



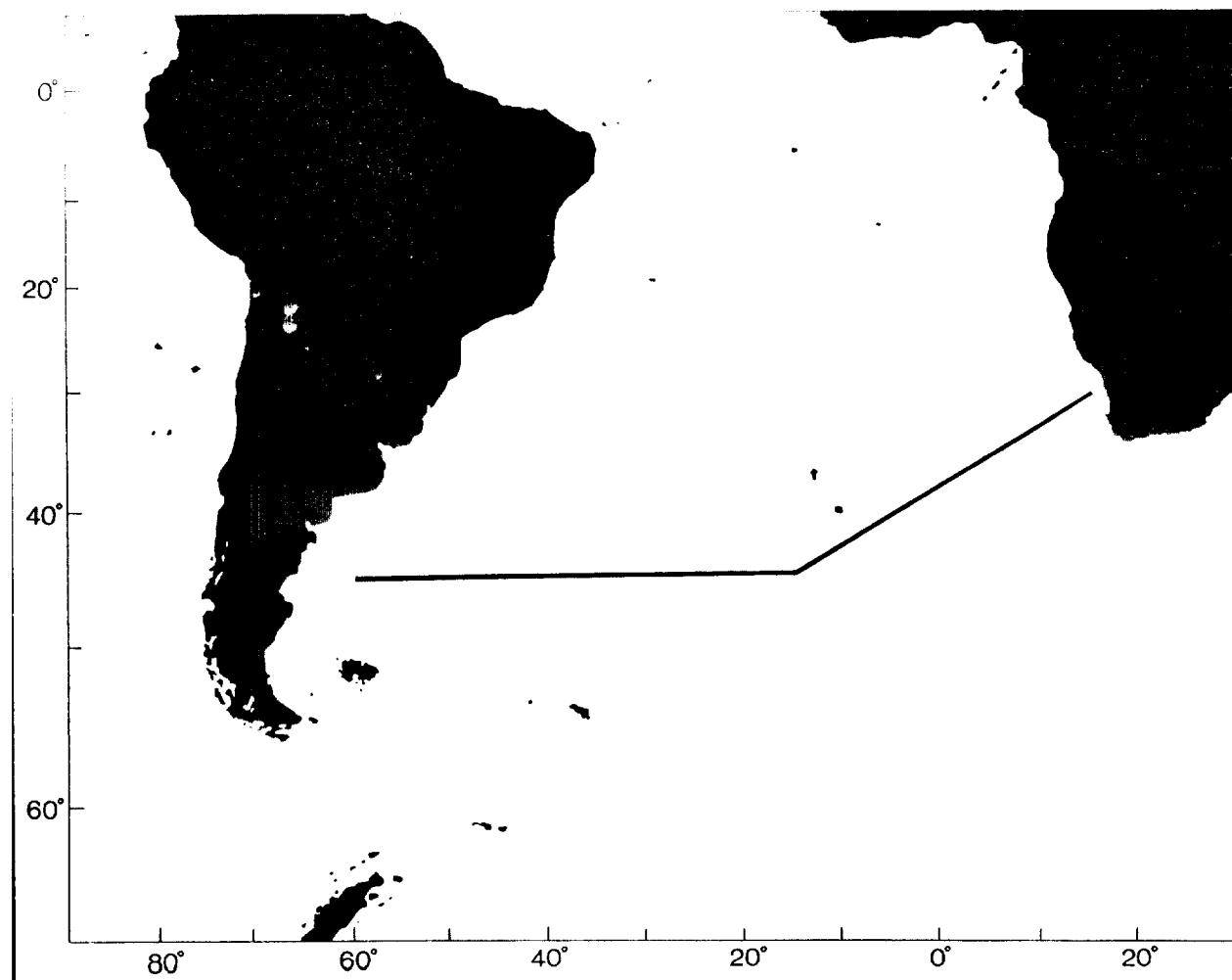
Institute of  
Oceanographic Sciences  
Deacon Laboratory

## **RRS *Discovery* Cruise 199**

**22 Dec 1992 - 01 Feb 1993**

**WOCE A11 in the South Atlantic**

**Cruise Report No 234 1993**



INSTITUTE OF OCEANOGRAPHIC SCIENCES  
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**INSTITUTE OF OCEANOGRAPHIC SCIENCES  
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CRUISE REPORT NO. 234**

**RRS DISCOVERY CRUISE 199  
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**WOCE A11 in the South Atlantic**

**Principal Scientist  
P M Saunders**

**1993**



DOCUMENT DATA SHEET

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ABSTRACT	<p>RRS <i>Discovery</i> cruise 199 was a UK contribution to the World Ocean Circulation Experiment (WOCE) one-time survey, its designation A11. The cruise ports were Punta Arenas, Chile to Cape Town, S.Africa. 91 full-depth stations were worked with a NBIS Mk3b CTD and a GO 24x10 litre rosette water sampler. Salinity, oxygen, silicate, nitrate, phosphate were measured on each station, CFC-11, CFC-12, and CFC-113 measured on every other station and XBT drops (mostly T7) made between stations. Meteorological parameters, sea-surface temperature and salinity, and current profiles to 300m (from a hull-mounted RDI 150 kHz ADCP) were measured throughout the cruise. To improve estimates of the ship's heading (and hence currents) a 3-dimensional gps receiver from Ashtech was employed.</p> <p>Provisional examination of the data indicates that it is of sufficient quality to meet the pricipal aim of the cruise, namely to determine the exchange of physical and chemical properties between the S.Atlantic and Southern Ocean.</p> <p>Electronic versions of the text of this document, plus hard copy figures are lodged with the WOCE Hydrographic planning office, Woods Hole, Mass and with the British Oceanographic Data Centre at Bidston, Merseyside.</p>		
KEYWORDS	<p>A11 WOCE ONE-TIME SURVEY      ACOUSTIC DOPPLER CURRENT PROFILER (ADCP)      CFC 11,12,113      CORE PROJECT 1      CTD OBSERVATIONS      "DISCOVERY"/RRS - cruise(1992-93)(199)      NUTRIENTS</p> <p>OXYGEN      SOUTH ATLANTIC      WATER EXCHANGE      WOCE</p>		
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## 1. CRUISE NARRATIVE

### 1.1 Highlights

Expedition Designation

WHP One-time Survey, A11

Chief Scientist

Peter M Saunders, IOSDL

Ship

*RRS Discovery*, newly lengthened to 90.2m

Ports of Call

Punta Arenas, Chile to Cape Town, S. Africa

Cruise Dates

December 22, 1992 to February 1, 1993

### 1.2 Cruise Summary

Cruise Track

The cruise track and station locations are shown in figure 1: only small volume samples were taken.

Sampling

The following water sample measurements were made:- salinity, oxygen, total nitrate, phosphate, silicate and CFCs 11,12 and 113, the freons on alternate stations. CTD salinity and oxygen were also measured.

The depths in m sampled were:- 5(10), 50, 100, 150, 200, 250, 350, 500, 750, 1000, 1250, 1500, 1750, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500, 6000 metres.

Number of Stations

A total of 91 CTD/rosette stations were occupied using a General Oceanics 24 bottle rosette equipped with 24 10-litre Niskin water sample bottles, and a NBIS Mk IIIb CTD equipped with a SensorMedic oxygen sensor, Sea Tech Inc 1m path transmissometer, Simrad altimeter model 807-200m, and IOSDL 10 kHz pinger.

Reporting

Electronic versions of the text of this document, plus hard copy figures are lodged with the WOCE Hydrographic planning office, Woods Hole, Mass and with the British Oceanographic Data

Centre at Bidston, Merseyside. We plan to lodge electronic copies of most of the data from the cruise at these same sites by the end of 1993.

### 1.3 List of Principle Investigators

The principal investigators responsible for the major parameters measured on the cruise are listed in Table 1. The responsibility for all tasks undertaken on the cruise will be found in table 2.

TABLE 1: PRINCIPAL INVESTIGATORS

Name	Responsibility	Affiliation
B.King	CTD	IOSDL
S.Bacon	Salinity	JRC
D.Hydes	Nutrients	IOSDL
P.Chapman	Oxygen	Texas A & M
D.Smythe-Wright	CFC	JRC
P.Saunders	ADCP	IOSDL

#### 1.4.1 Scientific Programme and Methods

The principal objectives of the cruise were:-

- a) To estimate the exchange of heat, freshwater, nutrients and freons across the section, i.e. between the Southern Ocean and the South Atlantic
- b) To determine the water mass characteristics on the section and to determine whether and where secular changes are found, and
- c) To submit to the WHPO a data set, a fit companion to other WHP one time survey cruises, and thereby contribute to the global measurements necessary to meet the objectives of WOCE.

