factory-calibration of the VFC [frequency = $10^5$ pulses (counts) generated/sec at 200 mA] and the measured current. If the VFC was perfectly calibrated at the factory, the electronic calibration procedure would yield a straight line passing through the origin (intercept = 0) with a slope of 1. For the BNL coulometer, the mean electronic calibration slope during the R/V *Meteor* Cruise 22/5 was 0.999616 ± 0.000056 ($n$ = 12, r.s.d. = 0.006%) with an intercept of –0.000533 μmol/min. From the factory calibration of the VFC and the value of the Faraday (96489 Coulomb/mol), a scaling factor of $4.82445 \times 10^3$ counts/μmol was derived. The theoretical number of micromoles of carbon titrated ($M$) from samples or the gas loops was

$$M = [\text{Counts}/4824.45 - (Blank \times T_t) - (INT_{ec} \times T_i)]/SLOPE_{ec} , \quad (5)$$

where $T_t$ is the length of the titration in minutes, *Blank* is the system blank in μmol/min, $INT_{ec}$ is the intercept from electronic calibration in μmol/min, $T_i$ is the time in minutes during the titration where current flow was continuous, and $SLOPE_{ec}$ is the slope from electronic calibration. Note that the slope obtained from the electronic calibration procedure applied for the entire length of the titration, but the intercept correction applied only for the period of continuous current flow (usually 3–4 min) because the electronic calibration can be carried out only for periods of continuous current flow. The $TCO_2$ concentration in µmol/kg was calculated from

$$TCO_2 = M \times CALFAC \times [1/(V_t \times \rho)] \times d_{Hg} \times CF_{crm} \, , \qquad (6)$$

where ρ is the density of sea water in g/mL at the measurement temperature and sample salinity calculated from the equation of state given by Millero and Poisson (1981), $d_{Hg}$ is the correction for sample dilution with bichloride solution (for this cruise $d_{Hg}$ = 1.0 for the BNL and Kiel analyses because $HgCl_2$ was not used), and $CF_{crm}$ is a correction factor based on the daily liquid calibration by CRM analysis ($CF_{crm}$ = 1.0 for all BNL analyses; no correction based on the CRM data).

The BNL SOMMA-coulometry system was equipped with a conductance cell (Model SBE-4, Sea-Bird Electronics, Inc., Bellevue, Wash.) for salinity measurement as described by Johnson et al. (1993). The conductance cell was factory calibrated, but SOMMA-measured salinities were continuously compared with the CTD salinities to ensure that the salinities of the analyzed samples matched the assigned salinities. Generally, agreement between CTD and SOMMA salinities was 0.02 or better.

A leak in the gas calibration hardware of the BNL system was discovered on January 12, 1993. It affected the gas calibrations by diluting the $CO_2$ calibration gas during the gas calibration procedure so that CALFACs determined between December 28, 1992, and January 12, 1993, were in error by approximately +0.1%. These CALFACs caused an error of +2 µmol/kg in the CRM analyses. Repairs were made on January 12, and from this point through January 28, daily CALFACs were determined and used to calculate the values of CRM and $TCO_2$. The mean CALFAC for the period January 12–28 was 1.004270 ± 0.000818 ($n$ = 12 ). This CALFAC was used to recalculate the values of CRM and $TCO_2$ for the period from December 28 through January 11.

The IfMK system did not possess a gas calibration system, and gas calibration was not carried out during the cruise. This IfMK system was calibrated at the IfMK in Kiel prior to the cruise with liquid standards ($Na_2CO_3$ solutions) according to the method of Goyet and Hacker (1992). A mean CALFAC (1.005 ± 0.07%) was obtained in the laboratory from the ratio (true $TCO_2$ / measured $TCO_2$). This value was used in Eq. 6 to calculate the CRM and $TCO_2$ values throughout the cruise. During the calibration and at-sea work, the pipette volume, $V_{cal}$ (also determined prior to the cruise), used for the IfMK system was 25.2347 mL at 20.02°C (see Eq. 4 ). This TD pipette volume was not redetermined gravimetrically during the cruise. Instead, an additional $CF_{crm}$ based on the daily (cell-specific) CRM results was used to account for changes in pipette volume and/or system response by multiplying the $TCO_2$ sample results by the ratio (see Eq. 6):

$$CF_{crm} = CRM \text{ (certified) } / \text{ CRM (measured) } .$$

In summary, the IfMK system was calibrated as follows: a daily (cell-specific) $CF_{crm}$ was applied to the water sample analysis results based on a laboratory-determined constant CALFAC (1.005) and a constant value of $V_{cal}$ (25.2347mL at 20.02°C). The IfMK coulometer was not electronically calibrated during the cruise, and the theoretical response (Slope = 1, Intercept = 0) was assumed in Eq. 5 for all calculations. Note, however, that the CRM analysis results from the IfMK system (also referred to as the Kiel system or Kiel SOMMA) (Fig. 3) were calculated with $CF_{crm}$ = 1 in order that the variability of the CRM analyses and the magnitude of $CF_{crm}$ could be assessed.

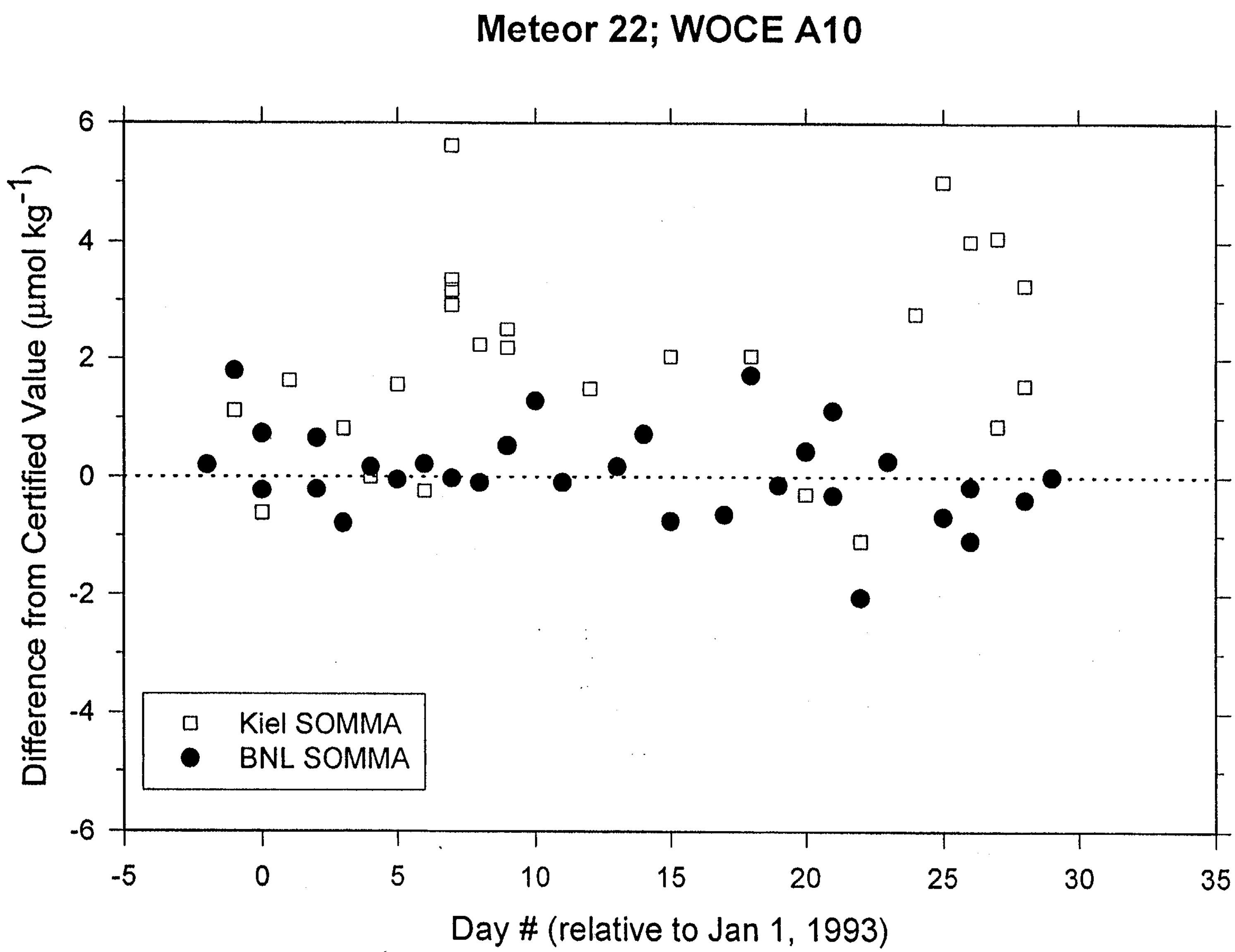


**Figure 3.** The distribution of differences between the measured and certified values of the CRM analyzed by the BNL SOMMA-coulometry system (closed circles) and the IfMK (Kiel) SOMMA-coulometry system (open squares) during R/V *Meteor* Cruise 22/5. The IfMK results have been calculated based on the pre-cruise calibration only.

Problems were encountered with the pinch-valve tension of the IfMK System. This valve controls the delivery of samples to the stripper. Although it always operated, it affected the analytical results by periodically allowing additional samples to be injected into the stripper. The weak valve tension prevented the complete sealing of the tubing connecting the pipette to the stripper. The resulting errors for the CRM analyses were on the order of 0.1 to 0.5%. The valve tension was adjusted during the cruise, and the effect of these errors on data quality was minimized because poor results for the CRM analyses caused by the malfunctioning pinch valve prompted repair of the system before any samples were run. However, the possibility remained that during the sample analyses periodic pinch valve failures may have occurred, and this prompted extensive quality assurance-quality control (QA-QC) of the data.

The first phase of the QA-QC procedure was an assessment of accuracy using the data from the CRM analyses. These data are shown in Fig. 3 and summarized in Table 1. For the BNL system, during the period from December 29, 1992, through January 11, 1993, a constant CALFAC (1.004270) was used to calculate CRM $TCO_2$, whereas between January 12 and 28, 1993, a daily (cell-specific) CALFAC was used to calculate CRM $TCO_2$. For the IfMK system, a constant CALFAC (1.005) was used for all calculations.

**Table 1. Summary of CRM $TCO_2$ determinations made during R/V *Meteor* Cruise 22/5**

| System | No. (n) | Batch[a] | Mean µmol/kg | St. Dev. µmol/kg | Diff[b] | Dates | CALFAC | Outliers[c] |
|---|---|---|---|---|---|---|---|---|
| BNL | 14 | 7 | 1926.7 | 0.65 | +0.27 | 12/29–01/11 | Constant | 1 |
| BNL | 16 | 11 | 2188.7 | 0.89 | −0.11 | 01/12–01/28 | Daily | 0 |
| IfMK | 18 | 7 | 1928.1 | 1.57 | +1.68 | 12/30–01/12 | Constant | 1 |
| IfMK | 11 | 11 | 2191 | 1.88 | +2.20 | 01/13–01/28 | Constant | 3 |

[a]The CRM were from Batch 7 and 11 with salinities of 37.12 and 38.50, and $TCO_2$ of 1926.41 ± 0.82 µmol/kg ($n$ = 13) and 2188.77 ± 0.56 µmol/kg ($n$= 5), respectively.
[b]The mean difference between measured and certified $TCO_2$.
[c]An outlier is defined as a CRM analysis with an error ≥5.0 µmol/kg.

Mean errors in the BNL system were significantly lower than the consistently positive errors observed in the IfMK system. For the BNL system, an outlier was obtained on January 4 (CRM bottle no. 2), but a second CRM (no. 275) run on the same cell gave a satisfactory result, and this cell was subsequently used to run samples. For the IfMK system, outliers were observed on January 7 and 12 (no. 353 and no. 8). In each case, a second CRM analysis (no. 318 and 244) gave satisfactory results, and the system was operated as normal. On January 20 two consecutive CRM analyses (no. 370 and 112) were classified as outliers, but a third CRM (no. 312) analysis gave a satisfactory result and the system was operated. Overall, 5 of 64 CRM analyses from Table 1 (7.8%) were classed as outliers, but 4 of these 5 outliers were obtained on the IfMK system which was further evidence for the slightly better performance of the BNL system. The greater number of outliers on the IfMK system could possibly be the result of malfunctioning of the IfMK pinch valve as described earlier. In general, the CRM results on the BNL system were identical to the manometric reference analyses at SIO. The BNL system response remained constant over the duration of the cruise (see Fig. 3) whether an average CALFAC (12/28/1992–01/11/1993) or a cell-specific CALFAC (01/12/1993–01/28/1993) was used to calculate CRM $TCO_2$. These results confirm a similar finding obtained when mean CALFACs were used to calculate the $TCO_2$ data of the R/V *Meteor* Cruise 18/1 (WOCE Leg A1E) (Johnson et al. 1996).

The second phase of the QA-QC procedure was an assessment of sample precision on each system (instrument-specific precision). The system precision data are given in Table 2. For these data, "within-sample" precision is the average absolute difference between two replicates analyzed from the same sample bottle, "between-sample" precision is the average absolute difference between duplicate sample bottles taken from the same Niskin bottle, and "between-Niskin" precision is the average absolute difference of analyses of samples taken from two Niskin bottles that were closed at the same depth. The IfMK group assessed instrument-specific precision by periodically running two replicates from the same bottle ("within-sample"), whereas precision on the BNL system was assessed by running one replicate from each of two sample bottles filled from the same Niskin bottle ("between-sample"). The pooled standard deviation ($S_p^2$) is the square root of the pooled variance from the "between-sample" replicates ($n$ = 2) according to Youden (1951):

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

where $K$ is the number of samples analyzed, and $\sum_{i=1}^{K} n_i - K$ are the degrees of freedom for the calculation.

**Table 2. Summary of sample precision for $TCO_2$ analyses made during R/V *Meteor* Cruise 22/5**

| System | Mean precision and St. Dev. (µmol/kg)[a] | | | $S_p^2$ ($K$, $n$, d.f.) |
|---|---|---|---|---|
| | within-sample ($n$) | between-sample ($n$) | between-Niskin ($n$) | |
| BNL | 0 | 1.04 ± 1.11 (53) | 1.26 ± 1.41 (12) | 1.07 (53, 106, 53) |
| IfMK | 1.16 ± 1.62 (46) | 0.98 ± 0.36 (6) | 1.53 ± 2.04 (5) | 0.73 (6, 12, 6) |
| Combined | | 1.03 ± 1.06 (59) | 1.34 ± 1.55 (17) | 1.04 (59, 118, 59) |

[a]Mean precision is $[\sum_{x=1}^{n} \text{abs}\,(x_1 - x_2)]\,/\,n$, where $n$ is the number of comparisons between duplicates analyses, $x_1$ and $x_2$.