The principal instruments employed in the measurement programme consisted of a NBIS Mk IIIa CTD and General Oceanics rosette mounted within a tubular aluminium frame of dimensions 1.8m height x 1.5m diameter. The package was weighted to give a free fall speed in excess of  $2 \text{ ms}^{-1}$ . Subsidiary instrumentation consisted of a 1m transmissometer, altimeter (with 200m range for bottom finding) and 10 kHz location pinger. Four of the rosette bottles were fitted with SIS digital reversing thermometers (6) and pressure meters (2). The wire was a single conductor 10mm steel rope manufactured by Rochester Cables, and the winch was of traction winch design built by Kley France. A

complex folding gantry of RVS Barry design ensured the virtually automatic launching and recovery of the CTD/rosette package in all conditions within which the ship could be safely operated.

After a cast the rosette was placed on deck and secured, the rosette pylon was drenched in fresh water and the CTD sensors covered with protective housings. Subsequently digital instrumentation was read and freon samples were drawn followed in order by samples for oxygen, nutrient and salinity analysis. The rosette was stored on deck throughout the cruise and all sampling was performed there. In moderate weather the rosette would be pushed forward on a railway about 3 m to obtain further shelter. In rain umbrellas could be clamped to the rosette frame in order to protect the samples and in rough seas the ship remained on station until sampling was completed.

Other and, in some cases, crucial additional measurements were made throughout the cruise. XBTs were launched between CTD stations and more frequently in the slope regions at each end of the cruise section. Acoustic Doppler Current Profiler (ADCP) measurements were made continuously employing a hull mounted 150 kHz unit manufactured by RDI. In support of the ADCP measurements a GPS3DF receiver manufactured by Ashtech, Inc provided heading information superior to that of the ship's gyro. Underway measurements of surface temperature and salinity were made by a FSI thermosalinograph and a Simrad 500 Echosounder provided continuous water depth measurements. Other navigation information was supplied by a Trimble GPS receiver and all data were logged by networked SUN workstations with terminals widely available in the main and computer labs.

A description of the methods of measurement, calibration and analysis of the data received from these various sources will be found in section 2 of this report.

#### 1.4.2 Preliminary Results

Figure 2 shows the distribution of sample observations made on the A11 section. Since data from the South Atlantic Ventilation Experiment (SAVE) were available on the ship (thanks to WHPO), we were able to compare A11 and SAVE sample data. The property distributions were very similar, but small differences were noted in the deep water which became evident with potential temperature  $< 1.0^{\circ}\text{C}$  or salinity in the range 34.66 - 34.72. A11 salinity measurements agreed well with the SAVE 5 leg data, but were more saline by 0.002 than adjacent SAVE 4 data: the differences amongst the SAVE data were not previously known to us. Nitrates showed agreement with both SAVE 4 and 5 measurements, but at the deepest levels silicates and oxygens were slightly lower by 2.5 umol/kg (Figure 3) and 2.5 umol/kg (Figure 4) respectively; phosphates were lower by about 0.08 umol/kg. These preliminary results, whose magnitude but not sign depends on which historic set is compared, apply principally within the Argentine Basin, and possible causes of the differences are under investigation.

A more unexpected result, which owed nothing to the accuracy of the measurements, was the extreme northern position of the Subtropical Convergence on the NE leg of the track (Figure 1). Although the water became progressively warmer along this leg, the surface salinity remained below

35 until a ring was encountered centred on 36° 20'S and 4° 00'E. The ring had a thermostad of temperature 13.5°C, salinity 35.2 and a maximum depth of 600m. An anticyclonic circulation of 30  $\text{cms}^{-1}$  was observed by the ADCP. It may have been an Agulhas ring which had over-wintered south of the convergence, or a Brazil Current ring shed in the WBC retroflexion zone which had migrated eastward. Opinions in the scientific party were split about equally, but a closer post-cruise examination of the data may well resolve the question. Beyond its NE edge, near 35° 40'S and 5° 00'E we encountered the subtropical gyre, with a surface salinity exceeding 36 and temperature of 20°C. This observation appears to confirm Deacon's (1937) assertion of the northward migration of the convergence in summer in this region.

Within the subtropical gyre a second hydrographic feature was encountered. This was defined by two hydrographic casts and 5 XBTs and was centred at 33° 30'S, 9° 45'E and extended for 300 km along the track. Within it, the 15°C isotherm plunged to a depth of 250m, while outside it the same isotherm was nearer a depth of 100m. An anticyclonic circulation was measured by the ADCP with currents approaching 75  $\text{cms}^{-1}$ . This was undoubtedly a recent Agulhas ring.

The ADCP instrumentation furnished, we believe, important new data on the cruise: it functioned incomparably better than when installed on the previous 10m-shorter version of the ship. The most important results derived from it were found in the western boundary region. On the Argentine Slope, on two crossings of the Falklands Current, large and persistent northward velocities were found at 100m depth (30 - 50  $\text{cms}^{-1}$ ). These were considerably in excess of those predicted by the geostrophic shear (relative to the bottom), and consequently bottom velocities of 15 - 30  $\text{cms}^{-1}$  are inferred. The consequences for transport in the WBC and exchange across the section are considerable. On the South African slope, along-slope velocities were also observed on a crossing of the Benguela Current. However these were quite small and variable in direction and a preliminary analysis suggested they were dominated by transient (tidal or inertial) components.

Also of note were ADCP observations made in a storm near 45S 21 W: winds approached 30  $\text{ms}^{-1}$  for a brief period, and striking inertial oscillations (circa 40  $\text{cms}^{-1}$ ) were recorded. Since meteorological measurements were made aboard the ship, it is hoped that given the high quality of the ADCP data, it may prove possible to deduce the integrated Ekman drift on this cruise.

### 1.5 Major Problems Encountered on the Cruise

Two GO rosettes were available and both were utilised. Misfiring and double tripping were initially widespread, but when their sensitivity to the lanyard tension was recognised it became possible to reduce them to acceptable levels. Nevertheless a post-cruise review estimates the overall number of double trips as nearly 10% of the total number of samples. Thus a larger than expected number of duplicate samples was achieved. It is our recommendation and intention for the future that lanyard tensions be measured, monitored and set to a value which allows a properly reliable operation of the unit.

As mentioned in Section 1.4.1 the winch was of complex traction winch design; it was put to use only on the previous cruise and because of its newness, inevitably there were difficulties. On the 1st of January at 0600, control failure occurred: it was approximately 36 hours before the fault was identified, the electronic component replaced and control settings optimised to allow station work to proceed. The efforts of all involved deserve recognition and thanks. Although we believe this was a unique situation, a different problem occurred twice and was potentially liable to occur anytime there was a large swell. Because the CTD/rosette takes time to shed air from all its component parts, very close to the surface it is vulnerable to heavy swell: it may 'float'. In such circumstances the wire goes slack, and on both occasions the wire jumped out of a sheave pair at the foot of the gantry (where the wire direction changed from horizontal to vertical). Even in the short term this is probably a rectifiable fault, but on the cruise it cost us 4 hours both times it occurred.

Concerning the instrumentation for analysis, two problems were noted. Early on, the SIS unit for determination of oxygen concentration became unreliable: the photometric end point detection system was no longer stable. Fortunately a backup amperometric system, the Metrohm 686 titroprocessor, was available, and this was used for the bulk of the cruise measurements.

The CFC measurements also experienced difficulties which led to the loss of some data. Shortly after the start of the cruise the CFC-12 measurements exhibited severe contamination which was believed to be due to the accidental release of oil from the ship and its capture in the non-toxic seawater system used to store the sample syringes. To bypass this problem, syringes were stored in surplus sample water, a practice however, which did not eliminate the contamination. Early CFC-12 measurements may be expected to be of lower quality than expected on the cruise, but the CFC-11 and CFC-113 measurements should be unaffected.

### **1.6 Other Observations of Note**

On the 16th January, a large iceberg was sighted: its location was determined as 44° 50'S 14° 22'W. In view of a much more southerly position and crossing of the Falkland Current three weeks earlier in the cruise, this was an odd location to observe one for the first time.

On the 19th January in about 3700m of water, RRS *Discovery* passed over a flat-topped seamount near 40° 48'S 5° 40'W: it is not recorded on the GEBCO chart and its minimum depth was near 750m. We propose the name New *Discovery* Seamount for this 3000m high feature.

### **1.7 List of Cruise Participants**

The members of the scientific party are listed in Table 2, along with their responsibilities.

TABLE 2: CRUISE PARTICIPANTS

Name	Responsibilities	Affiliation
S.Bacon	Salinity	JRC
M.Beney	Data acquisition	RVS
S.Boswell	CFCs	JRC
P.Chapman	Oxygens, nutrients	Texas A & M
V.Cornell	Data archiving, Macsat	JRC
N.Crisp	CTD operations	IOSDL
S.Cunningham	CTD/sample analysis	JRC
P.Gwilliam	CTD operations (IC)	IOSDL
V.Gouretski	ADCP/historical hydrography	UEA
K.Heywood	CTD/sample analysis	UEA
S.Holley	Oxygens, nutrients	JRC
D.Hydes	Nutrients, oxygens	IOSDL
S.Jordan	Mech. Eng (IC)	RVS
B.King	CTD/sample analysis	IOSDL
R.Marsh	ADCP	JRC
M.Meredith	Thermosalinograph, Macsat	UEA
D.Price	CFCs	JRC
R.Phipps	Mechanical Engineer	RVS
P.Saunders	PSO, ADCP	IOSDL
P.Smith	CTD operations, Meteorology	IOSDL
D.Smythe-Wright	CFCs (IC)	JRC
A.Taylor	Electrical Engineer	RVS
S.Thompson	GPS, XBTs	IOSDL
S.Whittle	Mechanical Engineer	IOSDL

## Abbreviations

IOSDL Institute of Oceanographic Sciences, Deacon Laboratory - Wormley

JRC James Rennell Centre - Southampton

RVS Research Vessel Services - Barry

UEA University of East Anglia - Norwich

IC In charge of

## 2 MEASUREMENT TECHNIQUES AND CALIBRATIONS

### 2.1 Sample salinity measurements

by: S. Bacon

On RRS *Discovery* cruise 199 the salinity analysis of samples was carried out exclusively on the IOSDL Guildline Autosal salinometer model 8400, modified by addition of an Ocean Scientific International peristaltic-type sample intake pump. The instrument was operated in the ship's constant temperature laboratory at a bath temperature of 24°C with the laboratory set to 20.5°C. This difference in temperature was larger than normally employed and only arose through a misunderstanding, but was allowed to remain rather than disturb the salinometer again when it became clear that the machine was quite 'happy' operating thus. Standardisation was effected by use of IAPSO Standard Seawater batch P120, of which 110 ampoules were consumed. Two of these were imperfectly sealed, and were discarded; two were evidently of incorrect (too high) salinity, and one more was thought dubious. These latter three were not used as standards. The standardisation history of the salinometer has been constructed, in which standardisation drift is represented as equivalent salinity (ES) change referenced to the first standard measurement of the cruise. The instrument was remarkably stable, not changing from its initial standardisation by more than 0.001 ES until the last ten days of the cruise, when the seas generally were calmer and the outside temperature increased, although it is difficult to associate such changes in external conditions with the observed behaviour of the salinometer, unless the ship's power supply is implicated in some way. Excluding the two bad standards, the mean standardisation drift was 0.0007 ES, with a standard deviation of 0.0007 ES, for 108 standards.

There were 46 pairs of replicate (ie from the same rosette bottle) samples drawn; and 210 pairs of duplicate (ie from different rosette bottles fired at the same depth) samples. Of the duplicate pairs, 87 were from below 3000m. The standard deviations of the three groups of sample pairs are given in table S1 below.

**TABLE S1**  
**Salinity replicate and duplicate statistics**

Quantity	Standard deviation	Number of pairs
Duplicates	0.0019	208
Duplicates (from >3000m)	0.0009	87
Replicates	0.0008	46

See text above table for the distinction between replicates and duplicates.

## 2.2 Sample oxygen measurements

by: P. Chapman, S.E. Holley and D.J. Hydes

### Equipment and techniques

Bottle oxygen samples were taken in calibrated clear glass bottles immediately following the drawing of samples for CFCs. The temperature of the water at the time of chemical fixation was measured to allow corrections to be made for the change in density of the sample between the closure of the rosette bottle and the fixing of the dissolved oxygen. Analysis followed the Winkler whole bottle method. The thiosulphate titration was carried out in a controlled environment laboratory maintained at temperatures between 21 and 22°C. Thiosulphate normality was determined on a daily basis and whenever new reagents were made up. Duplicate samples were taken on every cast; usually these were from the deepest four bottles.

For the early stations, the end point was determined by an automatic photometric method manufactured by SIS (Germany). After station 12253, however, the instrument began giving erroneous endpoint readings since a distinct yellow colour was sometimes still visible in the titration flasks. This was not consistent, and some analyses within each run appeared to titrate correctly; however, all samples from stations 12253, 12254, 12255, and 12257 have been flagged as suspect. For stations 12258 to 12337, i.e. the bulk of the cruise, an "amperometric titration to a dead stop" following the method of Culberson and Huang (1987) was used. A Metrohm Titrator and a Dosimat 665 (10 ml) automatic burette was employed. Titration volumes in deep waters were approximately 5 ml and the smallest increment from the burette was 2 microlitres.

The volume of oxygen dissolved in the water was converted to mass fraction by use of the factor 44.66 and an appropriate value of the density; corrections for the volume of oxygen added with the reagents and for impurities in the manganese chloride were also made as described in the WOCE Manual of Operations and Methods (Culberson, 1991).

### Reproducibility of measurements

Approximately 1900 samples were taken during the cruise; in addition, a large number of duplicates were analysed. Statistics on the duplicates are given in Table O1. These include both duplicates taken from the same bottle (replicates) and those taken from different bottles fired at the same depth and invariably unknown to the analysts.

While the photometric method was being used, 22 samples were taken from separate bottles all fired at a depth of 2500 m at station 12240 (Table O1). The data gave a standard deviation of 0.63  $\mu\text{mol}$ , or 0.3%. However, 12 pairs of duplicates taken from the same bottle for stations 12250-12256 gave a mean difference of 1.2  $\mu\text{mol}$  with a standard deviation of 1.29  $\mu\text{mol}$  (approximately 0.56%, Table O1). Duplicates from 223 pairs of samples taken from the same bottle later in the cruise while the amperometric method was in use had a mean difference of 0.64  $\mu\text{mol}$ , and standard deviation of 0.85  $\mu\text{mol}$ , while 13 samples from 5455m from station 12277 gave a standard deviation of 0.35  $\mu\text{mol}$  (0.15%, Table O1).

A further series of multiple samples was taken from different bottles fired at the same depth as a result of doubletrips by the rosette. The results of these are also given in Table O1. The mean difference for 166 sets taken over all depths and analysed by the amperometric method was 0.57  $\mu\text{mol}$ ; the standard deviation of the differences was 0.65  $\mu\text{mol}$ . These figures are not significantly different from duplicates taken from the same bottle (replicates).

### Comparisons with historical data

Data taken at on this cruise on stations 12271-12274, 12282-12286, and 12296-12299 were compared SAVE stations 289-293, 260-264, and 200-203 respectively. Additionally, stations 12313-12316 were compared with data obtained at AJAX stations 46 and 47 near the Greenwich meridian. Some of this is shown in Figs. 3 and 4. Apart from difference in the near surface data resulting from changes in water masses in the area, there is a large measure of agreement. However, at the deepest levels the present cruise data at a given potential temperature (or salinity) shows an offset of between 2 and 6  $\mu\text{mol kg}^{-1}$ , in all cases less than the historic data. We are currently investigating the cause of these offsets.

### References

CULBERSON, C.H. and S. HUANG, 1987. Automated amperometric oxygen titration.  
Deep-Sea Research, 34, 875-880.

CULBERSON, C.H. 1991. 15 pp in the WOCE Operations Manual (WHP Operations and Methods)  
WHPO 91/1, Woods Hole.

TABLE O1

Statistics of duplicates and replicates obtained by both the photometric and amperometric methods. Sample depths are given where appropriate.

stn(s)	number	depth(s)	oxygen concentration $\mu\text{M}/\text{kg}$			
			m	mean(diff)	std dev	%mean
<b>Photometric method</b>						
12240	22	2500	208.5		0.63	0.3
12250-56	12	all		1.2	1.29	0.56
<b>Amperometric method</b>						
12277	13	234	230.1	0.35		0.15
12258-337	223	all		0.64	0.85	0.40
12258-337	166	all		0.57	0.65	0.30

### 2.3 Nutrients

by: D.J. Hydes, P. Chapman and S.E. Holley

#### Equipment and techniques

The nutrient analyses were performed on an Alpkem Corporation Rapid Flow Analyser, Model RFA-300.