Table 2 shows that there was no significant difference between the precision estimated using the three different methods; however, the standard deviation of the between-sample estimates was the lowest of the three methods. The same pattern was found for the $TCO_2$ data of the R/V *Meteor* Cruise 18/1 (WOCE Section A1E) when within-sample and between-sample precisions were compared (see Johnson et al. 1996); these data were also consistent with results for other WOCE Sections (Johnson et al. 1995; Johnson et al. 1996). For the instrument-specific $S_p^2$, $K$ is the number of between-sample samples analyzed on the same instrument, $n$ is the total number of replicates analyzed from $K$ samples, and $n - K$ is the degrees of freedom (d.f.).

The third phase of the QA-QC procedure was to assess the performance of the systems by comparing results from aliquots of the same sample analyzed on each system. The precedent was set by the R/V *Meteor* Cruise 18/1 $TCO_2$ data set when two SOMMAs were also run in parallel to generate the data set (Johnson et al. 1996). For the R/V *Meteor* 18/1 data, a method-specific $S_p^2$, assuming homogeneous variance, was calculated from aliquots of the same sample analyzed on each system. The same calculation was made for the applicable R/V *Meteor* Cruise 22/5 samples, and the method-specific precision ($S_p^2$) for this cruise calculated from 31 such samples ($K$ = 31, $n$ = 2, d.f. = 31) was ±1.92 μmol/kg. This is a more conservative estimate of overall cruise-wide precision than the instrument-specific precision shown in Table 2. For any measurement, irrespective of the instrument it was made on, the precision was ±1.92 μmol/kg. This includes all sources of error-random as well as any uncorrected systematic errors (bias).

Figure 4 is a histogram that shows the frequency distribution of the differences between aliquots of 31 samples that were measured on both systems. The mean and standard deviation of the mean difference was 0.81 ± 2.46 μmol/kg (BNL – IfMK $TCO_2$ results) with most of the differences falling within the ±1.0 μmol/kg range (Fig. 4). The IfMK calibration procedure therefore appears to have been successful in eliminating any overall system bias seen for the IfMK CRM analyses given in Table 1. For the CRM, the BNL system (gas calibrated) gave more accurate results than the IfMK system (not gas calibrated), and no corrections have been made to any of the sample data analyzed on the BNL system based on the CRM results. In summary, the mean difference between aliquots of the same sample analyzed on both systems was <1.0 μmol/kg, and the method-specific pooled variance ($S_p^2$ = ±1.92 μmol/kg) calculated from Youden (1951) is a credible estimate of precision and accuracy for the R/V *Meteor* Cruise 22/5 data set generated by two systems run in parallel but calibrated differently.

The fourth step in the QA-QC procedure, the at-sea to onshore comparison, involved analyzing replicates of the same sample in real time at sea and later, after storage, on shore. This procedure was carried out on 14 samples collected at 7 stations. The onshore analyses were made by vacuum extraction/manometry in the laboratory of Dr. C. D. Keeling at SIO. The results of the comparison are given in Table 3 (Guenther et al., personal communication, 1998).

On the BNL system the initial comparisons (Jan. 13–15, $n$ = 4, mean error −1.93 μmol/kg) were consistent with the precision and accuracy (±1.92 μmol/kg) of the method, but larger differences were observed after January 15. The mean difference for the cruise was −3.54 μmol/kg [for the R/V *Meteor* Cruise 18/1, the corresponding results were −2.13 μmol/kg ($n$ = 7) with a method-specific precision and accuracy of ±1.65 μmol/kg]. Overall, the ship-to-shore difference is clearly not depth dependent. The poorest results were the very negative differences for samples collected on January 17 at station 62 and run on the IfMK system. There were other reasons to suspect the accuracy of the shipboard analyses from station 62 made on the IfMK system, so these samples have been averaged separately in Table 3. Note that only 3 of the remaining 12 differences were within the analytical precision of the shipboard method and these occurred early on in the cruise; 6 of the 12 were essentially within 2 standard deviations (±3.84 μmol/kg), but 3 differed by more than 2 standard deviations. All of the differences were negative. The CRM differences were not nearly as large as the ship-to-shore sample differences. The length of time the samples were stored prior to analysis onshore was also not correlated with the at-sea vs onshore differences. The reason for the difference between shipboard and shore-based analyses remains to be determined.

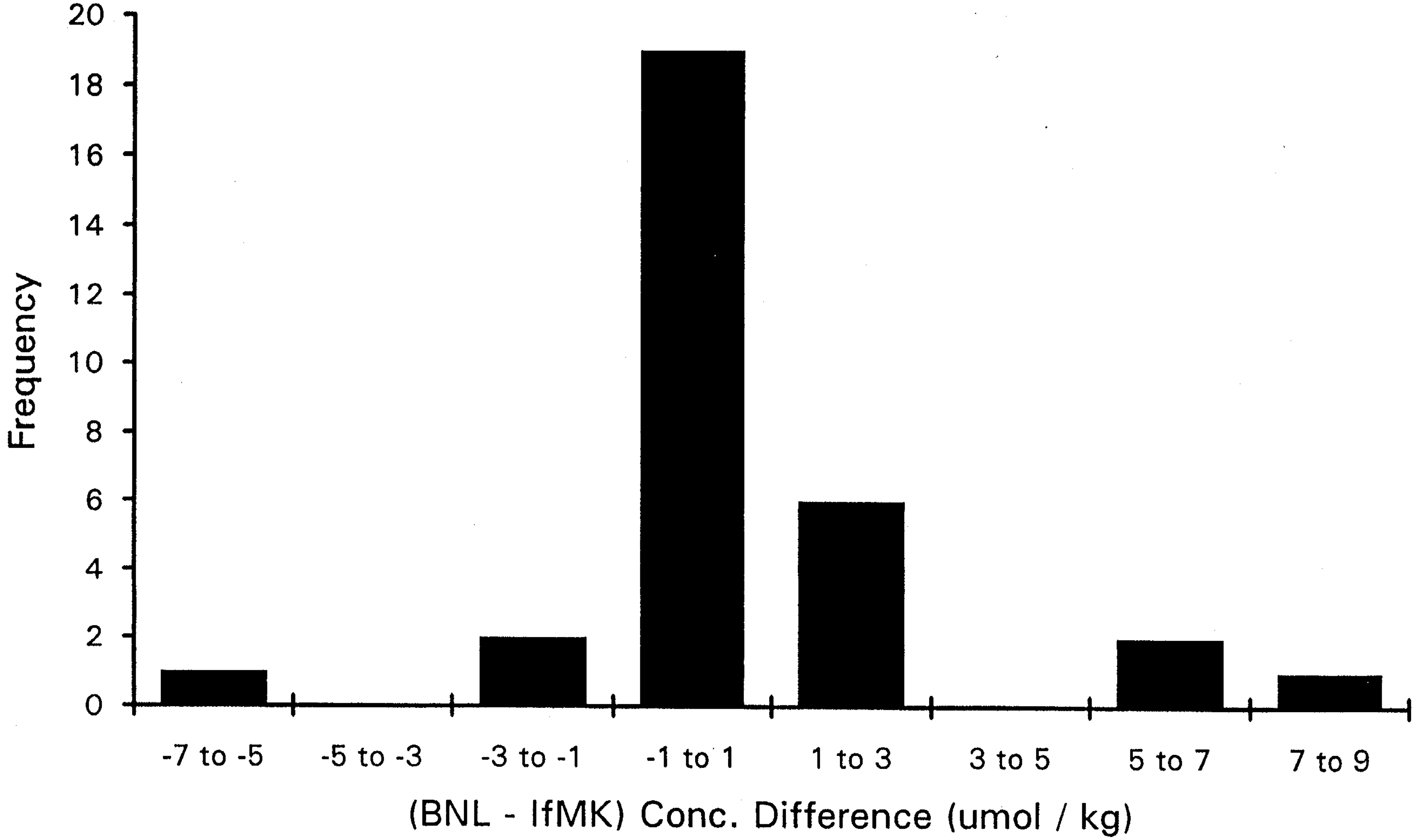


**Figure 4.** **A histogram showing the frequency and distribution of the magnitude of the differences for 31 samples for which aliquots were analyzed on both measurement systems (BNL and IfMK) during R/V *Meteor* Cruise 22/5.**

**Table 3. Comparison of at-sea analyses of $TCO_2$ by coulometry and the onshore analyses of $TCO_2$ by manometry on aliquots of the same sample**

| Date (1993) | Station (no.) | Niskin (no.) | Depth (m) | At-sea ($\mu$mol/kg) | Onshore ($\mu$mol/kg) | Storage[a] (mo) | Difference ($\mu$mol/kg) | CRM diff[b] |
|---|---|---|---|---|---|---|---|---|
| BNL analyses | | | | | | | | |
| 1/13 | 48 | 318 | 10.2 | 2045.68 | 2047.49 | 11 | −1.81 | 0.18 |
| 1/13 | 48 | 308 | 3002 | 2188.44 | 2189.98 | 10 | −1.54 | 0.18 |
| 1/15 | 54 | 323 | 10.7 | 2044.96 | 2047.51 | 5 | −2.55 | −0.76 |
| 1/15 | 54 | 301 | 2808 | 2200.83 | 2202.68 | 5 | −1.85 | −0.76 |
| 1/19 | 68 | 323 | 10.4 | 2064.83 | 2068.02 | 10 | −3.19 | −0.14 |
| 1/19 | 68 | 307 | 3003 | 2200.1 | 2203.27 | 10 | −3.17 | −0.14 |
| 1/21 | 76 | 208 | 12.4 | 2057.86 | 2060.61 | 4 | −2.75 | 1.12 |
| 1/21 | 76 | 306 | 3003 | 2203.31 | 2207.06 | 4 | −3.75 | 1.12 |
| 1/24 | 85 | 213 | 11.8 | 2041.48 | 2047.61 | 3 | −6.13 | −0.68 |
| 1/24 | 85 | 312 | 3002 | 2200.73 | 2207.66 | 4 | −6.93 | −0.68 |
| 1/27 | 93 | 213 | 12 | 2029.99 | 2033.69 | 3 | −3.70 | −0.39 |
| 1/27 | 93 | 305 | 3004 | 2200.52 | 2205.61 | 3 | −5.09 | −0.39 |
| Mean (n = 12) | | | | | | 6 | −3.54 | −0.11 |
| St. Dev. | | | | | | ±3 | ±1.71 | ±0.69 |
| IfMK analyses | | | | | | | | |
| 1/17 | 62 | 208 | 12 | 2046.45 | 2054.22 | 4 | −7.77 | 2.04 |
| 1/17 | 62 | 307 | 3004 | 2190.57 | 2202.12 | 5 | −11.55 | 2.04 |
| Mean (n=2) | | | | | | 4 | −9.66 | |
| St. Dev. | | | | | | ±1 | ±2.67 | |

[a]Storage refers to the elapsed time (in months) between sample collection and onshore analysis by manometry.

[b]The SIO difference between the determined and certified CRM $TCO_2$ for the specific coulometer cell used to titrate the at–sea replicate sample.

The data given in Tables 2 and 3 suggested that further QA-QC analysis of the data was justified. As described above, the two SOMMA systems used during R/V *Meteor* Cruise 22/5 employed different calibration strategies, and the number of replicate samples analyzed on both instruments was insufficient to assess bias on a station-by-station basis. As an additional cross-check on the intercomparability of $TCO_2$ concentrations measured using the two analytical systems, the correlation of the $TCO_2$ was compared with other measured oceanographic parameters. Brewer et al. (1995) and Wallace (1995) have previously noted that strong multivariate relationships exist between $TCO_2$ and other hydrographic parameters (e.g., temperature, salinity, oxygen, and nutrients). These relationships are remarkably robust over basin-scales and have been used to examine the temporal buildup of $CO_2$ in the oceans (Wallace 1995; Wallace et al. 1996; Holfort et al. 1998) and to interpolate sparse data (Brewer et al. 1995).

Multiple linear regressions were initially performed for $TCO_2$ data collected from three geographical sections of the R/V *Meteor* Cruise 22/5. Earlier work had suggested that regression fits varied slightly from one ocean basin to another. The section was therefore broken down into three groups of stations: those occupied in zone 1 defined as being west of 13° W (west of the Mid-Atlantic Ridge; southern Brazil Basin); stations occupied in zone 2, defined as being between 13° W and 3° E (between the Mid-Atlantic and Walvis Ridges; Southern Angola Basin); and stations occupied in zone 3, defined as being east of 3° E (east of the Walvis Ridge; Northern Cape Basin). For each group of stations, all samples collected from below 200 m for which $TCO_2$ had been measured (on either system) were extracted, and a stepwise multiple linear regression was performed with $TCO_2$ as the dependent variable and the wide range of other measured hydrographic parameters as independent variables. The regression models determined that only potential temperature, salinity, apparent oxygen utilization (AOU), and silicate were significant predictors [this is the same group of parameters as found previously by Wallace (1995) for the WOCE Section A9 along 19° S]. In addition, a single regression was performed for all of the data collected below 200 m from the entire section. The regression parameters for these four different geographical groupings of stations (the defined zones 1, 2, and 3 and the entire section) are presented in Table 4. For each of these four geographical groupings, two sets of regression coefficients are presented: one was derived from a regression that employed the measured silicate concentration as an independent variable and one for a regression that did not use silicate as a predictor.

This initial exercise was not particularly satisfactory, as illustrated by the regression coefficients that varied significantly from one geographical zone to another and depended on whether silicate was employed as a predictor (Table 4). For example, the AOU coefficient varied from 0.33 to 0.63 when silicate was employed as an independent variable, and it reached as high as 0.86 when silicate was not used as a predictor. The salinity coefficient was even more variable, ranging from –2 to +24. In general, the potential temperature, AOU, and salinity coefficients were stable across the geographical groupings when silicate was not used in the regression: the inclusion of silicate caused the other coefficients to vary significantly. Use of silicate as a predictor could also shift the coefficients for the other parameters outside of their "oceanographically reasonable" ranges. For example, the AOU coefficient, if interpreted to reflect the respiratory quotient for organic material, should be 0.68 (Takahashi et al. 1985), 0.69 (Anderson and Sarmiento 1994), or 0.77 (Redfield et al. 1963). Clearly the AOU coefficient derived from regression no. 2A falls well outside this accepted range. Likewise, even the sign of the salinity coefficient is variable. "Oceanographic reasoning" suggests that there should be a positive partial correlation between $TCO_2$ and salinity because of the strong positive correlation between carbonate alkalinity and salinity in the ocean (the countervailing tendency of $CO_2$ gas solubility to decrease with increasing salinity is a relatively minor effect). The use of silicate did significantly reduce the overall standard error of the predictions (Table 4) and eliminated or markedly reduced certain systematic patterns in the distribution of the residuals with depth (results not shown).