The methods used were:- Silicate: the standard AAII molybdate-ascorbic acid method with the addition of a 37°C heating bath (Hydes 1984) to reduce the reproducibility problems encountered when analysing samples of different temperatures, noted on an earlier cruise when the standard Alpkem method was used (Saunders et al 1991, c.f. Joyce et al 1991). Phosphate used the standard (Murphy and Riley 1962) reagents and reagent to sea water ratios but with separate additions of ascorbic acid and mixed molybdate - sulphuric acid - tartrate to overcome the problem of the instability of a mixed reagent including ascorbic acid. Nitrate was determined using the standard Alpkem method.

Previous experience has shown that better reproducibilities are achieved when the instrument is run in a laboratory with a stable temperature. The Alpkem was located in the new constant temperature laboratory on *Discovery*. The temperature was maintained between 21 and 22°C. A drawback of this location was that the large air circulation in the laboratory leads to enhanced evaporation of samples in the open cups sitting in the analyser tray, and possibly to some contamination due to dust circulating in the airstream. This was ameliorated by fitting a cardboard skirt round the sample tray lid.

### Sampling Procedures

Sampling of nutrients followed that for trace gases (CFCs on this cruise) and oxygen. Samples were drawn into virgin polystyrene 30ml Coulter Counter Vials (ElKay). These were rinsed three times before filling. Samples were then analysed as rapidly as possible after collection to avoid build up of a sample back log. Samples cups of 2.0 ml capacity were used. These were rinsed once by filling completely before filling with analyte. Tests carried out on the cruise showed that samples from all depths stored for a week in a refrigerator at 4°C were not significantly effected by storage.

### Calibration and Standards

The calibrations of all the volumetric flasks used on the cruise were checked before packing and these were recalibrated if necessary.

Calibrations of the three Finnpipettes used on the cruise were checked before packing. The six Eppendorf fixed volume pipettes were delivered too late to be calibrated before the cruise. However in use no difference was detectable between the results achieved with the Finnpipettes and Eppendorfs.

### Nutrient standards

Nutrient primary standards were prepared from salts dried at 110°C for two hours and cooled over silica gel in a dessicator before weighing. Precision of weighing was to better than 1 part per thousand.

#### Nitrate

0.510g of potassium nitrate was dissolved in 500ml of distilled water in a calibrated volumetric PP flask at a temperature of 21-22°C.

#### Nitrite

0.345g of sodium nitrite was dissolved in 500ml of distilled water in a calibrated volumetric PP flask at a temperature of 21-22°C.

#### Phosphate

0.681g of potassium dihydrogen phosphate was dissolved in 500ml of distilled water in a calibrated volumetric PP flask at a temperature of 21-22°C. Working standards were prepared from a secondary standard made by diluting 5.00ml of the primary standard measured using a Finnpipette Digital 1.00 to 5.00 ml adjustable volume, in a 100ml calibrated glass volumetric flask.

### Silicate

0.960g of sodium silica fluoride was dissolved in 500ml of distilled water in a calibrated volumetric PP flask at a temperature of 21-22°C. Dissolution was started by grinding the fluoride powder to a paste with a few drops of water in 30ml polythene beaker using a plastic rod for three to four minutes.

### Secondary calibration standards.

A uniform set of six mixed secondary standards were prepared in artificial seawater, Concentrations ( $\mu\text{M}$ ) were Nitrate 40, 30, 20, 10, and 0; Phosphate 2.5, 2.0, 1.5, 1.0, 0.5 and 0, Silicate 150, 100, 75, 50, 25 and 0 up to station 12288 and 150, 120, 90, 60, 30 and 0 thereafter.

The artifical seawater was a 40ppt solution of Analar grade Sodium Chloride. Nutrients were undetectable in these solutions relative to Ocean Science International (OSI) Low Nutrient Sea Water which contains  $0.7\mu\text{M}$  Si,  $0.0\mu\text{M}$  NO<sub>3</sub> and  $0.0\mu\text{M}$  PO<sub>4</sub>. On one occasion the solution was found to contain  $0.6\mu\text{M}$  PO<sub>4</sub> and consequently was not used.

### Establishment of a Quality Control QC Sample

At a test station 12240 occupied on 26 December a large volume of deep water was collected with the idea of using this as a quality control standard when its stablity had been verified. Samples of this water where run at intervals over the next two weeks.

From station 12291 onwards a sample of 12240 water was measured as a "QC" sample on each analyser run. The scatter of the data are shown in Fig 5. Silicate returned a consistent result with occasional flyers. The phosphate results suggest that the first (up to 12301) and second (up to 12319) one litre subsample were unstable but the third sample was stable. This may be due to the surface of the polythene bottle storage equilibrating with the sample. The sharp shift in the apparent nitrate concentration in the QC between stations 12311 and 12312 is currently inexplicable. It does not correspond to a change in primary standard concentration. It was difficult to detect in the contour plots, but does appear to be present when concentrations were compared along isopycnal surfaces.

### Reproducibility

For the QC standard 189 measurements were made. The means were Silicate 78.85, Nitrate 28.85, Phosphate 1.79, percent standard deviations Silicate 1.05, Nitrate 2.45, Phosphate 2.35.

For 10 replicates of the top standard run after station 12337 the percent standard deviations were Silicate 0.22, Nitrate 0.25, Phosphate 1.1.

### Pressure calibration

The following calibration was applied to the CTD pressure data:-

$$P = P_{\text{raw}}^{**2} \times 3.066286E-7 + P_{\text{raw}} \times 0.997845 - 9$$

The calibration applied to the data included an offset different from that found in the lab calibration and given in section 2.5b. The chosen offset gave correct pressures on deck and over the top few metres of the cast. A further correction was made for the effect of temperature on the CTD pressure offset:-

$$P_{\text{new}} = P_{\text{old}} - 0.4 (T_{\text{lag}} - 20)$$

Here  $T_{\text{lag}}$  is a lagged temperature, in degrees C, constructed from the CTD temperatures. The time constant for the lagged temperature was 400 seconds. Lagged temperature is updated in the following manner. If  $T$  is the CTD temperature,  $t_{\text{del}}$  the time interval in seconds over which  $T_{\text{lag}}$  is being updated, and  $t_{\text{const}}$  the time constant, then

$$W = \exp(-t_{\text{del}}/t_{\text{const}})$$

$$T_{\text{lag}}(t=t_0+t_{\text{del}}) = W \times T_{\text{lag}}(t=t_0) + (1 - W) \times T(t=t_0+t_{\text{del}}).$$

The values of 400 seconds for  $t_{\text{const}}$  and the sensitivity of 0.4 db per degree C are based on laboratory tests. During the cruise, the variation of deck pressure value with ambient temperature was monitored. A least squares linear fit to the set of 73 deck pressure/temperature pairs collected had a slope of 0.49 and an offset of 5.4 db at 10°: this agrees with the applied correction to within 1.5 dbar over the range 0 to 20°C.

A final adjustment to pressure is to make a correction to upcast pressures for hysteresis in the sensor. This is calculated on the basis of laboratory measurements of the hysteresis. The hysteresis after a cast to 5500m (denoted by  $dp5500(p)$ ) is given in Table H1a for pressures at 500db intervals. Intermediate values are found by linear interpolation. If the observed pressure lies outside the range defined by the table,  $dp5500(p)$  is set to zero. For a cast in which the maximum pressure reached is  $p_{\text{max}}$  dbar, the correction applied to the upcast CTD pressure ( $p_{\text{in}}$ ) is

$$p_{\text{out}} = p_{\text{in}} - (dp5500(p_{\text{in}}) - ((p_{\text{in}}/p_{\text{max}}) * dp5500(p_{\text{max}})))$$

Two thirds of the way through the cruise, at station 12303, a slight hysteresis between the up and down theta-S relationship was noted. On the upcast salinity was lower than on the down. The size of the difference was small near the bottom of the cast, growing to a maximum of about 0.002 at about 3000 metres. At shallower depths the shape of the theta-S curve made it impossible to determine differences to the required accuracy. After some consideration, it was felt that the most likely cause of this was the CTD pressure (after the above correction for hysteresis) still reading slightly too high on

give better chromatographic resolution. Gases were forward flushed off the trap into a 3 m precolumn and subsequently chromatographcally separated using a 75 m long DB 624 megabore column. The precolumn was of the same material as the main column. Samples for analysis were drawn first from the Niskin bottles and stored under clean sea water. The analysis was completed mostly within 12 hours of the samples coming on board. Duplicate samples were run on most but not all casts due to the long analytical turn over time. Air samples were run daily from an air intake high up on the foremast. Air was pumped from this location through a single length of Dekoron tubing using a metal bellow pump.

#### Calibration

All CFC-11 and CFC-12 analyses were calibrated using 12 point calibration curves constructed from a gas standard calibrated by Weiss at SIO. This standard was contained in an Airco spectra seal cylinder as recommended in WHP, 1991. CFC-113 analyses were calibrated in a similar fashion using a compressed air standard prepared at the JRC and calibrated by Haine at PML.

#### Contamination

Because of a delay in customs clearance of the air freight, the CFC equipment was delivered to the ship less than 24 hours before departure. This delay had a knock-on effect and compounded a number of teething problems, mainly due to two blocked valves and a contamination problem which masked the CFC-12 chromatographic peak. This resulted in the loss of data from a number of stations at the beginning of the cruise. The nature and source of the contamination problems was never totally discovered. It seemed to be related to the aquarium baths and the non toxic seawater supply used for storing the syringes prior to analysis. The problem appeared some days after sailing and was overcome chromatographically by reducing the carrier gas flow and thereby separating the contamination from the CFC-12 peak. This meant that the overall analysis time was lengthened to 25 minutes and consequently restricted CFC analysis to every other CTD cast.

#### Comparison with historical data

Data accuracy was checked by comparision with Save leg 4 and 5 data and with data from the Ajax experiment. Some comparisons are given in Figure 6. Since four years has elapsed since these programmes some deviation in the data was expected particularly in the surface and deepest waters. In all cases deviations were consistent with the increase in atmospheric concentrations over the four year period.

## References

SMYTHE-WRIGHT, D., 1990a. Chemical Tracer Studies at IOSDL I. The design and construction of analytical equipment for the measurement of Chlorofluorocarbons in seawater and air. Institute of Oceanographic Sciences Deacon Laboratory Report No 274, 78 pp.

SMYTHE-WRIGHT, D., 1990b. Chemical Tracer Studies at IOSDL II. Method manual for the routine shipboard measurement of Chlorofluorocarbons in seawater and air. Institute of Oceanographic Sciences Deacon Laboratory Report No 275, 64 pp.

WHPO, 1991 WOCE Operations Manual. WHP Office Report WHPO 91-1 WOCE Report No 68/91. Woods Hole Mass, USA.

### 2.5 Samples taken for other chemical measurements

#### a) Oxygen and Hydrogen isotope ratios

by: S.M. Boswell

A total of 241 samples were collected from 12 stations for isotope analysis by UEA. These included 18 duplicate samples from station 12333. Samples were collected directly into 50 ml glass vials following an initial rinse and two filling/emptying method. The caps were then sealed using parafilm and stored in the refrigerator. A total of 8 samples from the first three stations were lost when the fridge opened in rough weather. Samples thereafter were stored in the cold store.

#### b) Iodine

by: P. Chapman

A total of 78 samples were collected from full water depth casts at Stations 12255, 12288, 12305 and 12335. These will be analysed by Dr G Luther, University of Delaware USA.

### 2.6 CTD Measurements

#### a) Gantry and Winch Arrangements

by: S. Jordan, R. Phipps, S. Whittle

Midships Gantry

This gantry is of a novel design, and basically acts in the manner of a parallelogram lifting table. While the gantry is moving from the inboard to outboard positions, the block from which the package is suspended describes an arc of a circle; due to the lifting action of the gantry, no winch movement is normally necessary while the package is being lifted outboard. Various loads, in our case the CTD package, can be safely deployed in virtually any sea state in which the ship can keep station.

The performance of the gantry surpassed expectations. One reservation of note concerns the leading of the wire around a number of sheaves required to make the wire follow the parallelogram shape of the gantry. On two occasions, during deployment and with the CTD package at the sea surface, there became sufficient slack in the wire for it to jump off one of the sheaves.

#### 10 Ton Traction Winch

The CTD package was deployed using the 10T Traction Winch. The maximum descent/ascent rate required was 60m/min, therefore only one boost and two main pumps were required for successful operation (two boost and four main pumps being available). The following problems were noted:-

- a) A bearing on the scrolling gear was found to be excessively worn. This was replaced with a minimal loss of scientific cruise time (25/12/92). Inspection of the bearing showed it to be incorrectly designed or assembled.
- b) The 37kW storage system hydraulic power packs failed to provide power, a fault which persisted after various valves were stripped, cleaned and reassembled (1/1/93). The fault was eventually traced to an erratically operating potentiometer (by P.Gwilliam and A.Taylor). Approximately 36 Hours of scientific time was lost.
- c) Inboard compensator and back tension adjustments were needed more or less continuously. Although these were carried out with no loss of scientific time, a satisfactory solution was not found on the cruise.

With known limitations the winch worked reasonably well and appears to have future expansion potential. It must be noted that the manufacturers intend to modify some of this system during the next ship refit, which should eliminate the problems encountered. The mechanical technicians are gaining more knowledge and confidence of the traction winch system and are especially pleased to have managed to repair/maintain the system with minimal down time.

#### b) Equipment, calibrations and standards

by: T.J.P. Gwilliam

The CTD equipment used on this cruise was the property of IOS. The following equipment was deployed on the CTD/multisampler underwater frame:-

1. Neil Brown MK. 3 CTD complete with Sensormedics oxygen cell. IOS identification: DEEP01
2. Sea Tech. 100cm folded path transmissometer. Serial No.: 35.
3. General Oceanics 10 litre 24 bottle rosette. Model 1015. IOS identification: 01.
4. Six SIS (Sensoren Instrumente Systeme) digital reversing thermometers and two SIS digital reversing pressure meters. Serial numbers are detailed elsewhere in the report.

5. Simrad Altimeter, Model 807-200M
6. IOSDL 10 kHz. pinger.

Backup equipment consisted of spare CTD, transmissometer, rosette, Niskin bottles, pinger and underwater frame.

The shipboard equipment consisted of two complete integral systems for demodulating and displaying the CTD data as well as controlling the rosette multisampler. Each system included the following major units:-

1. EG&G demodulator. Model 1401.
2. IBM PS2 PC system with 80Mbyte tape system for archiving the data.
3. EG&G non data interrupt rosette firing module.

Calibration of the MK3 CTD temperature and pressure sensors was carried out at the IOSDL calibration facility. Conductivity and oxygen cell calibration was carried out at sea by reconciliation with sample values. Reversing thermometers were also calibrated in the lab, three at IOSDL and four at the Research Vessel Base.

CTD temperature calibration - IOSDL DEEP01 - 19 June 92

CTD temperature was calibrated in degrees centigrade in the ITS-90 scale at six temperatures ranging from 0.19 to 25.3°. The transfer standard had been calibrated on 25 March 92 at the triple points of Mercury and water, and at the melting point of Gallium. The following linear fit for CTD temperature was found, with a rms error of 0.4 millidegrees.

$$T = 0.9986622 \times T_{raw} - 0.01282084$$

No post-cruise laboratory calibration is available at present (March 1993). The CTD equipment is required on *Discovery* for two subsequent cruises, and will not be returned to IOSDL until at least June 1993. Stability of temperature calibration during the cruise was monitored by comparison with reversing thermometers, and this is discussed in the description of reversing thermometer data.

CTD pressure calibration - IOSDL DEEP01 - 24 June 92

CTD pressure was calibrated by comparison with a Paroscientific Digiquartz model 240 portable transfer standard, in series with a deadweight tester; the Digiquartz was used as the pressure standard. The following quadratic fit for CTD pressure was found at an ambient temperature of 20°C, with a rms error of 1.8 dbar.

$$P = 3.066286E-07 \times P_{raw}^{**2} + 0.9978454 \times P_{raw} - 12.6$$

Further corrections were applied during data processing for variation of offset with temperature, and up/down hysteresis.

## Equipment performance

### General

With deployments at approximately four hourly intervals, power to the CTD was maintained throughout the cruise to minimise interruption problems. For satisfactory operation the optimum sea cable input voltage and current levels were 80 volts at 640 milliamps. Power distribution for the CTD, rosette and altimeter was controlled by a simple circuit in a separate 6 inch diameter pressure case mounted on the frame. The sea cable was terminated before sailing and a further three times during the cruise when cable damage occurred on deployment in heavy swell conditions. In two of the instances, the slack was sufficient to bounce the cable from the winch gantry pulleys, resulting in the instrument package free falling through the water for several metres. Approximately 30/40 metres of cable had to be discarded when this occurred.

### CTD

As usual at the start of a cruise, the oxygen sensor was renewed before installing the system into the underwater frame. The first cast, to test the winch and CTD system, highlighted a wiring fault with the conductivity electronics which was quickly identified and corrected. Before station 12287 (near mid-cruise) the conductivity cell was flushed out with 10% hydrochloric acid as data from the previous two stations had indicated contamination.