**Table 4. Summary of initial multiple regression results with (A) and without (B) silicate as an independent variable.**

| Regression no. | Longitude range | Intercept | Coefficients | | | | Standard error |
|---|---|---|---|---|---|---|---|
| | | | Pot. temp. | Salinity | AOU | $SiO_4$ | |
| 0A | All section | 1987.32 | −4.296 | 4.045 | 0.62 | 0.482 | 4.37 |
| 0B | All section | 1370.4 | −6.254 | 22.038 | 0.827 | | 6.88 |
| 1A | Zone 1 | 1975.58 | −4.259 | 4.37 | 0.633 | 0.462 | 4.77 |
| 1B | Zone 1 | 1395.65 | −5.957 | 21.178 | 0.864 | 0.462 | 7.12 |
| 2A | Zone 2 | 2858.72 | −2.531 | 21.163 | 0.327 | 1.126 | 4.44 |
| 2B | Zone 2 | 1316.58 | −6.623 | 23.822 | 0.754 | 1.126 | 4.42 |
| 3A | Zone 3 | 2201 | −3.949 | −2.246 | 0.621 | 0.538 | 2.65 |
| 3B | Zone 3 | 1540.28 | −7.049 | 17.431 | 0.764 | 0.538 | 7.76 |

In order to examine further the influence of silicate, the residuals evaluated from regressions based upon only potential temperature, salinity, and AOU against silicate were plotted. This plot (not shown) showed that for silicate concentrations between 0 and ~40 µmol/kg, the residuals averaged zero and there was no discernible trend; however, for silicate concentrations greater than ~40 µmol/kg, there was a very clear positive correlation of the residuals with silicate. On the basis of this it was decided to define a new parameter, the "silicate index" ($I_{Si}$), as

$$I_{Si} = ([SiO_4] > 40) \times ([SiO_4] - 40) \; .$$

This index is equal to zero for $SiO_4$ concentrations less than 40 µmol/kg, and it is equal to $[SiO_4] - 40$ when silicate is greater than or equal to 40 µmol/kg.

The results of regressions using the silicate index, potential temperature, salinity, and AOU as independent variables are presented in Table 5. It can be seen that use of the silicate index, rather than the silicate concentration, makes the regression coefficients for the other parameters much more consistent from one geographical zone to another (see Table 4). Given the overall consistency of fit, it is right to use a single regression equation to predict the $TCO_2$ over the entire section (Regression no. 0, Table 5).

The distribution of residuals arising from this single section-wide regression equation is presented separately for the three defined geographical zones in Figure 5. Separate symbols are employed for the residuals derived from measurements made on the BNL and IfMK SOMMA systems. In general, there was little or no systematic structure apparent in the residual distribution (except perhaps at the very low $TCO_2$ concentrations that are found close to the surface where seasonal effects may be significant), and the regression fits the data from all three zones reasonably well.

**Table 5. Summary of multiple regression results when the Silicate Index ($I_{si}$) was used as a predictor**

| Regression no. | Longitude range | Intercept | Coefficients | | | | Standard error |
|---|---|---|---|---|---|---|---|
| | | | Pot. temp. | Salinity | AOU | $I_{Si}$ | |
| 0 | All section | 1706.33 | –5.747 | 12.474 | 0.722 | 0.434 | 4.59 |
| 1 | Zone 1 | 1704.61 | –5.565 | 12.443 | 0.746 | 0.422 | 4.98 |
| 2 | Zone 2 | 1863.67 | –6.075 | 8.217 | 0.618 | 0.77 | 4.17 |
| 3 | Zone 3 | 1964.15 | –5.867 | 5.135 | 0.688 | 0.464 | 2.99 |

In order to assess the intercomparability of $TCO_2$ measurements made on the two SOMMA systems on a station-by-station basis, the mean residuals (calculated for each station) have been plotted (Fig. 6) on the basis of the section-wide fit. This plot permits an assessment of the overall consistency of the measured $TCO_2$ with the other measured hydrographic parameters over the entire cruise. The plot demonstrates the following:

1. There is some slight spatial structure to the station-mean residuals, with the mean residual in zone 2 (12.9° W < longitude < 3° E) being ~1–2 µmol/kg higher than for the rest of the section. No corresponding trend in the CRM analyses on the BNL system was seen (see Fig. 3), and it was therefore hypothesized that this slight variation is "real" and is associated with different origins for water masses in this zone.

2. In general, there is no consistent difference between the station-mean residuals on the basis of measurements made with the BNL and IfMK SOMMA systems. The overall consistency of the two sets of measurements appears to be better than ±2 µmol/kg, which is consistent with the accuracy and precision bounds (±1.9 µmol/kg,) for the overall data set. This confirms that the cruise-wide calibration of the $TCO_2$ data analyzed with the two instruments was nearly identical.

3. Three stations (625, 46, and 62) appear to be outliers from the overall pattern. These stations have a mean residual that is significantly different from the overall mean of the station-mean residuals analyzed with the BNL SOMMA. All of these three stations were measured by means of the IfMK SOMMA. While the possibility could not be ruled out that these deviations arise from errors in the measurement of the independent variables used in the regressions (e.g., the oxygen or silicate analyses or from "real" oceanographic variability), it was hypothesized that they were the result of calibration error of the $TCO_2$ analysis at these stations.

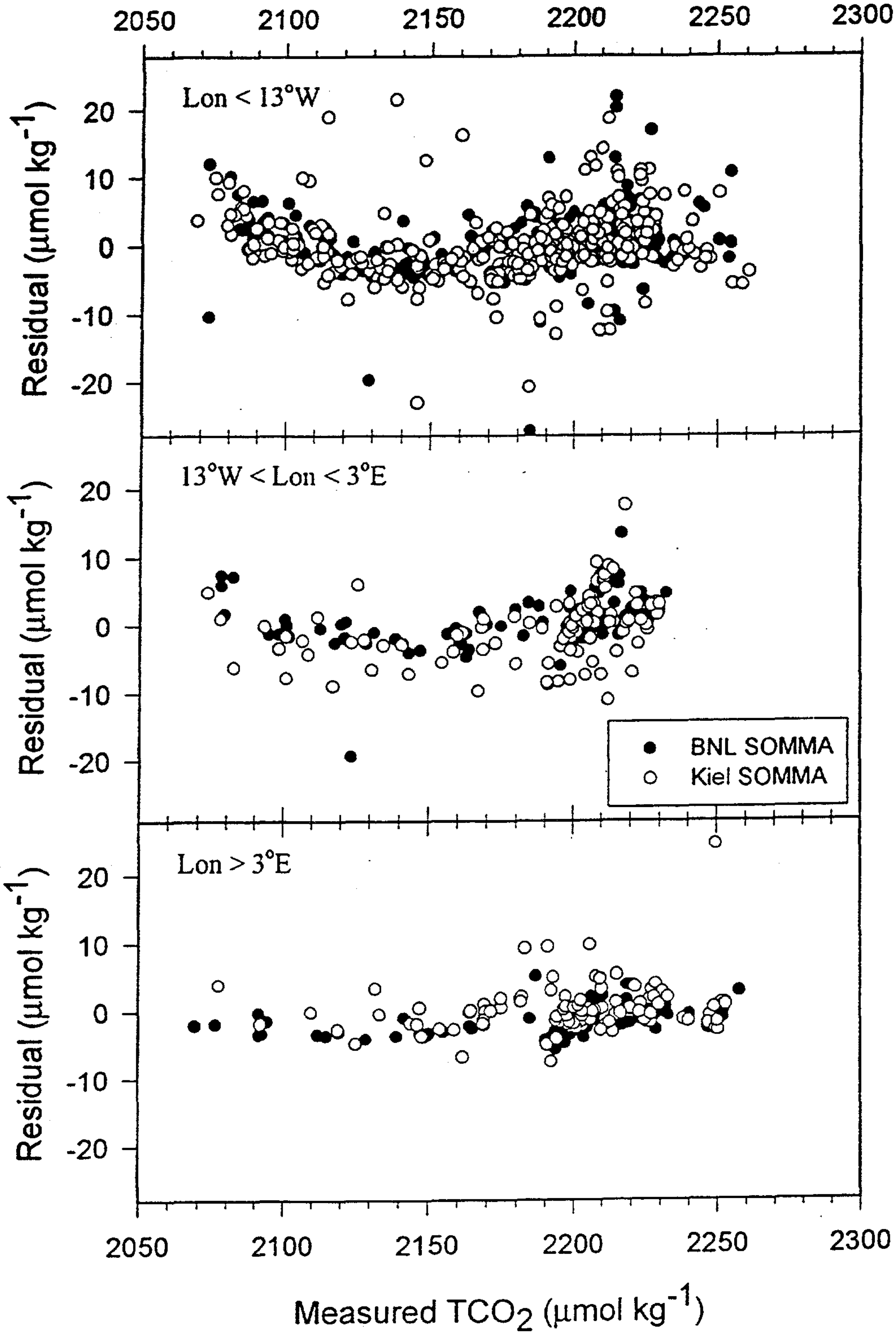


**Figure 5. Residuals (observed – predicted) of $TCO_2$ versus the observed $TCO_2$ concentration for three separate geographical groupings of stations occupied during R/V *Meteor* Cruise 22/5.** The residuals were evaluated against a multiple linear regression equation derived from all the $TCO_2$ data collected during the cruise (at depths > 200 m). The independent variables used in the regression were potential temperature, salinity, apparent oxygen utilization, and a silicate index. The regression coefficients used were those presented for regression no. 0 in Table 5.

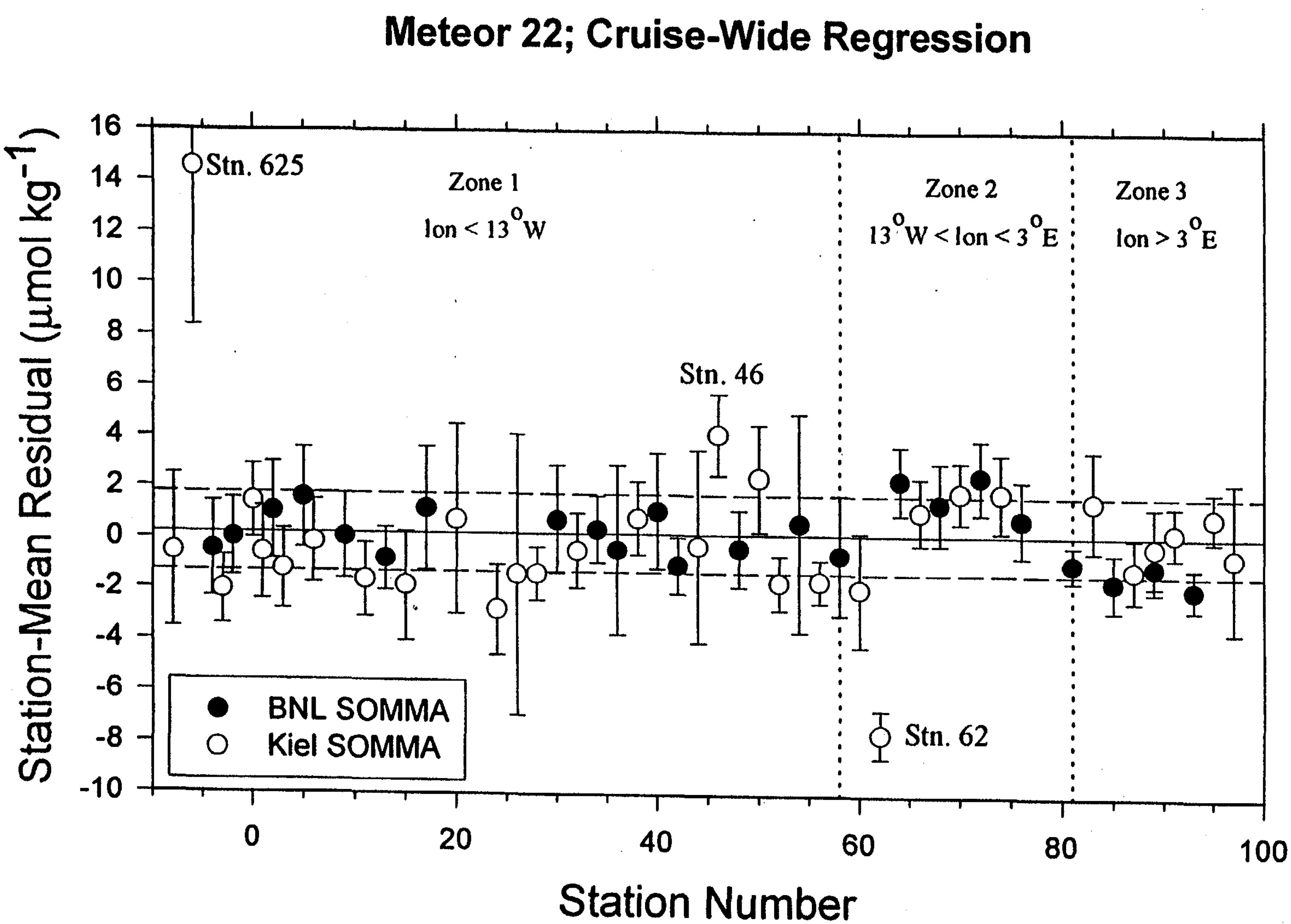


**Figure 6. The mean $TCO_2$ residual (observed – predicted) for each station occupied during R/V *Meteor* Cruise 22/5; residuals were evaluated using a section-wide multiple linear regression (coefficients given for regression no. 0 in Table 5).** The error bars denote the 95% confidence interval of the station-mean residual. Filled symbols reflect stations analyzed using the BNL SOMMA, open symbols reflect analyses using the IfMK (Kiel) SOMMA. The demarcation of three geographical zones reflecting three separate ocean basins sampled during the cruise is denoted with the vertical lines. The horizontal lines represent the cruise-wide mean and 95% confidence intervals calculated for the station-mean residuals using the BNL SOMMA results only.

Given the approach used to calibrate the IfMK SOMMA, such deviations could arise from a single incorrect analysis of a CRM which would cause the correction factor ($CF_{crm}$ in Eq. 6) for an entire station to shift based on an incorrect analysis. The BNL SOMMA analyses were less prone to such errors because the primary calibration was based on analyses of pure $CO_2$ (gas calibration) with the CRM analyses being used as an independent cross-check on this primary calibration. With this approach, any calibration errors that may lead to systematic errors for an entire station are more likely to be identified and corrected.

The residual intercomparison confirms that the overall quality of the combined BNL and IfMK data set is very high. However, three anomalous stations were identified. The $TCO_2$ results at station 62 appear to be low by 5–7 µmol/kg. This station was also sampled for onshore manometric analyses, and the results in Table 3 confirm that, whereas other stations had a mean (ship-shore) difference of −3.54 µmol/kg (±1.71 µmol/kg), the shipboard analyses from station 62 were 8–12 µmol/kg lower than the shore-based results. Therefore it was concluded from these two independent lines of evidence that the station 62 results are too low, and they have been flagged as incorrect in the original data file. On the basis of the residual analysis, the $TCO_2$ results at station 46 may also be high by ~2–4 µmol/kg ,and $TCO_2$ results from station 625 may be high by as much as 14 µmol/kg. However, there is no independent way to assess the data from these stations, and the anomalous residual could be "real" as a result of error in the predictor variables. Therefore, the $TCO_2$ data from these stations have been flagged as "questionable." Only these three stations have been flagged; the data collected at the remaining 51 stations that were sampled for $TCO_2$ appear to be internally consistent.