### 24 Bottle Rosette System.

It was this system that gave the most problems, non closing of bottles and double bottle closing producing a lack operational confidence. Cures seemed, at times, to be the result of a "black art" rather than engineering expertise. The pylon was washed down immediately after each recovery with hot fresh water and the mechanical switching mechanism lubricated with silicon oil before the next deployment. Several times during the cruise the operational rosette pylon (01) was serviced on the frame and also interchanged with the backup unit (IOS identification 02) for a more detailed mechanical inspection and overhaul.

The present system of codes, indicating bottle firing information, is not satisfactory. Misfire codes transmitted when one or more bottles had in fact closed, multiple trips that could not be identified, and a lack of cam position information are just a few of the problems that need to be resolved.

In one instance seawater ingress via the camshaft, on pylon 01, caused corrosion damage to the 24 way rotary code switch which had to be replaced. Perhaps there would have been greater protection had the switch been mounted on the shaft beneath the motor.

Prior to the cruise the springs in all the bottles had been changed for ones of a different type at the request of the CFC analysts: these alternative springs had a different length and tension from the originals. Unfortunately, during the cruise the spring fastenings on the bottle end caps were mechanically breaking down to such an extent that the original springs were restored. During the cruise, three bottles were changed as suspected "leakers".

#### Transmissometer.

The transmissometer worked well throughout most of the cruise, but there were times when noise on the data, although not at an unacceptable level, proved difficult to trace and eliminate. The voltage in air was 4.310 volts, and the blackout offset was 16 millivolts. Towards the end of the cruise a slight leak in the prism pressure balancing mechanism was observed, which will require attention back at the laboratory.

#### SIS Thermometers and Pressure Meters.

Apart from routine battery replacements, one unit, T228, was removed after station 12248; the temperature readings were found to be in error by several hundred millidegrees. Comparison studies with the CTD data to check stability and accuracy were carried out and the results are shown elsewhere in this report.

#### Altimeter and 10 kHz Pinger.

This was the first IOSDL cruise where "depth off bottom" information was included into the CTD data stream and digitally displayed on the CTD monitor: the results were very satisfactory. The unit invariably locked onto the bottom from a range of 200 metres and tracked to the depth required with no problems. The 10 kHz. pinger, working in conjunction with the ship's Echosounder had in the past been the only way of obtaining this information. As the cruise progressed, and confidence increased with the altimeter, the 10 kHz. system was used more in a backup role. Apart from requiring battery changes the pingers themselves were totally reliable.

#### Shipboard Equipment

Overall the deck equipment worked satisfactorily with only one minor problem on one of the 1401 deck units. The acquisition software worked well and 12 tapes of 80 Mbytes of backup CTD data were archived.

c) CTD Data Collection and Processing

by: B.A. King

Data Capture and Reporting

CTD data are passed from the CTD Deck Unit to a small dedicated microcomputer ('LevelA') where one-second averages of all the raw values are assembled. This process includes checking for pressure jumps exceeding 100 raw units (10db for the pressure transducer on the CTD) and discarding of spikes detected by a median-sorting routine. The rate of change of temperature is also estimated. A fuller account of this procedure is given by Pollard et al. (1987). The one-second data are passed to a SUN workstation and archived. Calibration algorithms are then applied (as will be described) along with further editing procedures. Partially processed data are archived after various stages of processing. CTD salinity and dissolved oxygen concentrations are reconciled with sample values, and any necessary adjustments made. CTD temperatures and pressures are compared with reversing measurements. The downcast data are extracted, sorted on pressure and averaged to 2db intervals: any gaps in the averaged data are filled by linear interpolation. Information concerning all the CTD stations is shown in the accompanying station list (either at the end of this report or in the accompanying .SUM file).

Temperature calibration

The following calibration was applied to the CTD temperature data:-

$$T = T_{raw} \times 0.998662 - 0.01282$$

This calibration was in degrees C on the ITS-90 scale, which was used for all temperature data reported from this cruise. For the purpose of computing derived oceanographic variables, temperatures were converted to the 1968 scale, using

$$T_{68} = 1.00024 T_{90}$$

as suggested by Saunders (1990).

In order to allow for the mismatch between the time constants of the temperature and conductivity sensors, the temperatures were corrected according to the procedure described in the SCOR WG 51 report (Crease et al., 1988). The time constant used was 0.20 seconds. Thus a time rate of change of temperature (called  $\delta T$ ) was computed, from 16Hz data in the levelA, for each one-second data ensemble. Temperature  $T$  was then replaced by

$$T + 0.2 \times \delta T$$

### Pressure calibration

The following calibration was applied to the CTD pressure data:-

$$P = P_{\text{raw}}^{**2} \times 3.066286E-7 + P_{\text{raw}} \times 0.997845 - 9$$

The calibration applied to the data included an offset different from that found in the lab calibration and given in section 2.5b. The chosen offset gave correct pressures on deck and over the top few metres of the cast. A further correction was made for the effect of temperature on the CTD pressure offset:-

$$P_{\text{new}} = P_{\text{old}} - 0.4 (T_{\text{lag}} - 20)$$

Here  $T_{\text{lag}}$  is a lagged temperature, in degrees C, constructed from the CTD temperatures. The time constant for the lagged temperature was 400 seconds. Lagged temperature is updated in the following manner. If  $T$  is the CTD temperature,  $t_{\text{del}}$  the time interval in seconds over which  $T_{\text{lag}}$  is being updated, and  $t_{\text{const}}$  the time constant, then

$$W = \exp(-t_{\text{del}}/t_{\text{const}})$$

$$T_{\text{lag}}(t=t_0+t_{\text{del}}) = W \times T_{\text{lag}}(t=t_0) + (1 - W) \times T(t=t_0+t_{\text{del}}).$$

The values of 400 seconds for  $t_{\text{const}}$  and the sensitivity of 0.4 db per degree C are based on laboratory tests. During the cruise, the variation of deck pressure value with ambient temperature was monitored. A least squares linear fit to the set of 73 deck pressure/temperature pairs collected had a slope of 0.49 and an offset of 5.4 db at 10°: this agrees with the applied correction to within 1.5 dbar over the range 0 to 20°C.

A final adjustment to pressure is to make a correction to upcast pressures for hysteresis in the sensor. This is calculated on the basis of laboratory measurements of the hysteresis. The hysteresis after a cast to 5500m (denoted by  $dp5500(p)$ ) is given in Table H1a for pressures at 500db intervals. Intermediate values are found by linear interpolation. If the observed pressure lies outside the range defined by the table,  $dp5500(p)$  is set to zero. For a cast in which the maximum pressure reached is  $p_{\text{max}}$  dbar, the correction applied to the upcast CTD pressure ( $p_{\text{in}}$ ) is

$$p_{\text{out}} = p_{\text{in}} - (dp5500(p_{\text{in}}) - ((p_{\text{in}}/p_{\text{max}}) * dp5500(p_{\text{max}})))$$

Two thirds of the way through the cruise, at station 12303, a slight hysteresis between the up and down theta-S relationship was noted. On the upcast salinity was lower than on the down. The size of the difference was small near the bottom of the cast, growing to a maximum of about 0.002 at about 3000 metres. At shallower depths the shape of the theta-S curve made it impossible to determine differences to the required accuracy. After some consideration, it was felt that the most likely cause of this was the CTD pressure (after the above correction for hysteresis) still reading slightly too high on

the upcast. Accordingly the size of the hysteresis correction was increased, so that upcast pressures read slightly lower, and Table H1b was used.

TABLE H1

(a) Laboratory measurements of hysteresis in pressure sensor  $dp5500(p) = (upcast - downcast)$  pressure at various pressures,  $p$ , in a simulated 5500m cast. (b) revised form of hysteresis used for stations 12303-12337

$p$	(a)	(b)
db	$dp5500(p)$	$dp5500(p)$
5500	0.0	0.0
5000	1.0	0.0
4500	1.2	1.2
4000	1.8	2.8
3500	2.4	4.4
3000	3.0	6.0
2500	3.4	6.8
2000	4.8	6.6
1500	5.6	6.5
1000	6.0	6.4
500	6.3	6.3
0	0.0	0.0

#### Salinity calibration

Salinity was calibrated during the course of the cruise, by comparison with sample salinities. This was done on a station by station basis. A cell conductivity ratio of 0.996683 was estimated from early stations, and this was applied to all station data as an initial calibration. The initial calibration was followed by the correction to conductivity ratio:-

$$C_{new} = C_{old} \times (1 - 6.5E-6 \times (T-15) + 1.5E-8 \times P)$$

After reconciliation with sample salinities, vertical profiles of residuals showed a systematic depth dependence. A final salinity calibration on a station by station basis was made by fitting the residuals with the form

$$a + b * T + c * P.$$

The need for this procedure is not understood. The offset at the bottom of each station introduced by the expression above, which may be used as a description of the drift of the cell, was monitored and varied between -0.006 and +0.004 (but not monotonically). A full list of the coefficients will be submitted with the CTD station data in due course.