## 3.3 TALK Measurements

TALK measurements were collected in 500 mL bottles for 665 samples from 26 stations with the same precautions as for $TCO_2$. The bottles were stored in the dark at 4°C and analyzed within 24 hours. The samples were transferred into a closed titration cell with a volume of approximately 120 mL and titrated at 25 ± 0.1°C with 0.1 M HCl containing 0.6 M NaCl. The titration cell was based on the systems described by Bradshaw and Brewer (1988) and Millero et al. (1993). The potential was followed with an electrode pair consisting of a ROSS (Orion Inc.) glass pH electrode and a ROSS AgCl reference electrode connected to a high precision digital voltmeter. The titration was controlled by a computer that waited for stable emf-readings before adding the next acid increment. The titration curve was analyzed through a modified GRAN-plot method described by Stoll et al. (1993) that used the carbonic acid constants of Goyet and Poisson (1989) and that takes into account the silicate and phosphate concentrations of the sample to obtain the titration alkalinity. The precision of the method was ±2.0 µmol/kg as determined by replicate analyses of samples. Standardization was accomplished with $NaCO_3$ standards in NaCl solutions corrected for the blank arising from impurities in the salt. No reference materials were analyzed for alkalinity during this cruise.

## 3.4 Underway $pCO_2$ Measurements

Underway $pCO_2$ was measured by the method of Schneider et al. (1992). Surface seawater was continuously pumped at a rate of 200–300 mL/min into a glass equilibrator with a volume of approximately 300 mL. The seawater was equilibrated with continuously circulating air entering the bottom of the equilibrator through a frit from a closed loop system. The latter included a heat exchanger to keep the air at the sample temperature, a filter and water trap, and an infrared analyzer (Siemens, Ultramat 5F) to determine the $CO_2$ content of the equilibrated air. The IR analyzer and the equilibrator temperature sensor were connected to a PC and to an analog recorder for data display and preservation. The time constant for the equilibration was about 3 min, which corresponded to a spatial resolution of 0.5 mi with the ship speed at 10 kn. Atmospheric air was periodically measured, and the system was calibrated every 12 h using calibration gases with $CO_2$ mixing ratios of 252.5 and 412.8 ppm. Pressure corrections were made for the effect of water vapor and the pressure at the inlet of the IR analyzer, while the correction for the small difference between in situ and measuring temperature (<10°C) was made according to Gordon and Jones (1973). Fig. 7 shows the plot of underway measurements of temperature, salinity, sea surface $pCO_2$, and air $pCO_2$ during the R/V *Meteor* Cruise 22/5 in South Atlantic Ocean.

## 3.5 Secchi Disk Readings

Between December 30, 1992, and January 28, 1993, as the ship moved eastward, Secchi disk readings were made during daylight hours when the opportunity arose. These data are given in Table 6.

**Table 6. Secchi Disk readings made during R/V *Meteor* Cruise 22/5**

| Date | Local time | Latitude (°S) | Longitude (−°W, +°E) | Conditions | Depth (m) |
|---|---|---|---|---|---|
| 12/30/1992 | 15:30 | 27°55′ | −46°40′ | clear | 25 |
| 12/31/1992 | 12:00 | 28°05′ | −45°56′ | clear | 30 |
| 01/01/1993 | 17:00 | 28°50′ | −43°35′ | cloudy | 19 |
| 01/03/1993 | 12:30 | 30°00′ | −40°00′ | cloudy | 26 |
| 01/05/1993 | 15:30 | 30°00′ | −36°10′ | clear | 33 |
| 01/06/1993 | 13:00 | 30°00′ | −34°00′ | partly cloudy | 30 |
| 01/07/1993 | 13:00 | 30°00′ | −32°00′ | hazy | 19 |
| 01/09/1993 | 16:00 | 30°00′ | −27°00′ | hazy | 29 |
| 01/15/1993 | 18:00 | 30°00′ | −13°40′ | clear | 31 |
| 01/16/1993 | 13:00 | 30°00′ | −11°40′ | clear | 42 |
| 01/18/1993 | 13:00 | 30°00′ | −07°00′ | clear | 42 |
| 01/20/1993 | 13:00 | 30°00′ | −01°00′ | clear | 37 |
| 01/23/1993 | 16:30 | 29°45′ | 05°06′ | sunny | 32 |
| 01/28/1993 | 14:00 | 28°37′ | 14°41′ | sunny | 17 |
| 01/28/1993 | 17:00 | 28°30′ | 15°00′ | sunny | 7 |

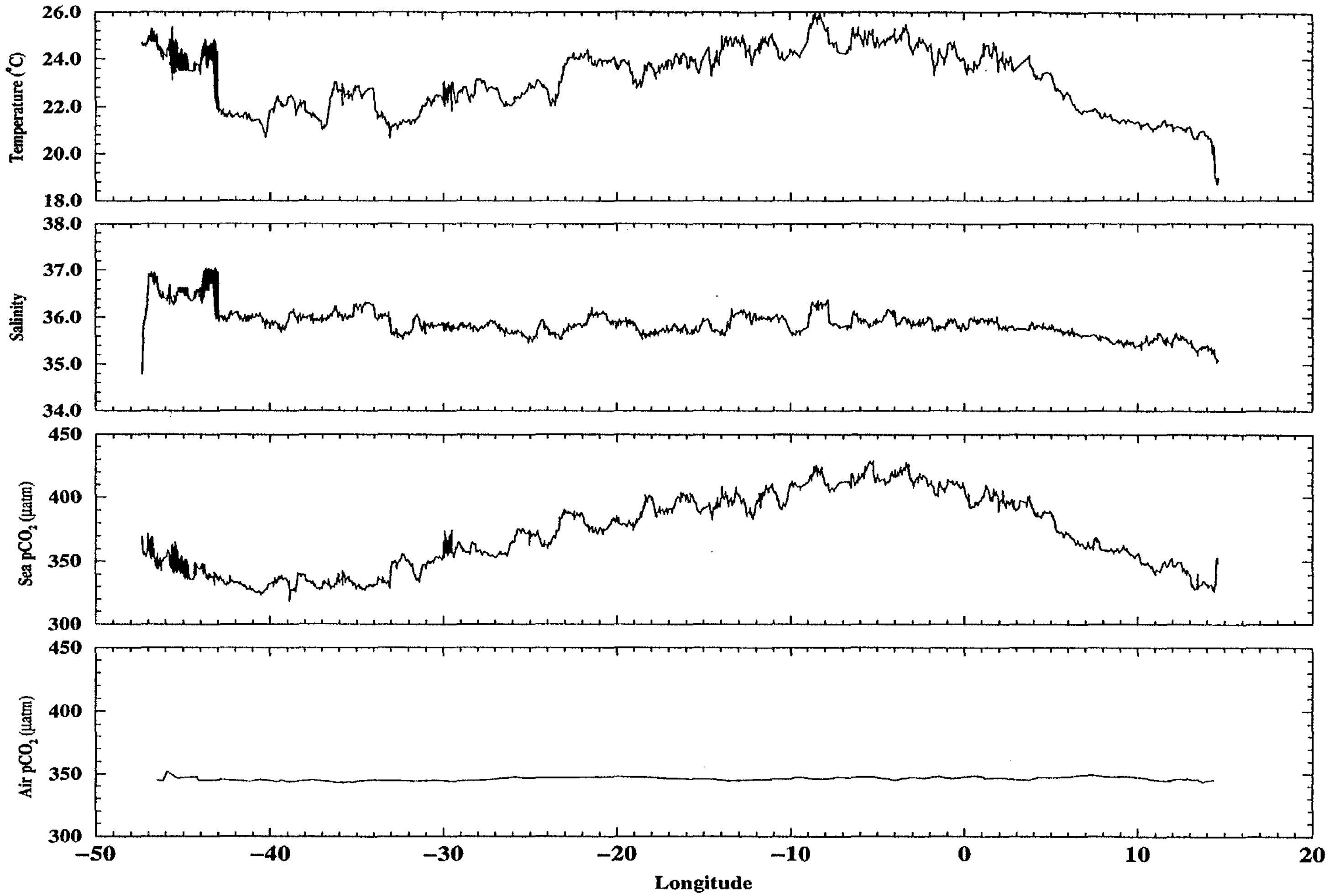


**Figure 7. Plot of underway measurements of temperature, salinity, sea surface $pCO_2$, and air $pCO_2$ during R/V *Meteor* Cruise 22/5.**

# 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 information summarizes the data-processing and QA checks performed by CDIAC on the data obtained during the R/V *Meteor* Cruise 22/5 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 (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. 8, 9).

3. To identify "noisy" data and possible systematic, methodological errors, property-property plots for all parameters were generated (Fig. 10), 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 < 1992 or > 1993; TIME < 0000 or > 2400; LAT < –25.000 or > 17.000; and LONG < –60.000 or > 20.000).

6. Station locations (latitudes and longitudes) and sampling times were examined for consistency with maps and 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.

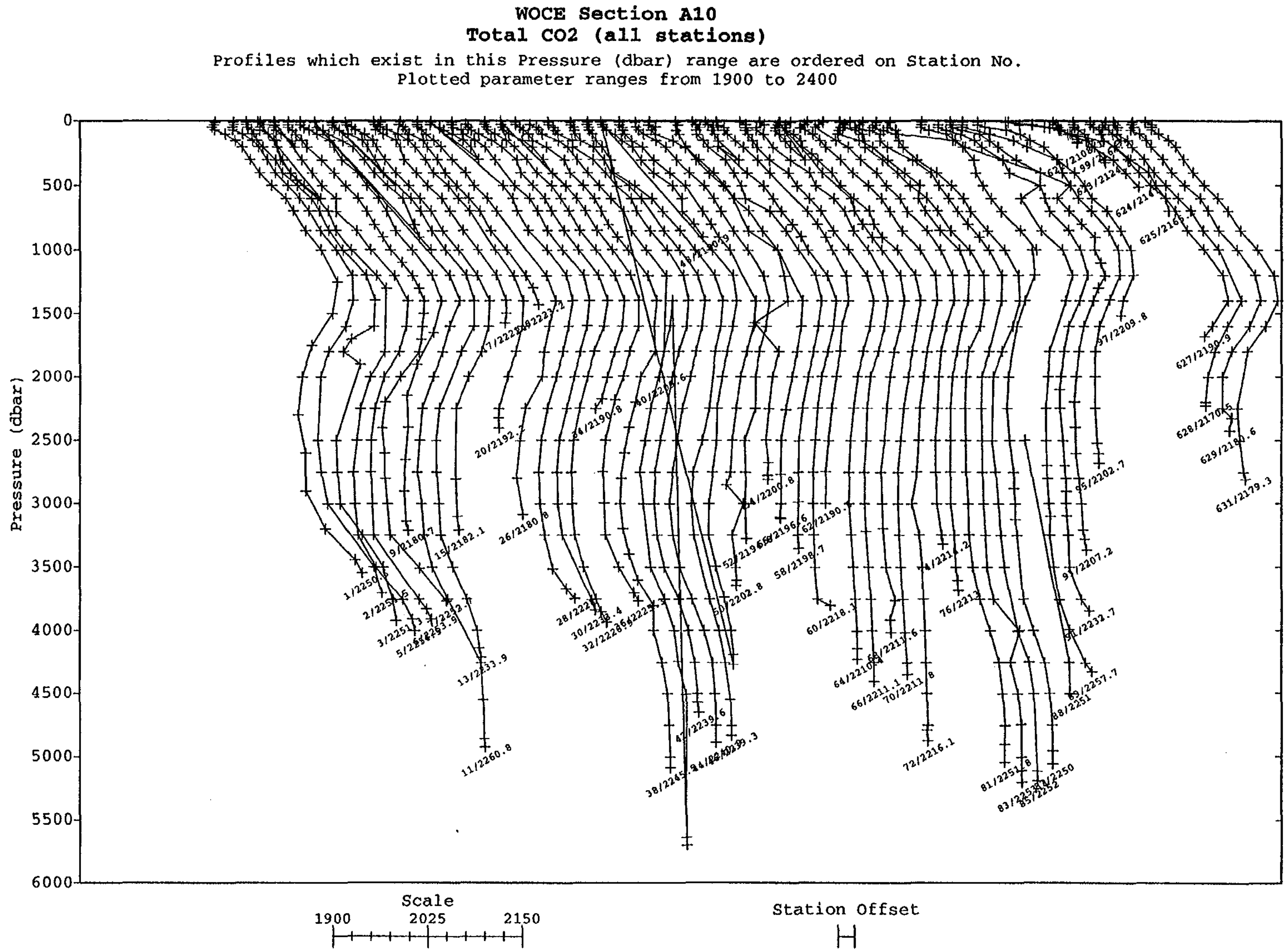


**Figure 8. Nested profiles: total carbon dioxide ($\mu$mol/kg) vs pressure for all stations of WOCE Section A10.**

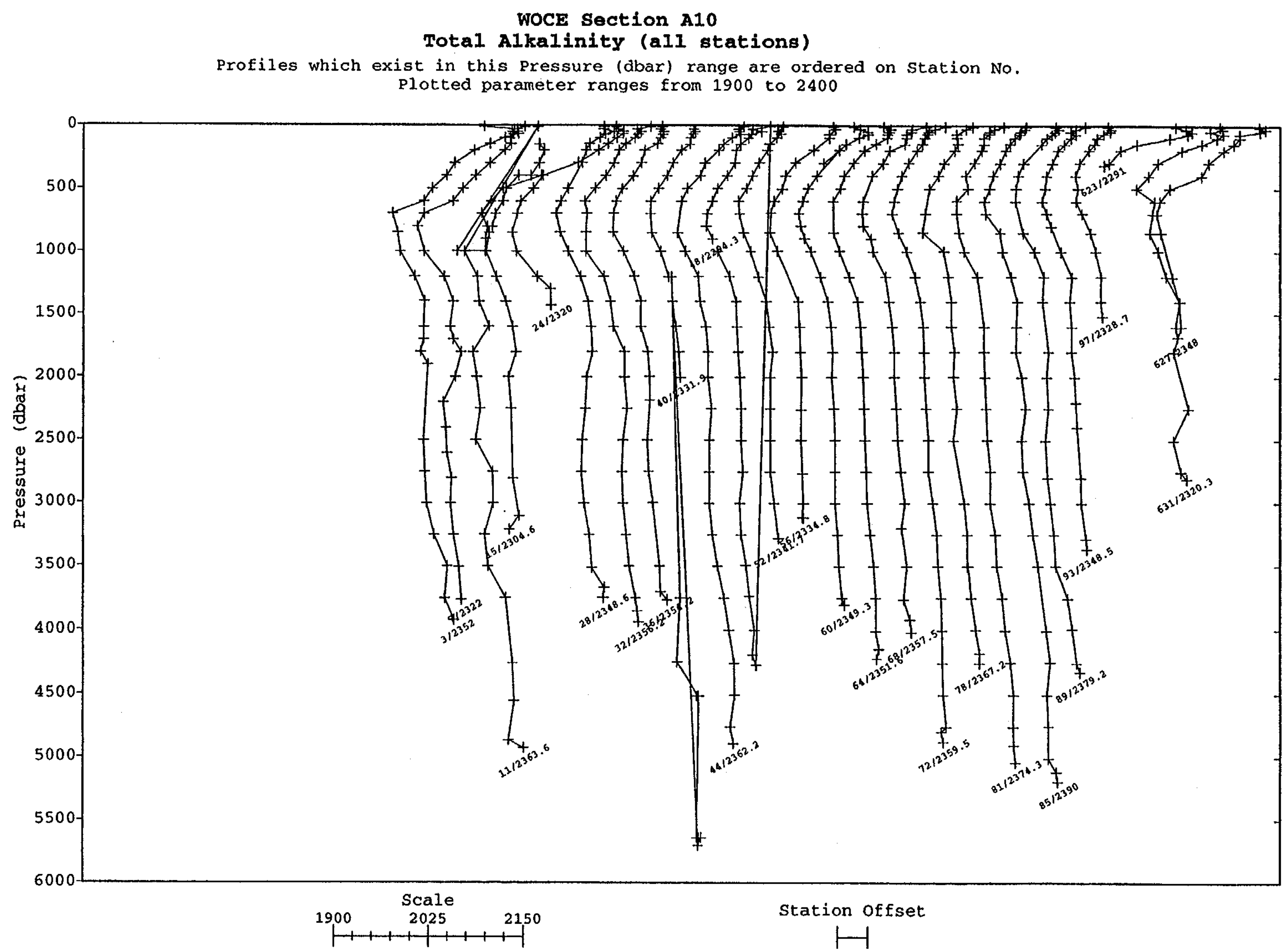


**Figure 9.** Nested profiles: total alkalinity ($\mu$mol/kg) vs pressure for all stations of WOCE Section A10.

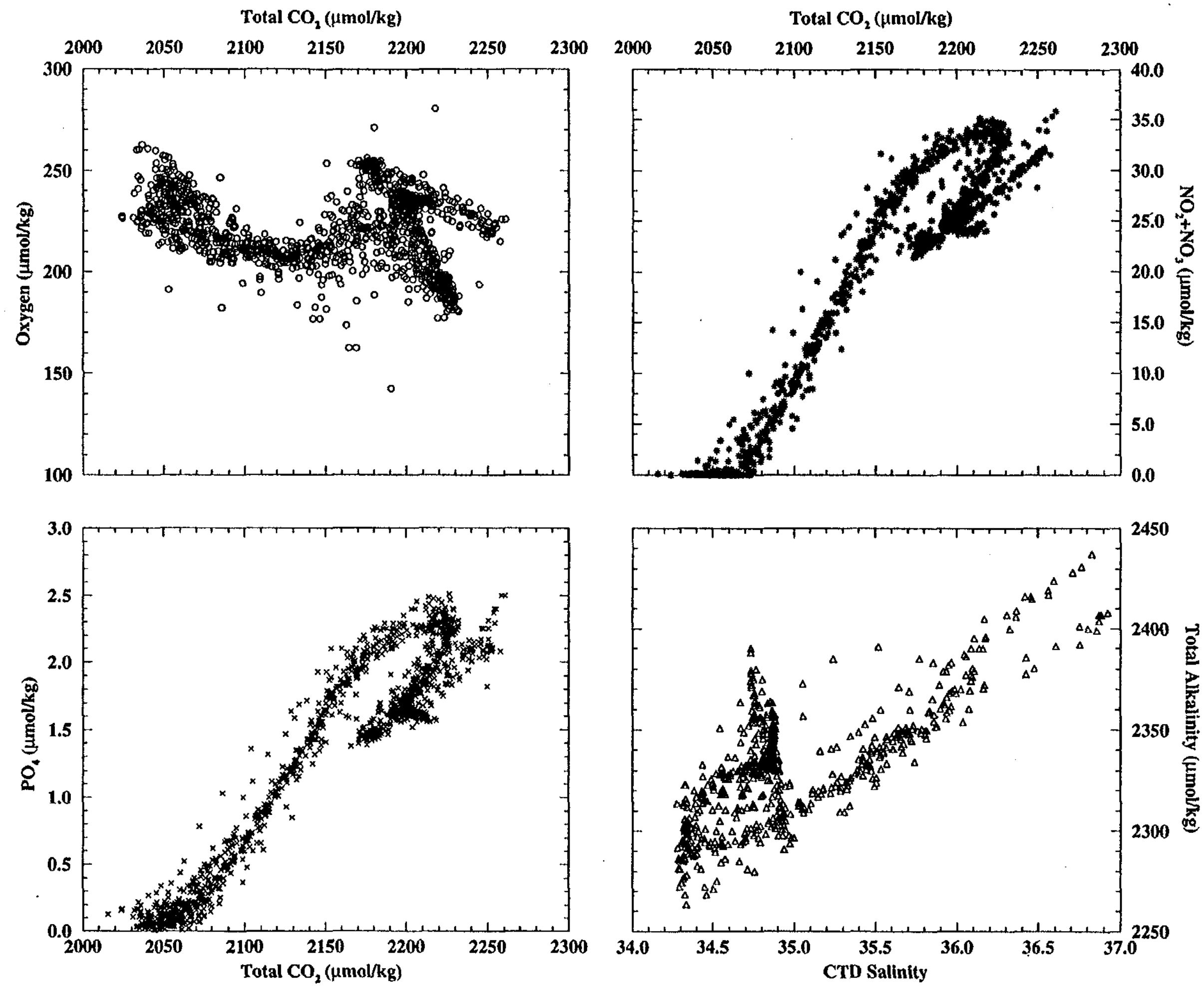


**Figure 10. Property-property plots for all stations occupied during R/V *Meteor* Cruise 22/5.**

# 5. HOW TO OBTAIN THE DATA AND DOCUMENTATION

This database (NDP-066) 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). Commands used to obtain the database are

```
>ftp cdiac.esd.ornl.gov  or  >ftp 128.219.24.36
Login: anonymous or ftp
Password: YOU@your internet address
Guest login ok, access restrictions apply.
ftp> cd pub/ndp066/
ftp> dir
ftp> mget (files)
ftp> quit
```

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

For non-FTP data acquisitions (e.g., floppy diskette, 8-mm tape, CD-ROM, etc.), users may order through CDIAC's online ordering system (http://cdiac.esd.ornl.gov/pns/how_order.html) or contact CDIAC directly to request the data and 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
URL: 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 seven files that comprise this NDP (see Table 7). Because CDIAC distributes the data set in several ways (e.g., via anonymous FTP and on floppy diskette), each of the seven files is referenced by both an ASCII file name, which is given in lower-case, bold-faced type (e.g., **ndp066.txt**) and a file number. The remainder of this section describes (or lists, where appropriate) the contents of each file.

**Table 7. Content, size, and format of data files**

| File number, name, and description | Logical records | File size in bytes |
|---|---|---|
| 1. **ndp066.txt**: a detailed description of the cruise network, the three FORTRAN 77 data-retrieval routines, and the three oceanographic data files | 1,836 | 115,581 |
| 2. **stainv.for**: a FORTRAN 77 data-retrieval routine to read and print **a10sta.txt** (File 5) | 45 | 1,342 |
| 3. **a10dat.for:** a FORTRAN 77 data-retrieval routine to read and print **a10dat.txt** (File 6) | 55 | 2,075 |
| 4. **a10pco2.for**: a FORTRAN 77 data retrieval routine to read and print **a10pco2.txt** (File 7) | 49 | 1,743 |
| 5. **a10sta.txt**: a listing of the station locations, sampling dates, and sounding bottom depths for each of the 112 stations | 196 | 14,850 |
| 6. **a10dat.txt:** hydrographic, carbon dioxide, and chemical data from 112 stations | 3,422 | 522,873 |

**Table 7. (continued)**

| File number, name, and description | Logical records | File size in bytes |
|---|---|---|
| 7. **a10pco2.txt:** underway measurements of $pCO_2$ along the cruise track | 2,822 | 304,320 |
| Total | 6,425 | 962,784 |

## 7.1 ndp066.txt (File 1)

This file contains a detailed description of the data set, the three FORTRAN 77 data retrieval routines, and the three 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 77 data-retrieval routine to read and print **a10sta.txt** (File 5). 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 **a10sta.txt**.

```
c***********************************************************************
c* FORTRAN 77 data retrieval routine to read and print the file       *
c* named "a10sta.txt" (File 5).                                       *
c***********************************************************************

c*Defines variables*

       INTEGER  stat, cast, depth
       REAL latdcm, londcm
       CHARACTER expo*10, sect*9, date*10, time*4
       OPEN (unit=1, file='a10sta.txt')
       OPEN (unit=2, file='a10stat.txt')
       write (2, 5)

c*Writes out column labels*

 5     format (1X, 'STATION INVENTORY: R/V Meteor Cruise 22/5',/,
     1 1X,'EXPOCODE',3X,'SECT',1X,'STNBR',2X,'CAST',9X,
     2 'DATE',2X,'TIME',2X,'LATITUDE',2X,'LONGITUDE',2X,
     3 'DEPTH',/)
```

```
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) expo, sect, stat, cast, date, time,
     1 latdcm, londcm, depth

 10    format (A9, 4X, A3, 3X, I3, 5X, I1, 3X, A10, 2X, A4, 3X,
     1 F7.3, 3X, F8.3, 3X, I4)

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

 20    format (A9, 4X, A3, 3X, I3, 5X, I1, 3X, A10, 2X, A4, 3X,
     1 F7.3, 3X, F8.3, 3X, I4)

       GOTO 7
 999   close(unit=5)
       close(unit=2)
       stop
       end
```

## 7.3 a10dat.for (File 3)

This file contains a FORTRAN 77 data retrieval routine to read and print **a10dat.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 **a10dat.txt**.

```
c*********************************************************************
c* FORTRAN 77 data retrieval routine to read and print the file     *
c* named "a10dat.txt" (File 6).                                      *
c*********************************************************************
       CHARACTER qualt*11
       INTEGER sta, cast, bot, pre, som
       REAL ctdtmp, ctdsal, theta, sal, oxy, silca
       REAL phspht, nitr, cfc11, cfc12, tcarb, talk
       OPEN (unit=1, file='a10dat.txt')
       OPEN (unit=2, file='a10data.txt')
       write (2, 5)

c*Writes out column labels*

 5     format (2X,'STNNBR',2X,'CASTNO',2X,'BTLNBR',2X,
     1 'CTDPRS',2X,'CTDTMP',2X,'CTDSAL',3X,'THETA',4X,
     2 'SALNTY',2X,'OXYGEN',2X,'SILCAT',2X,'PHSPHT',1X,
     3 'NO2+NO3',3X,'CFC-11',3X,'CFC-12',2X,'TCARBN',1X,
     4 'SOMMA#',2X,'ALKALI', 8X,'QUALT',/,
     5 28X,'DBAR',2X,'ITS-90',2X,'PSS-78',2X,'ITS-90',
     6 4X,'PSS-78',1X,4('UMOL/KG',1X),1X,'PMOL/KG',2X,'PMOL/KG',
     7 1X,'UMOL/KG',8X,'UMOL/KG',12X,'*',/,
     8 17X,'*******',17X,'*******',11X,5('*******',1X),1X,
     9 '*******',2X,2('*******',1X),7X,'*******'12X,'*')

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, bot, pre, ctdtmp,
     1 ctdsal, theta, sal, oxy, silca, phspht, nitr,
     2 cfc11, cfc12, tcarb, som, talk, qualt

 10   format (5X, I3, 7X, I1, 5X, I3, 4X, I4, 1X, F7.4,
     1 1X, F7.4, 1X, F7.4, 1X, F9.4, 1X, F7.1, 1X, F7.2,
     2 1X, F7.2, 1X, F7.2, 1X, F8.3, 1X, F8.3, 1X, F7.1,
     3 5X, I2, 1X, F7.1, 2X, A11)

      write (2, 20) sta, cast, bot, pre, ctdtmp,
     1 ctdsal, theta, sal, oxy, silca, phspht, nitr,
     2 cfc11, cfc12, tcarb, som, talk, qualt

 20   format (5X, I3, 7X, I1, 5X, I3, 4X, I4, 1X, F7.4,
     1 1X, F7.4, 1X, F7.4, 1X, F9.4, 1X, F7.1, 1X, F7.2,
     2 1X, F7.2, 1X, F7.2, 1X, F8.3, 1X, F8.3, 1X, F7.1,
     3 5X, I2, 1X, F7.1, 2X, A11)

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

## 7.4 a10pco2.for (File 4)

This file contains a FORTRAN 77 data retrieval routine to read and print **a10pco2.txt** (File 7). 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 **a10pco2.txt**.

```
c*****************************************************************
c* FORTRAN 77 data retrieval routine to read and print the file    *
c* named "a10pco2.txt" (File 7).                                   *
c*****************************************************************

c*Defines variables*

      REAL jday, latdcm, londcm, sst, salt, airpre, airxco2
      REAL airpco2, waterpco2
      CHARACTER sect*3, date*10, time*5
      OPEN (unit=1, file='a10pco2.txt')
      OPEN (unit=2, file='a10pco2.dat')
      write (2, 5)

c*Writes out column labels*

 5    format (2X,'UNDERWAY MEASUREMENTS R/V METEOR CRUISE 22/5',/,
     1 2X,'SECT',9X,'DATE',4X,'TIME',5X,'JULIAN',3X,'LATIT',2X,
     2 'LONGIT',3X,'SSTMP',2X,'SALNTY',2X,'ATMPRS',4X,'XCO2',5X,
     3 'PCO2AIR',1X,'PCO2WATER',/,8X,'DAY/MO/YEAR',5X,'GMT',7X,
     4 'DATE',5X,'DCM',5X,'DCM',3X,'DEG_C',5X,'PSS',4X,'ATM',2X,
     5 'DRY_AIR_PPM',3X,'UATM',6X,'UATM',/)

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, date, time, jday, latdcm, londcm,
     1 sst, salt, airpre, airxco2, airpco2, waterpco2

10    format (3X, A3, 3X, A10, 3X, A5, 2X, F9.3, 1X, F7.2, 1X,
     1 F7.2, 1X, F7.2, 1X, F7.2, 1X, F7.1, 2X, F7.2, 3X, F7.1,
     2 3X, F7.1)

      write (2, 20) sect, date, time, jday, latdcm, londcm, sst,
     1 salt, airpre, airxco2, airpco2, waterpco2

20    format (3X, A3, 3X, A10, 3X, A5, 2X, F9.3, 1X, F7.2, 1X,
     1 F7.2, 1X, F7.2, 1X, F7.2, 1X, F7.1, 2X, F7.2, 3X, F7.1,
     2 3X, F7.1)