#### Oxygen calibration

CTD oxygens were calibrated by fitting to sample values using the following formula:-

$$O_2 = oxsat(T, S) \times \rho \times \text{oxyc} \times \exp(a \times (W \times \text{ctdT} + (1-W) \times \text{oxyT}) + b \times P)$$

where the coefficients  $\rho$ ,  $a$ ,  $b$  were chosen on a station by station basis to minimise the rms residual.

The weight  $W$  was not fitted for each station, but rather was chosen in order to give the best overall fit of groups of stations. The fitting of oxygen data achieved at sea was not entirely satisfactory, rms errors were about 3-4  $\mu\text{mol/kg}$ . Also there was a tendency for the calibrated CTD data to produce the wrong oxygen gradient in the deep water. Introducing the time rate of change of  $\text{oxyc}$  had little effect but, in contrast, an offset in  $\text{oxyc}$  (of the order of -0.07  $\mu\text{A}$ ) produced a significant improvement. This will be fully discussed when the CTD data are reported. IOSDL has not previously found it necessary to introduce an offset in  $\text{oxyc}$  in order to achieve satisfactory oxygen fits, and the value required is rather greater than suggested in the WOCE Manual of operations and methods.

SIS thermometer data, and the stability of the CTD temperature sensor

Six SIS digital temperature meters and two digital pressure meters were used throughout the cruise. These, along with salinity and chemical data from the rosette water samples, were used to determine the depth of bottle firings.

#### Digital Reversing Temperature Meters (RTM)

The digital temperature meters were calibrated using the linear fits given in Table H2. In addition to these another sensor, T228, was discarded after the first station of the A11 cruise.

TABLE H2

Digital RTM calibrations.  $T_{cal} = b \times T_{raw} + a$

Position on rosette	Thermometer	b	a	Date off calibration	Source
1	T399	1.00031	-0.00331	20/7/92	IOSDL
1	T400	1.00006	0.00146	20/7/92	IOSDL
4	T401	1.00016	-0.01002	20/7/92	IOSDL
4	T219	0.99992	-0.01250	18/8/92	RVS
8	T238	0.99992	0.00175	18/8/92	RVS
12	T220	0.99999	-0.00570	18/8/92	RVS

A comparison of CTD and RTM temperatures is given in Table H3 below. The table has four parts. Parts (a) and (b) present data from the entire section, with part (b) for temperature colder than 2°; as expected, the latter have generally smaller standard deviations. Parts (c) and (d) show the data colder than 2° further subdivided about station 12293, which is one of the stations over the mid-Atlantic Ridge. Three numbers of observations are given in each part, corresponding to the number of differences greater than 10 millidegrees, considered as outliers and discarded, the number less than 10 millidegrees, from which mean and standard deviation are calculated, and the number within two standard deviations of the mean.

TABLE H3

## Summary of RTM data

(a) All Data												(b) T < 2°											
Pair	n	n	n	mean	sd		n	n	n	mean	sd												
	>10	<10	<2sd	mdeg	mdeg		>10	<10	<2sd	mdeg	mdeg												
	mdeg	mdeg		mdeg	mdeg		mdeg	mdeg		mdeg	mdeg												
ctd-T399	1	92	90	1.0	1.6		0	75	72	1.1	1.5												
ctd-T400	2	91	88	0.8	1.3		1	74	70	0.9	1.1												
ctd-T401	3	90	84	2.1	2.2		2	60	56	2.0	1.7												
ctd-T219	5	82	76	-6.7	2.3		2	56	52	-6.8	1.7												
ctd-T238	9	80	75	1.6	2.5		0	17	16	0.7	3.0												
ctd-T220	9	69	65	2.0	2.6		0	1	1	1.9	-												
T400-T399	0	93	89	0.4	0.9		0	75	72	0.4	0.9												
T401-T219	4	82	79	-8.7	1.8		2	56	55	-8.6	1.4												
(c) stnnbr < 12293												(d) stnnbr > 12293											
Pair	n	n	n	mean	sd	mean	n	n	n	mean	sd	mean											
	>10	<10	<2sd	mdeg	mdeg	temp	>10	<10	<2sd	mdeg	mdeg	temp											
	mdeg	temp		degC	mdeg	temp		degC		mdeg	temp	degC											
ctd-T399	0	38	36	0.6	0.9	0.33	0	36	35	1.9	0.8	1.19											
ctd-T400	0	38	37	0.3	1.0	0.33	0	36	35	1.6	0.9	1.19											
ctd-T401	1	39	37	2.0	1.5	0.60	1	20	19	2.2	1.8	1.46											
ctd-T219	0	36	34	-6.8	1.7	0.48	2	19	18	-6.6	1.5	1.46											
T400-T399	0	38	36	0.3	0.9	0.33	0	36	34	0.3	0.5	1.19											
T401-T219	0	36	35	-8.9	1.5	0.48	2	19	18	-8.9	1.1	1.46											

The most significant feature of these tables is the change in mean value of ctd-T399 and ctd-T400 between the two halves of the cruise, the mean difference changing by 1.3 millidegrees. This is rather more than the standard deviation of the measurement, and much more than the standard error of

the estimate of the mean for each group. Although this might be thought to indicate an offset in CTD temperature calibration (there being no change in the T400-T399 difference), there is no evidence for this in the ctd-T401 and ctd-T219 pairs. Our tentative conclusion is that the difference arises because the temperature observed at rosette position 1 is generally warmer in the eastern basin than in the western basin. Note the mean temperature of the observations, which is shown in the last column of table H3 (c) and (d). We suppose that nonlinearity in the response of either CTD or RTM temperature near zero may be the cause of the change in CTD-RTM difference. If it is the behaviour of the RTM thermometers that is nonlinear, then it must be very similar in the two thermometers; this is not unreasonable for two instruments of the same type. On the other hand, we do not exclude the possibility of nonlinear behaviour in the CTD temperature. When the CTD is recalibrated on return to IOSDL, careful attention will be paid to establishing the linearity or otherwise of the calibration near zero. In any case the overall consistency of the CTD and RTM comparisons and the magnitude of the change in differences amongst them strongly imply that there was no significant change in the CTD calibration between the start and the end of the cruise.

#### Digital Reversing Pressure Meters (RPM)

Two reversing pressure meters were used :-

Rosette position	Pressure meter
1	P6132H
8	P6075S

Despite the shortcomings in the RPM performances, which are described below, their data were very useful in confirming or identifying the depth of bottle closures.

Calibration of P6075S were carried out by the manufacturer on both 13.2.88 and 27 3 90 the latter at temperatures of both 3 and 20°C. These indicated that corrections of between -7 and +3 dbar were required over the range 0 to 5400 dbar. However residuals between the calibrated RPM and the CTD were found on cruise 199 to exceed 30 dbar at pressures greater than 3000 dbar.

P6132H was calibrated by the manufacturer on 22.2.90. Linear interpolation was used to correct the RPM between the following calibration values in dbars:-

(P6132H pressure, correction applied), (0006,-6), (0975,+6), (1949,+12), (2930,+12), (3915,+8), (4907,-4), (5405,-11), (6022,-22).

The last pair was not supplied by the manufacturer, but was an extrapolation of the manufacturer's information. In general, after applying the above calibration, P6132H shows a consistent offset compared with the CTD of about 14 dbars over the range 1800 - 6000 dbar.

Discrepancies of similar magnitude between RPM and CTD pressures have been noted on a number of previous IOS cruises, see for example the CONVEX cruise report (Gould et al, 1992). On cruise 199 the CTD bottom pressures were converted to depth and were compared with corrected Echosounder depths minus depth of CTD off bottom: the differences had a mean value of 3 metres and 75 percent were smaller than 12 metres. On the CONVEX cruise an even smaller mean for nearly 100 stations was found. We are therefore quite confident of the CTD pressure calibration and in the near future plan to carry out calibration and other tests of the RPM instruments at IOSDL.