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

## 7.5 a10sta.txt (File 5)

This file provides station inventory information for each of the 112 stations occupied during R/V *Meteor* Cruise 22/5. 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 77 code (contained in **stainv.for**, File 2):

```
      INTEGER stat, cast, depth
      CHARACTER expo*10, 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 (A9, 4X, A3, 3X, 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 | 10 | 1 | 10 |
| **sect** | Character | 3 | 14 | 16 |
| **stat** | Numeric | 3 | 20 | 22 |
| **cast** | Numeric | 1 | 28 | 28 |
| **date** | Character | 10 | 32 | 41 |
| **time** | Character | 4 | 44 | 47 |
| **latdcm** | Numeric | 7 | 51 | 57 |
| **londcm** | Numeric | 8 | 61 | 68 |
| **depth** | Numeric | 4 | 72 | 75 |

The variables are defined as follows:

**expo** is the expocode 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).

## 7.6 a10dat.txt (File 6)

This file provides hydrographic, carbon dioxide, and chemical data for the 112 stations occupied during R/V *Meteor* Cruise 22/5. Each line consists of a station number, cast number, bottle number, CTD pressure, CTD temperature, CTD salinity, potential temperature, bottle salinity, oxygen, silicate, phosphate, nitrate plus nitrite, CFC-11, CFC-12, total $CO_2$, SOMMA number, total alkalinity, 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 **10dat.for,** File 3):

```
      CHARACTER qualt*11
      INTEGER sta, cast, bot, pre, som
      REAL ctdtmp, ctdsal, theta, sal, oxy, silca
      REAL phspht, nitr, cfc11, cfc12, tcarb, talk

      read (1, 10, end=999) sta, cast, bot, pre, ctdtmp,
     1 ctdsal, theta, sal, oxy, silca, phspht, nitr,
     2 cfc11, cfc12, tcarb, som, talk, qualt

 10   format (5X, I3, 7X, I1, 5X, I3, 4X, I4, 1X, F7.4,
     1 1X, F7.4, 1X, F7.4, 1X, F9.4, 1X, F7.1, 1X, F7.2,
     2 1X, F7.2, 1X, F7.2, 1X, F8.3, 1X, F8.3, 1X, F7.1,
     3 5X, I2, 1X, F7.1, 2X, A11)
```

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 |
| **bot** | Numeric | 3 | 22 | 24 |
| **pre** | Numeric | 4 | 29 | 32 |
| **ctdtmp** | Numeric | 7 | 34 | 40 |
| **ctdsal** | Numeric | 7 | 42 | 48 |
| **theta** | Numeric | 7 | 50 | 56 |
| **sal** | Numeric | 9 | 58 | 66 |
| **oxy** | Numeric | 7 | 68 | 74 |
| **silca** | Numeric | 7 | 76 | 82 |
| **phspht** | Numeric | 7 | 84 | 90 |
| **nitr** | Numeric | 7 | 92 | 98 |
| **cfc11** | Numeric | 8 | 100 | 107 |
| **cfc12** | Numeric | 8 | 109 | 116 |
| **tcarb** | Numeric | 7 | 118 | 124 |
| **som** | Numeric | 2 | 130 | 131 |
| **talk** | Numeric | 7 | 133 | 139 |
| **qualt** | Character | 11 | 142 | 152 |

The variables defined as follows:

**sta** is the station number;

**cast** is the cast number;

**bot**[a] is the bottle number;

**pre** is the CTD pressure (in dbar);

**ctdtmp** is the CTD temperature (in °C);

**ctdsal**[a] is the CTD salinity [on the Practical Salinity Scale (PSS)];

**theta** is the potential temperature (in °C);

**sal**[a] is the bottle salinity (on the PSS);

**oxy**[a] is the oxygen concentration (in μmol/kg);

**silca**[a] is the silicate concentration (in μmol/kg);

**phspht**[a] is the phosphate concentration (in μmol/kg);

**nitr**[a] is the nitrate plus nitrite concentration (in μmol/kg);

**cfc11**[a] is the trichlorofluoromethane-11 concentration ($CCl_3F$) (in pmol/kg);

**cfc12**[a] is the dichlorodifluoromethane-12 concentration ($CCl_2F_2$) (in pmol/kg);

**tcarb**[a] is the total carbon dioxide concentration (in μmol/kg);

**som** is the SOMMA number;

**talk** is the total alkalinity concentration (in μmol/kg);

**qualt** is a 11-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.

## 7.7 a10pco2.txt (File 7)

This file provides underway measurements of $pCO_2$ during R/V *Meteor* Cruise 22/5. Each line of the file contains a sampling date (month/date/year), latitude, longitude, underway measurements of sea surface temperature, salinity, air $pCO_2$, and water $pCO_2$. The file is sorted by longitude and can be read by using the following FORTRAN 77 code (contained in **a10pco2.for**, File 4):

```
      REAL jday, latdcm, londcm, sst, salt, airpre, airxco2
      REAL airpco2, waterpco2
      CHARACTER sect*3, date*10, time*5

      read (1, 10, end=999) sect, date, time, jul, latdcm, londcm,
     1 sst, salt, pre, xco2, pco2a, pco2w

 10   format (3X, A3, 3X, A10, 3X, A5, 2X, F9.3, 1X, F7.2, 1X,
     1 F7.2, 1X, F7.2, 1X, F7.2, 1X, F7.1, 2X, F7.2, 3X, F7.1,
     2 3X, F7.1)
```

Stated in tabular form, the contents include the following:

| Variable | Variable type | Variable width | Starting column | Ending column |
|---|---|---|---|---|
| **sect** | Character | 3 | 4 | 6 |
| **date** | Character | 10 | 10 | 19 |
| **time** | Character | 5 | 23 | 27 |
| **jday** | Numeric | 9 | 30 | 38 |
| **latdcm** | Numeric | 7 | 40 | 46 |
| **londcm** | Numeric | 7 | 48 | 54 |
| **sst** | Numeric | 7 | 56 | 62 |
| **salt** | Numeric | 7 | 64 | 70 |
| **airpre** | Numeric | 7 | 72 | 78 |
| **airxco2** | Numeric | 7 | 81 | 87 |
| **airpco2** | Numeric | 7 | 91 | 97 |
| **waterpco2** | Numeric | 7 | 101 | 107 |

The variables are defined as follows:

**sect** is the WOCE Section number;

**date** is the sampling date (day/month/year);

**time** is the sampling time (GMT);

| | |
|---|---|
| **jday** | is the julian day of the century relative to 1900 with time of the day represented as a fractional day (i.e., noon on 1/1/1900 = 0.5); |
| **latdcm** | is the latitude of the sampling (in decimal degrees; negative values indicate the Southern Hemisphere); |
| **londcm** | is the longitude of the sampling (in decimal degrees; negative values indicate the Western Hemisphere); |
| **sst** | is the sea surface temperature (in °C); |
| **salt** | is the sea surface salinity (on the PSS); |
| **airpre** | is the atmospheric pressure (in atm); |
| **airxco2** | is the observed mole fraction of $pCO_2$ in air [in ppm (dry air)]; |
| **airpco2** | is the air $pCO_2$ (in $\mu$atm); |
| **waterpco2** | is the sea surface water $pCO_2$ (in $\mu$atm). |

# 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 8, 9, and 10. Each of these tables contains the first and last twenty five lines of a data file.

**Table 8. Partial listing of a10sta.txt (File 5)**

*First twenty-five lines of the file:*

```
****************************************************************************
*  Source: K. Johnson                         B. Schneider                 *
*          D. Wallace                   Baltic Sea Research Institute      *
*                                            Warnemunde, Germany           *
*  Brookhaven National Laboratory                                          *
*      Apton, New York, USA                   L. Mintrop                   *
*                                       Institute for Marine Sciences      *
*  CDIAC NDP-066, September 1998              Kiel, Germany                *
****************************************************************************
*STATION INVENTORY: R/V METEOR
*EXPOCODE   SECT STNBR  CAST       DATE  TIME  LATITUDE  LONGITUDE  DEPTH
 06MT22/5    A10   620     1 12/28/1992  1506   -25.645    -42.175   2290
 06MT22/5    A10   622     1 12/30/1992  0626   -27.730    -47.385    177
 06MT22/5    A10   623     1 12/30/1992  0914   -27.774    -47.207    326
 06MT22/5    A10   624     1 12/30/1992  1129   -27.816    -47.026    536
 06MT22/5    A10   625     1 12/30/1992  1348   -27.860    -46.847    758
 06MT22/5    A10   626     1 12/30/1992  1755   -27.905    -46.670   1250
 06MT22/5    A10   627     1 12/30/1992  2212   -27.950    -46.485   1693
 06MT22/5    A10   628     1 12/31/1992  0224   -27.992    -46.308   2217
 06MT22/5    A10   629     1 12/31/1992  0650   -28.039    -46.129   2408
 06MT22/5    A10   630     1 12/31/1992  1140   -28.088    -45.939   2596
 06MT22/5    A10   631     1 12/31/1992  1712   -28.153    -45.674   2782
 06MT22/5    A10   632     1 12/31/1992  2240   -28.224    -45.408   2965
 06MT22/5    A10     1     2 01/01/1993  0726   -28.418    -44.768   3509
 06MT22/5    A10     2     1 01/01/1993  1315   -28.615    -44.222   3694
```

*Last twenty-five lines of the file:*

```
 06MT22/5    A10    85     2 01/24/1993  1622   -29.746      7.621   5200
 06MT22/5    A10    85     3 01/24/1993  1816   -29.736      7.627   5203
 06MT22/5    A10    86     1 01/25/1993  0110   -29.746      8.465   5091
 06MT22/5    A10    86     2 01/25/1993  0247   -29.744      8.465   5086
 06MT22/5    A10    87     2 01/25/1993  1036   -29.750      9.297   5032
 06MT22/5    A10    87     3 01/25/1993  1235   -29.755      9.307   4986
 06MT22/5    A10    88     1 01/25/1993  1925   -29.748     10.148   4900
 06MT22/5    A10    88     2 01/25/1993  2141   -29.747     10.185   4853
 06MT22/5    A10    89     2 01/26/1993  0527   -29.749     10.980   4296
 06MT22/5    A10    89     3 01/26/1993  0700   -29.748     10.981   4271
 06MT22/5    A10    90     2 01/26/1993  1419   -29.752     11.830   4002
 06MT22/5    A10    90     3 01/26/1993  1615   -29.755     11.852   3994
 06MT22/5    A10    91     2 01/26/1993  2025   -29.622     12.171   3818
 06MT22/5    A10    91     3 01/26/1993  2150   -29.621     12.187   3812
 06MT22/5    A10    92     2 01/27/1993  0248   -29.497     12.467   3657
 06MT22/5    A10    92     3 01/27/1993  0436   -29.489     12.474   3652
 06MT22/5    A10    93     2 01/27/1993  0944   -29.373     12.795   3358
 06MT22/5    A10    93     3 01/27/1993  1104   -29.372     12.815   3341
 06MT22/5    A10    94     2 01/27/1993  1620   -29.243     13.114   3098
 06MT22/5    A10    95     2 01/27/1993  2135   -29.119     13.428   2640
 06MT22/5    A10    96     2 01/28/1993  0248   -29.001     13.735   2136
 06MT22/5    A10    97     2 01/28/1993  0645   -28.879     14.045   1490
 06MT22/5    A10    98     2 01/28/1993  0955   -28.752     14.366    461
 06MT22/5    A10    99     2 01/28/1993  1240   -28.622     14.687    160
 06MT22/5    A10   100     2 01/28/1993  1457   -28.503     14.999    174
```

# Table 9. Partial listing of a10dat.txt (File 6)

*First twenty-five lines of the file*

```
***********************************************************************
*  Source: K. Johnson                     B. Schneider                *
*           D. Wallace              Baltic Sea Research Institute     *
*                                        Warnemunde, Germany          *
*  Brookhaven National Laboratory                                     *
*      Apton, New York, USA                L. Mintrop                 *
*                                   Institute for Marine Sciences     *
*  CDIAC NDP-066, September 1998           Kiel, Germany              *
***********************************************************************
* EXPOCODE 06MT22/5             R/V METEOR 22 LEG 5   WOCE SECTION A10                                                                                *
* STNNBR  CASTNO  BTLNBR  CTDPRS  CTDTMP  CTDSAL   THETA    SALNTY  OXYGEN  SILCAT  PHSPHT NO2+NO3    CFC-11    CFC-12  TCARBN SOMMA#  ALKALI       QUALT
*                           DBAR  ITS-90  PSS-78  ITS-90    PSS-78 UMOL/KG UMOL/KG UMOL/KG UMOL/KG   PMOL/KG   PMOL/KG UMOL/KG         UMOL/KG           *
*                 *******                 *******          ******* ******* ******* ******* *******   *******   ******* *******         *******           *
     620       1     324    2271  3.0620 34.9410  2.8832   34.9400  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22299999999
     620       1     323    2271  3.0610 34.9410  2.8822   34.9400  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22299999999
     620       1     322    2270  3.0600 34.9410  2.8813   34.9380  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22299999999
     620       1     321    2270  3.0590 34.9420  2.8803   34.9370  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22299999999
     620       1     320    2270  3.0590 34.9420  2.8803   34.9370  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22299999999
     620       1     319    2270  3.0610 34.9420  2.8823   34.9370  -999.9 -999.90 -999.90 -999.90     0.019     0.180  -999.9      -9  -999.9 22299992499
     620       1     318    2269  3.0610 34.9410  2.8824   34.9380  -999.9 -999.90 -999.90 -999.90     0.055     0.273  -999.9      -9  -999.9 22299992499
     620       1     317    2269  3.0580 34.9420  2.8794   34.9400  -999.9 -999.90 -999.90 -999.90     0.221     0.228  -999.9      -9  -999.9 22299994499
     620       1     316    2268  3.0630 34.9420  2.8844   34.9400  -999.9 -999.90 -999.90 -999.90     0.009     0.161  -999.9      -9  -999.9 22299992499
     620       1     315    2268  3.0610 34.9410  2.8825   34.9400  -999.9 -999.90 -999.90 -999.90     0.032     0.040  -999.9      -9  -999.9 22299992299
     620       1     314    2268  3.0590 34.9410  2.8805   34.9380  -999.9 -999.90 -999.90 -999.90     0.009     0.095  -999.9      -9  -999.9 22299992299
     620       1     313    2267  3.0620 34.9420  2.8835   34.9400  -999.9 -999.90 -999.90 -999.90     0.016     0.113  -999.9      -9  -999.9 22299992299
```

*Last twenty-five lines of the file*

```
      99       2     315      30 17.6020 35.2190 17.5970 -999.9000   226.2    3.24    0.36    3.40  -999.900  -999.900  2054.9       1  -999.9 22922229929
      99       2     314      30 17.5930 35.2190 17.5880 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
      99       2     313      30 17.5930 35.2200 17.5880 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
      99       2     312      49 14.5570 35.2530 14.5498 -999.9000   210.0    4.75    0.67    8.74  -999.900  -999.900  2087.8       1  -999.9 22922229929
      99       2     311      49 14.5320 35.2540 14.5248 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
      99       2     310      49 14.5280 35.2560 14.5208 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
      99       2     309      70 12.7110 35.1020 12.7016 -999.9000   204.3    5.67    0.88   12.55  -999.900  -999.900  2108.5       1  -999.9 22922229929
      99       2     308      70 12.7200 35.1030 12.7106 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
      99       2     307      70 12.7170 35.1030 12.7076 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
      99       2     306     101 11.7430 34.9880 11.7301 -999.9000   200.0    7.09    1.06   15.15  -999.900  -999.900  2121.1       1  -999.9 22922229929
      99       2     305     101 11.7490 34.9890 11.7361 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
      99       2     304     100 11.7540 34.9900 11.7412 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
      99       2     303     157  9.8380 34.7720  9.8201 -999.9000   162.6   13.43    1.59   21.95  -999.900  -999.900  2164.5       1  -999.9 22922229929
      99       2     302     156  9.8350 34.7710  9.8172   34.7840  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22299999999
      99       2     301     156  9.8320 34.7710  9.8140 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
     100       2     324      13 18.3230 34.9820 18.3207 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
     100       2     315      13 18.2810 34.9810 18.2787 -999.9000   248.8    3.02    0.35    1.27  -999.900  -999.900  -999.9      -9  -999.9 22922229999
     100       2     313      30 16.7330 34.9500 16.7281 -999.9000   236.1    3.19    0.52    3.83  -999.900  -999.900  -999.9      -9  -999.9 22922229999
     100       2     311      50 14.9330 35.0500 14.9255 -999.9000   213.9    4.34    0.70    8.33  -999.900  -999.900  -999.9      -9  -999.9 22922229999
     100       2     309      70 12.3020 35.0480 12.2928 -999.9000   192.6    6.12    1.01   14.71  -999.900  -999.900  -999.9      -9  -999.9 22922229999
     100       2     307      99 10.9840 34.8930 10.9718 -999.9000   185.6    8.40    1.23   17.81  -999.900  -999.900  -999.9      -9  -999.9 22922229999
     100       2     306     100 11.0030 34.8980 10.9907 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
     100       2     304     150  9.7980 34.7740  9.7808 -999.9000   145.3   15.62    1.71   23.15  -999.900  -999.900  -999.9      -9  -999.9 22922229999
     100       2     302     160  9.7200 34.7640  9.7018 -999.9000  -999.9 -999.90 -999.90 -999.90  -999.900  -999.900  -999.9      -9  -999.9 22999999999
     100       2     301     159  9.7270 34.7640  9.7089 -999.9000   143.8   16.41    1.73   23.61  -999.900  -999.900  -999.9      -9  -999.9 22922229999
```

## Table 10. Partial listing of a10pco2.txt (File 7)

*First twenty-five lines of the file:*

```
*********************************************************************
*  Source: K. Johnson                          B. Schneider         *
*           D. Wallace                 Baltic Sea Research Institute *
*                                          Warnemunde, Germany      *
*  Brookhaven National Laboratory                                   *
*      Apton, New York, USA                    L. Mintrop           *
*                                      Institute for Marine Sciences *
*  CDIAC NDP-066, September 1998               Kiel, Germany        *
*********************************************************************
*UNDERWAY MEASUREMENTS: R/V METEOR CRUISE 22/5
*       DATE LATITUDE LONGITUDE  TEMP    SALT AIR_PCO2 WAT_PCO2
30/Dec/1992  -27.731   -47.385  24.70  34.83   -999.9    369.2
30/Dec/1992  -27.730   -47.384  24.67  34.83   -999.9    365.3
30/Dec/1992  -27.731   -47.384  24.67  34.84   -999.9    368.6
30/Dec/1992  -27.728   -47.383  24.68  34.82   -999.9    363.3
30/Dec/1992  -27.727   -47.383  24.69  34.78   -999.9    363.0
30/Dec/1992  -27.739   -47.342  24.59  35.19   -999.9    364.9
30/Dec/1992  -27.747   -47.311  24.61  35.45   -999.9    357.2
30/Dec/1992  -27.755   -47.280  24.61  35.68   -999.9    356.2
30/Dec/1992  -27.763   -47.249  24.56  35.94   -999.9    354.9
30/Dec/1992  -27.771   -47.218  24.66  35.88   -999.9    357.1
30/Dec/1992  -27.778   -47.185  24.61  35.99   -999.9    355.2
30/Dec/1992  -27.787   -47.153  24.54  36.19   -999.9    353.8
30/Dec/1992  -27.795   -47.123  24.67  36.10   -999.9    356.0
30/Dec/1992  -27.805   -47.092  24.64  36.43   -999.9    356.3
```

*Last twenty-five lines of the file:*

```
28/Jan/1993  -28.910    13.980  20.78  35.41   -999.9    331.9
28/Jan/1993  -28.890    14.010  20.77  35.38   -999.9    331.0
28/Jan/1993  -28.890    14.030  20.76  35.38   -999.9    329.4
28/Jan/1993  -28.880    14.040  20.76  35.39   -999.9    329.6
28/Jan/1993  -28.880    14.050  20.76  35.36    344.8   -999.9
28/Jan/1993  -28.890    14.050  20.76  35.34   -999.9    331.7
28/Jan/1993  -28.880    14.060  20.64  35.32   -999.9    331.4
28/Jan/1993  -28.870    14.090  20.62  35.35   -999.9    331.4
28/Jan/1993  -28.860    14.120  20.62  35.34   -999.9    330.5
28/Jan/1993  -28.840    14.150  20.66  35.32   -999.9    331.3
28/Jan/1993  -28.830    14.180  20.65  35.34   -999.9    331.5
28/Jan/1993  -28.810    14.210  20.61  35.36   -999.9    331.6
28/Jan/1993  -28.800    14.240  20.35  35.25   -999.9    330.3
28/Jan/1993  -28.790    14.270  20.16  35.31   -999.9    329.6
28/Jan/1993  -28.770    14.300  19.97  35.27   -999.9    327.6
28/Jan/1993  -28.760    14.330  20.34  35.26   -999.9    330.3
28/Jan/1993  -28.760    14.350  20.35  35.24   -999.9    329.9
28/Jan/1993  -28.750    14.380  20.21  35.34    345.2   -999.9
28/Jan/1993  -28.740    14.400  19.70  35.28   -999.9    327.5
28/Jan/1993  -28.730    14.430  19.94  35.21   -999.9    330.6
28/Jan/1993  -28.710    14.460  19.06  35.14   -999.9    331.7
28/Jan/1993  -28.700    14.500  18.87  35.12   -999.9    346.5
28/Jan/1993  -28.690    14.530  18.71  35.06   -999.9    350.6
28/Jan/1993  -28.680    14.560  18.69  35.10   -999.9    352.9
28/Jan/1993  -28.660    14.580  18.76  35.09   -999.9    352.6
```

# APPENDIX A:

# STATION INVENTORY

# APPENDIX A:
# STATION INVENTORY

This appendix lists station inventory information for the 112 sites occupied during R/V *Meteor* Cruise 22/5 in the South Atlantic Ocean. The meanings of the column headings in Table A-1 are as follows.

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

## Table A.1 Station inventory information for the 112 sites occupied during R/V *Meteor* Cruise 22/5

```
***************************************************************************
*  Source: K. Johnson                          B. Schneider               *
*          D. Wallace                   Baltic Sea Research Institute     *
*                                            Warnemunde, Germany          *
*  Brookhaven National Laboratory                                         *
*      Apton, New York, USA                    L. Mintrop                 *
*                                       Institute for Marine Sciences     *
*  CDIAC NDP-066, September 1998               Kiel, Germany              *
***************************************************************************
```

*STATION INVENTORY: R/V METEOR

| *EXPOCODE | SECT | STNBR | CAST | DATE | TIME | LATITUDE | LONGITUDE | DEPTH |
|---|---|---|---|---|---|---|---|---|
| 06MT22/5 | A10 | 620 | 1 | 12/28/1992 | 1506 | -25.645 | -42.175 | 2290 |
| 06MT22/5 | A10 | 622 | 1 | 12/30/1992 | 0626 | -27.730 | -47.385 | 177 |
| 06MT22/5 | A10 | 623 | 1 | 12/30/1992 | 0914 | -27.774 | -47.207 | 326 |
| 06MT22/5 | A10 | 624 | 1 | 12/30/1992 | 1129 | -27.816 | -47.026 | 536 |
| 06MT22/5 | A10 | 625 | 1 | 12/30/1992 | 1348 | -27.860 | -46.847 | 758 |
| 06MT22/5 | A10 | 626 | 1 | 12/30/1992 | 1755 | -27.905 | -46.670 | 1250 |
| 06MT22/5 | A10 | 627 | 1 | 12/30/1992 | 2212 | -27.950 | -46.485 | 1693 |
| 06MT22/5 | A10 | 628 | 1 | 12/31/1992 | 0224 | -27.992 | -46.308 | 2217 |
| 06MT22/5 | A10 | 629 | 1 | 12/31/1992 | 0650 | -28.039 | -46.129 | 2408 |
| 06MT22/5 | A10 | 630 | 1 | 12/31/1992 | 1140 | -28.088 | -45.939 | 2596 |
| 06MT22/5 | A10 | 631 | 1 | 12/31/1992 | 1712 | -28.153 | -45.674 | 2782 |
| 06MT22/5 | A10 | 632 | 1 | 12/31/1992 | 2240 | -28.224 | -45.408 | 2965 |
| 06MT22/5 | A10 | 1 | 2 | 01/01/1993 | 0726 | -28.418 | -44.768 | 3509 |
| 06MT22/5 | A10 | 2 | 1 | 01/01/1993 | 1315 | -28.615 | -44.222 | 3694 |
| 06MT22/5 | A10 | 3 | 1 | 01/01/1993 | 1902 | -28.833 | -43.585 | 3897 |
| 06MT22/5 | A10 | 3 | 2 | 01/01/1993 | 2032 | -28.833 | -43.588 | 3882 |
| 06MT22/5 | A10 | 4 | 2 | 01/02/1993 | 0315 | -29.036 | -42.910 | 4009 |
| 06MT22/5 | A10 | 4 | 3 | 01/02/1993 | 0432 | -29.031 | -42.909 | 4009 |
| 06MT22/5 | A10 | 5 | 2 | 01/02/1993 | 1015 | -29.232 | -42.329 | 4001 |
| 06MT22/5 | A10 | 5 | 3 | 01/02/1993 | 1150 | -29.228 | -42.332 | 4000 |
| 06MT22/5 | A10 | 6 | 2 | 01/02/1993 | 1720 | -29.422 | -41.737 | 3874 |
| 06MT22/5 | A10 | 6 | 3 | 01/02/1993 | 1836 | -29.413 | -41.731 | 3847 |
| 06MT22/5 | A10 | 7 | 2 | 01/03/1993 | 0013 | -29.604 | -41.158 | 3782 |
| 06MT22/5 | A10 | 7 | 3 | 01/03/1993 | 0142 | -29.596 | -41.157 | 3792 |
| 06MT22/5 | A10 | 8 | 2 | 01/03/1993 | 0723 | -29.807 | -40.587 | 3786 |
| 06MT22/5 | A10 | 8 | 3 | 01/03/1993 | 0858 | -29.802 | -40.586 | 3781 |
| 06MT22/5 | A10 | 9 | 2 | 01/03/1993 | 1450 | -30.006 | -39.998 | 3187 |
| 06MT22/5 | A10 | 10 | 1 | 01/03/1993 | 1902 | -30.003 | -39.530 | 3972 |
| 06MT22/5 | A10 | 10 | 2 | 01/03/1993 | 2041 | -30.002 | -39.528 | 4017 |
| 06MT22/5 | A10 | 11 | 2 | 01/04/1993 | 0048 | -29.998 | -39.381 | 4902 |
| 06MT22/5 | A10 | 11 | 3 | 01/04/1993 | 0245 | -30.002 | -39.377 | 4901 |
| 06MT22/5 | A10 | 12 | 1 | 01/04/1993 | 0712 | -30.004 | -38.917 | 4282 |
| 06MT22/5 | A10 | 12 | 2 | 01/04/1993 | 0913 | -30.010 | -38.917 | 4277 |
| 06MT22/5 | A10 | 13 | 2 | 01/04/1993 | 1333 | -30.004 | -38.494 | 4226 |
| 06MT22/5 | A10 | 13 | 3 | 01/04/1993 | 1503 | -30.015 | -38.490 | 4203 |
| 06MT22/5 | A10 | 14 | 1 | 01/04/1993 | 1916 | -30.003 | -38.003 | 3856 |
| 06MT22/5 | A10 | 14 | 2 | 01/04/1993 | 2037 | -30.005 | -38.008 | 3868 |
| 06MT22/5 | A10 | 15 | 1 | 01/05/1993 | 0155 | -29.999 | -37.500 | 3204 |
| 06MT22/5 | A10 | 16 | 1 | 01/05/1993 | 0550 | -30.002 | -37.169 | 2334 |
| 06MT22/5 | A10 | 17 | 2 | 01/05/1993 | 0943 | -30.005 | -36.824 | 1573 |
| 06MT22/5 | A10 | 18 | 1 | 01/05/1993 | 1300 | -30.006 | -36.500 | 1803 |
| 06MT22/5 | A10 | 19 | 2 | 01/05/1993 | 1610 | -30.000 | -36.163 | 1268 |
| 06MT22/5 | A10 | 20 | 1 | 01/05/1993 | 1926 | -30.004 | -35.836 | 2380 |
| 06MT22/5 | A10 | 21 | 2 | 01/05/1993 | 2328 | -30.004 | -35.485 | 2325 |
| 06MT22/5 | A10 | 22 | 1 | 01/06/1993 | 0300 | -29.996 | -35.167 | 2170 |
| 06MT22/5 | A10 | 23 | 2 | 01/06/1993 | 0650 | -30.009 | -34.823 | 1637 |
| 06MT22/5 | A10 | 24 | 1 | 01/06/1993 | 1012 | -29.997 | -34.501 | 1430 |
| 06MT22/5 | A10 | 25 | 2 | 01/06/1993 | 1437 | -29.989 | -34.004 | 2046 |
| 06MT22/5 | A10 | 26 | 1 | 01/06/1993 | 1908 | -29.992 | -33.509 | 3175 |
| 06MT22/5 | A10 | 27 | 2 | 01/06/1993 | 2352 | -29.993 | -33.000 | 3528 |
| 06MT22/5 | A10 | 27 | 3 | 01/07/1993 | 0115 | -29.981 | -33.009 | 3529 |
| 06MT22/5 | A10 | 28 | 1 | 01/07/1993 | 0543 | -29.997 | -32.499 | 3747 |
| 06MT22/5 | A10 | 28 | 2 | 01/07/1993 | 0712 | -29.986 | -32.503 | 3747 |

## Table A.1 (continued)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 06MT22/5 | A10 | 29 | 2 | 01/07/1993 | 1205 | -29.998 | -32.000 | 3853 |
| 06MT22/5 | A10 | 29 | 3 | 01/07/1993 | 1334 | -29.986 | -31.990 | 3867 |
| 06MT22/5 | A10 | 30 | 1 | 01/07/1993 | 1751 | -30.000 | -31.504 | 3858 |
| 06MT22/5 | A10 | 30 | 2 | 01/07/1993 | 1925 | -30.001 | -31.502 | 3814 |
| 06MT22/5 | A10 | 31 | 2 | 01/07/1993 | 2347 | -30.000 | -30.996 | 4087 |
| 06MT22/5 | A10 | 31 | 3 | 01/08/1993 | 0120 | -30.013 | -31.001 | 4090 |
| 06MT22/5 | A10 | 32 | 1 | 01/08/1993 | 0530 | -30.000 | -30.501 | 3946 |
| 06MT22/5 | A10 | 32 | 2 | 01/08/1993 | 0701 | -30.002 | -30.508 | 3937 |
| 06MT22/5 | A10 | 33 | 2 | 01/08/1993 | 1130 | -30.001 | -29.991 | 3528 |
| 06MT22/5 | A10 | 33 | 3 | 01/08/1993 | 1256 | -29.997 | -29.997 | 3485 |
| 06MT22/5 | A10 | 34 | 1 | 01/08/1993 | 1756 | -29.998 | -29.509 | 2238 |
| 06MT22/5 | A10 | 35 | 2 | 01/09/1993 | 0558 | -29.997 | -28.997 | 3202 |
| 06MT22/5 | A10 | 36 | 1 | 01/09/1993 | 1025 | -29.998 | -28.420 | 3761 |
| 06MT22/5 | A10 | 36 | 2 | 01/09/1993 | 1154 | -29.999 | -28.430 | 3763 |
| 06MT22/5 | A10 | 37 | 2 | 01/09/1993 | 1800 | -30.000 | -27.568 | 4881 |
| 06MT22/5 | A10 | 37 | 3 | 01/09/1993 | 1948 | -30.007 | -27.579 | 4883 |
| 06MT22/5 | A10 | 38 | 1 | 01/10/1993 | 0200 | -29.998 | -26.719 | 5323 |
| 06MT22/5 | A10 | 38 | 2 | 01/10/1993 | 0345 | -29.997 | -26.731 | 4920 |
| 06MT22/5 | A10 | 39 | 2 | 01/10/1993 | 0955 | -29.999 | -25.862 | 4489 |
| 06MT22/5 | A10 | 39 | 3 | 01/10/1993 | 1125 | -30.001 | -25.872 | 4474 |
| 06MT22/5 | A10 | 40 | 1 | 01/10/1993 | 1732 | -29.996 | -25.018 | 5592 |
| 06MT22/5 | A10 | 40 | 2 | 01/10/1993 | 1958 | -30.014 | -25.025 | 5673 |
| 06MT22/5 | A10 | 40 | 3 | 01/10/1993 | 2238 | -30.028 | -25.038 | 5705 |
| 06MT22/5 | A10 | 41 | 2 | 01/11/1993 | 0425 | -30.000 | -24.170 | 4805 |
| 06MT22/5 | A10 | 41 | 3 | 01/11/1993 | 0600 | -29.999 | -24.180 | 4786 |
| 06MT22/5 | A10 | 42 | 1 | 01/11/1993 | 1157 | -30.000 | -23.315 | 4627 |
| 06MT22/5 | A10 | 42 | 2 | 01/11/1993 | 1327 | -29.998 | -23.317 | 4658 |
| 06MT22/5 | A10 | 43 | 2 | 01/11/1993 | 1940 | -29.998 | -22.468 | 4692 |
| 06MT22/5 | A10 | 43 | 3 | 01/11/1993 | 2120 | -30.006 | -22.479 | 4678 |
| 06MT22/5 | A10 | 44 | 1 | 01/12/1993 | 0325 | -29.998 | -21.622 | 4874 |
| 06MT22/5 | A10 | 44 | 2 | 01/12/1993 | 0505 | -29.992 | -21.621 | 4897 |
| 06MT22/5 | A10 | 45 | 2 | 01/12/1993 | 1145 | -30.002 | -20.762 | 4770 |
| 06MT22/5 | A10 | 45 | 3 | 01/12/1993 | 1330 | -30.001 | -20.767 | 4782 |
| 06MT22/5 | A10 | 46 | 1 | 01/12/1993 | 1929 | -29.999 | -19.919 | 4848 |
| 06MT22/5 | A10 | 46 | 2 | 01/12/1993 | 2114 | -30.003 | -19.933 | 4748 |
| 06MT22/5 | A10 | 47 | 2 | 01/13/1993 | 0400 | -29.988 | -19.067 | 4064 |
| 06MT22/5 | A10 | 47 | 3 | 01/13/1993 | 0550 | -30.000 | -19.055 | 4136 |
| 06MT22/5 | A10 | 47 | 4 | 01/13/1993 | 0719 | -29.979 | -19.052 | 4250 |
| 06MT22/5 | A10 | 48 | 1 | 01/13/1993 | 1240 | -30.008 | -18.385 | 4203 |
| 06MT22/5 | A10 | 48 | 2 | 01/13/1993 | 1422 | -30.020 | -18.392 | 4273 |
| 06MT22/5 | A10 | 49 | 2 | 01/14/1993 | 0436 | -30.001 | -17.698 | 3989 |
| 06MT22/5 | A10 | 49 | 3 | 01/14/1993 | 0608 | -30.003 | -17.690 | 3949 |
| 06MT22/5 | A10 | 50 | 1 | 01/14/1993 | 1101 | -29.999 | -17.013 | 3677 |
| 06MT22/5 | A10 | 50 | 2 | 01/14/1993 | 1210 | -30.014 | -17.003 | 3566 |
| 06MT22/5 | A10 | 51 | 2 | 01/14/1993 | 1703 | -30.002 | -16.333 | 3698 |
| 06MT22/5 | A10 | 51 | 3 | 01/14/1993 | 1824 | -30.007 | -16.329 | 3680 |
| 06MT22/5 | A10 | 52 | 1 | 01/15/1993 | 0002 | -30.000 | -15.663 | 3283 |
| 06MT22/5 | A10 | 53 | 2 | 01/15/1993 | 0507 | -30.003 | -15.000 | 3834 |
| 06MT22/5 | A10 | 53 | 3 | 01/15/1993 | 0652 | -30.004 | -15.003 | 3835 |
| 06MT22/5 | A10 | 54 | 1 | 01/15/1993 | 1245 | -30.006 | -14.335 | 2753 |
| 06MT22/5 | A10 | 55 | 2 | 01/15/1993 | 1810 | -30.009 | -13.661 | 2297 |
| 06MT22/5 | A10 | 56 | 1 | 01/15/1993 | 2331 | -30.013 | -12.989 | 3096 |
| 06MT22/5 | A10 | 57 | 2 | 01/16/1993 | 0444 | -29.997 | -12.333 | 3151 |
| 06MT22/5 | A10 | 57 | 3 | 01/16/1993 | 0608 | -29.990 | -12.338 | 3131 |
| 06MT22/5 | A10 | 58 | 1 | 01/16/1993 | 1115 | -30.002 | -11.676 | 3434 |
| 06MT22/5 | A10 | 58 | 2 | 01/16/1993 | 1230 | -30.018 | -11.678 | 3323 |
| 06MT22/5 | A10 | 59 | 2 | 01/16/1993 | 1726 | -30.003 | -10.994 | 3760 |
| 06MT22/5 | A10 | 59 | 3 | 01/16/1993 | 1839 | -30.010 | -10.985 | 3632 |
| 06MT22/5 | A10 | 60 | 1 | 01/16/1993 | 2327 | -30.001 | -10.330 | 3781 |
| 06MT22/5 | A10 | 60 | 2 | 01/17/1993 | 0041 | -30.005 | -10.330 | 3791 |
| 06MT22/5 | A10 | 61 | 2 | 01/17/1993 | 0537 | -30.001 | -9.661 | 3727 |
| 06MT22/5 | A10 | 61 | 3 | 01/17/1993 | 0700 | -30.006 | -9.650 | 3730 |
| 06MT22/5 | A10 | 62 | 1 | 01/17/1993 | 1153 | -30.000 | -8.998 | 3972 |
| 06MT22/5 | A10 | 62 | 2 | 01/17/1993 | 1310 | -30.024 | -8.992 | 3984 |
| 06MT22/5 | A10 | 63 | 2 | 01/17/1993 | 1845 | -30.003 | -8.162 | 3948 |
| 06MT22/5 | A10 | 63 | 3 | 01/17/1993 | 2014 | -30.015 | -8.154 | 4025 |
| 06MT22/5 | A10 | 64 | 1 | 01/18/1993 | 0210 | -30.002 | -7.332 | 4177 |

Table A.1 (continued)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 06MT22/5 | A10 | 64 | 2 | 01/18/1993 | 0334 | -30.005 | -7.323 | 4246 |
| 06MT22/5 | A10 | 65 | 2 | 01/18/1993 | 0924 | -30.007 | -6.498 | 4556 |
| 06MT22/5 | A10 | 65 | 3 | 01/18/1993 | 1055 | -30.012 | -6.506 | 4135 |
| 06MT22/5 | A10 | 65 | 4 | 01/18/1993 | 1341 | -30.029 | -6.519 | 3635 |
| 06MT22/5 | A10 | 66 | 1 | 01/18/1993 | 1914 | -29.999 | -5.668 | 4373 |
| 06MT22/5 | A10 | 66 | 2 | 01/18/1993 | 2058 | -29.998 | -5.664 | 4390 |
| 06MT22/5 | A10 | 67 | 2 | 01/19/1993 | 0241 | -30.000 | -4.827 | 4315 |
| 06MT22/5 | A10 | 67 | 3 | 01/19/1993 | 0416 | -30.006 | -4.813 | 4444 |
| 06MT22/5 | A10 | 68 | 1 | 01/19/1993 | 1002 | -29.997 | -4.001 | 3990 |
| 06MT22/5 | A10 | 68 | 2 | 01/19/1993 | 1117 | -29.999 | -3.993 | 3977 |
| 06MT22/5 | A10 | 69 | 2 | 01/19/1993 | 1719 | -30.010 | -3.171 | 4401 |
| 06MT22/5 | A10 | 69 | 3 | 01/19/1993 | 1903 | -30.012 | -3.172 | 4369 |
| 06MT22/5 | A10 | 70 | 2 | 01/20/1993 | 0055 | -29.995 | -2.323 | 4302 |
| 06MT22/5 | A10 | 70 | 3 | 01/20/1993 | 0225 | -29.993 | -2.303 | 4323 |
| 06MT22/5 | A10 | 71 | 2 | 01/20/1993 | 0822 | -30.002 | -1.498 | 4779 |
| 06MT22/5 | A10 | 71 | 3 | 01/20/1993 | 1013 | -29.984 | -1.477 | 4806 |
| 06MT22/5 | A10 | 72 | 1 | 01/20/1993 | 1622 | -30.016 | -0.730 | 4874 |
| 06MT22/5 | A10 | 72 | 2 | 01/20/1993 | 1806 | -30.015 | -0.726 | 4875 |
| 06MT22/5 | A10 | 73 | 2 | 01/20/1993 | 2340 | -29.997 | 0.002 | 4008 |
| 06MT22/5 | A10 | 73 | 3 | 01/21/1993 | 0056 | -29.993 | 0.007 | 3962 |
| 06MT22/5 | A10 | 74 | 1 | 01/21/1993 | 0617 | -29.858 | 0.567 | 3329 |
| 06MT22/5 | A10 | 75 | 2 | 01/21/1993 | 1058 | -29.731 | 1.133 | 3739 |
| 06MT22/5 | A10 | 75 | 3 | 01/21/1993 | 1215 | -29.723 | 1.138 | 3735 |
| 06MT22/5 | A10 | 76 | 1 | 01/21/1993 | 1641 | -29.604 | 1.701 | 3665 |
| 06MT22/5 | A10 | 76 | 2 | 01/21/1993 | 1802 | -29.604 | 1.701 | 3647 |
| 06MT22/5 | A10 | 77 | 2 | 01/21/1993 | 2255 | -29.475 | 2.267 | 2712 |
| 06MT22/5 | A10 | 78 | 1 | 01/22/1993 | 0332 | -29.337 | 2.830 | 4251 |
| 06MT22/5 | A10 | 78 | 2 | 01/22/1993 | 0510 | -29.348 | 2.826 | 4241 |
| 06MT22/5 | A10 | 79 | 2 | 01/22/1993 | 0938 | -29.474 | 3.304 | 4777 |
| 06MT22/5 | A10 | 79 | 3 | 01/22/1993 | 1116 | -29.476 | 3.312 | 4770 |
| 06MT22/5 | A10 | 80 | 1 | 01/22/1993 | 1538 | -29.608 | 3.778 | 4944 |
| 06MT22/5 | A10 | 80 | 2 | 01/22/1993 | 1723 | -29.604 | 3.772 | 4933 |
| 06MT22/5 | A10 | 81 | 2 | 01/23/1993 | 0730 | -29.747 | 4.239 | 4971 |
| 06MT22/5 | A10 | 81 | 3 | 01/23/1993 | 0902 | -29.744 | 4.243 | 4985 |
| 06MT22/5 | A10 | 82 | 1 | 01/23/1993 | 1524 | -29.752 | 5.100 | 5253 |
| 06MT22/5 | A10 | 82 | 2 | 01/23/1993 | 1719 | -29.746 | 5.107 | 5262 |
| 06MT22/5 | A10 | 83 | 2 | 01/23/1993 | 2349 | -29.745 | 5.932 | 5198 |
| 06MT22/5 | A10 | 83 | 3 | 01/24/1993 | 0138 | -29.742 | 5.945 | 5192 |
| 06MT22/5 | A10 | 84 | 1 | 01/24/1993 | 0817 | -29.754 | 6.780 | 5207 |
| 06MT22/5 | A10 | 84 | 2 | 01/24/1993 | 1007 | -29.739 | 6.780 | 5209 |
| 06MT22/5 | A10 | 85 | 2 | 01/24/1993 | 1622 | -29.746 | 7.621 | 5200 |
| 06MT22/5 | A10 | 85 | 3 | 01/24/1993 | 1816 | -29.736 | 7.627 | 5203 |
| 06MT22/5 | A10 | 86 | 1 | 01/25/1993 | 0110 | -29.746 | 8.465 | 5091 |
| 06MT22/5 | A10 | 86 | 2 | 01/25/1993 | 0247 | -29.744 | 8.465 | 5086 |
| 06MT22/5 | A10 | 87 | 2 | 01/25/1993 | 1036 | -29.750 | 9.297 | 5032 |
| 06MT22/5 | A10 | 87 | 3 | 01/25/1993 | 1235 | -29.755 | 9.307 | 4986 |
| 06MT22/5 | A10 | 88 | 1 | 01/25/1993 | 1925 | -29.748 | 10.148 | 4900 |
| 06MT22/5 | A10 | 88 | 2 | 01/25/1993 | 2141 | -29.747 | 10.185 | 4853 |
| 06MT22/5 | A10 | 89 | 2 | 01/26/1993 | 0527 | -29.749 | 10.980 | 4296 |
| 06MT22/5 | A10 | 89 | 3 | 01/26/1993 | 0700 | -29.748 | 10.981 | 4271 |
| 06MT22/5 | A10 | 90 | 2 | 01/26/1993 | 1419 | -29.752 | 11.830 | 4002 |
| 06MT22/5 | A10 | 90 | 3 | 01/26/1993 | 1615 | -29.755 | 11.852 | 3994 |
| 06MT22/5 | A10 | 91 | 2 | 01/26/1993 | 2025 | -29.622 | 12.171 | 3818 |
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