## References

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### 2.7 XBTs

by: S.R. Thompson

XBT profiles during *Discovery* cruise 199 were collected using the Bathy Systems Inc. XBT program version 1.1 and SA-810 XBT controller, with the probes launched from a Sippican Corporation hand-held launcher. The inflection points calculated by the program were transmitted to the GTS network after each launch via the GOES satellite. ASCII versions of the raw data were transferred to the RVS level A using a diskette.

An intercomparison was carried out by comparing profiles made in a marked mixed layer with the surface temperature measured on the thermosalinograph in regions of low horizontal temperature gradient. Linear regression of TSG onto XBT temperature gave a slope of 0.99 and an uncertainty of 0.01, with an offset of 0.2° at 10°C.

Launch 107 was a calibration run using the test probe. This yielded 14.85° for a resistor chosen to give a value of 15.0.

Two problems were noted with the software:-

- 1) The bucket temperature information in the header does not appear to be saved. This means that if a file is not transmitted to the satellite immediately after the launch then the temperature must be re-entered in the header.
- 2) The column indicating whether the file has been transmitted sometimes fails to show a 'Y' after transmission.

Information concerning all the successful launches is shown in the accompanying XBT station list (end of the report). All launches were T7 probes unless marked otherwise and breaks in the launch numbers indicate probe failures, of which there were nine (eight T7 and one T5). Launches 101 to 125 did not form part of the A11 section

## 2.8 Acoustic Doppler Current Profiler (ADCP)

by: P.M. Saunders and R. Marsh

The instrument used was a RDI 150 kHz unit, hull-mounted approximately 2m to port of the keel of the ship and approximately 33m aft of the bow at the waterline. On this cruise the firmware version was 17.10 and the data acquisition software was 2.48. For most of its operation the instrument was used in the water tracking mode, recording 2 minute averaged data in 64 x 8m bins from 8m to 512m. On the shelf at the start and end of the cruise, the instrument was put into a mode in which both water and the bottom are tracked. Here 2 minute averaged data was collected in 50 x 4m bins from 6m to 200m depth.

The performance of the instrument was excellent throughout the cruise: on station, profiles were almost always recorded to 300m depth, and whilst steaming, except in the heaviest weather, profiles in excess of 200m were the norm. Data were passed in real time from the deck unit to a SUN workstation acquisition area: once a day, 24 hours of the data were read into the processing area.

Our processing has much in common with that of Griffiths (1992) except in one or two important respects, but for completeness will be outlined here. Stage 0 was to capture the 24 hours of data and write it into an appropriate format. Stage 1 consisted of correcting the time base for instrument clock drift and changing the time stamp from end of data period to centre of data period. Stage 2 consisted of applying misalignment corrections (to be described below), averaging data into 10 minute periods, merging with the ship's motion over the earth from GPS navigation and thereby deriving, by algebraic addition, current components averaged over the same interval. At this stage error velocities were displayed as time series to identify both depths of good data and periods of poor data: there were remarkably few of the latter.

Stages 3 and 4 of the processing were novel: average profiles were constructed in approximate 4 hour chunks whose boundaries were selected by inspection and corresponded to 'on station' and 'steaming' activities. Data for manoeuvring periods were excluded. The average profiles were identified by the station number, with the addition of the letter A to indicate the steaming period

after the station. A cruise data set was constructed by appending the files together and we expect to employ this modest body of data in a combined analysis with the hydrographic data. For more detailed studies of the Ekman layer, for example, and the response of the upper ocean to storm force winds, the 10 minute data set will be utilised.

As is well known, a key element in the determination of currents (water motion over the Earth's surface) from the ADCP is the ship's gyro. This allows the fore and aft and athwartships components of flow determined from the RDI instrument to be resolved into east and north components and so added to the ship's motion determined by navigation (GPS). The results are sensitive to gyro error, gyro drift, and the alignment of the transducers on the hull. In order to evaluate these errors, zigzag calibration exercises (Pollard and Read, 1989) were carried out on 4 occasions:- 24 December (courses 0°, 090°), 8 January (courses 045°, 135°), 21 January (courses 015°, 105°), and 31 January (courses 015°, 105°). The results from the first 3 calibration exercises showed a small increase in the misalignment angle from 0.5° to 1.0° to the right of the apparent gyro direction. On board the initial value of 0.55° was used in the preliminary analysis of the data. Ashore considerable post processing will be undertaken to correct for both mispointing and gyro errors (see the section 2.9c).

## References

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James Rennell Centre for Ocean Circulation Internal document No.4, 24pp.

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## 2.9 Navigation

### a) GPS-Trimble

by: P.M. Saunders and M.G. Beney

Navigation, i.e. ship position and velocity over the ground, was provided throughout the cruise by a Trimble GPS receiver. No rubidium clock was available so at least 3 satellites were required for a fix. The observations are interfaced via a level A microprocessor (see section 2.11 on computing) into the SUN acquisition system. In order to prevent hanging or crashing of the level A, which was of new design, the sample rate was set to 0 and data was logged at approximately 1 Hz. Editing of this data was carried out to exclude a small but tiresome number of zero times, zero latitudes, zero longitudes, northern hemisphere positions (!) or otherwise suspect data and subsampled at 30 second intervals. This data known as 'gps' was archived and provided coverage for approximately 95 % of the cruise.

In order to complete the navigation data set for 100 % of the time, during periods of absent or inaccurate GPS fixes the ship's gyro and Emlog data were combined to give a dead reckoning position. Such data is flagged and the data is known as 'bestnav'. Transit satellite data were not used on the cruise.

Positions were logged in port at the start of the cruise and a rms position error of approximately 30 m was found. Evidently selective availability was in operation at this time. Underway errors are known to be larger.

**b) Electromagnetic log and gyrocompass**

by: A.J. Taylor

Ship speed is determined by a Chernikeeff log with sensor head approximately 0.25 m beyond the hull of the ship. Because of a sensor failure on the previous cruise a new unit was installed in Punta Arenas and zeroed whilst at the dock. Initially when underway a nominal calibration was applied, but at 11.0 kt smg as determined by a navigation unit (decca Mk52), the indicated speed was 12.24 kt, so a scaling was introduced to bring the two into agreement. The same adjustment was made to the port/starboard component.

On January 8 the sensor head was rotated approximately 5° anticlockwise to reduce a spurious athwartship drift of about 1.3 kt at full speed. Improved log calibrations will be obtained by comparison with ADCP data (including the zig-zags) but because this will have a minor impact on 'bestnav' calculations we do not anticipate recalculating navigation for this reason.

Two S.G.Brown gyrocompass units (SGB1000) are installed on the Bridge. Because of a long lag noted with unit 1 on the previous cruise, unit 2 was employed for primary navigation throughout cruise 199. The output was logged via a level A microprocessor at 1 Hz and was free of gaps. The accuracy of heading is discussed in the following section.

**c) Ashtech GPS3DF Instrument**

by: S.R. Thompson

This instrument, newly acquired for the cruise, measures not only the position but also the three dimensional attitude of the ship from the GPS system, i.e. ship's roll, pitch and, most significantly for the ADCP work, heading. The determination of attitude is performed by an array of four antennas approximately in the form of a square of side 8m. Data were logged in the deck unit of the receiver at 0.2 Hz frequency (because the level A failed to work reliably) and down loaded to the SUN workstations twice per day.

King and Cooper (1993) have described details of the instrument, its installation and preliminary results on a 7 day trial cruise of RRS *Discovery*. They demonstrated that the gyro error is a function of ship's heading and also that it changes with time after a ship manoeuvre: in port they

confirm the accuracy claimed by the manufacturer of 0.05°. On cruise 199 we elected to use the second of the two ship's Gyro compass units, (i.e. a different one from King and Cooper), and our preliminary results show that this instrument also experiences gyro error related to the ship's heading and time-dependent errors after manoeuvring. Also long term drift of the gyro is apparent. For both instruments, these variations are of the order of 1°.

Data quality control was implemented in the manner described by King and Cooper (loc cit). For reasons not currently understood only approximately one third of one minute averages of the difference between Ashtech and gyro headings contain data, far less than they encountered at the same latitude in the North Atlantic. Ten minute average differences have also been constructed and assembled in 5 day summaries. These will be used in post processing of the ADCP data and are expected to bring significant changes especially for underway estimates of currents.

## **References**

KING, B.A. and E.B. COOPER, 1993. Comparison of ship's heading determined from an array of GPS antennas with heading from conventional gyrocompass measurements.  
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### **2.10 Underway Observations**

#### **a) Echosounding**

by: A.J. Taylor

##### **Equipment**

The bathymetry equipment installed on RRS *Discovery* consists of:- Hull mounted transducer, Precision Echosounding (PES) 'fish' transducer, and Simrad EA500 Hydrographic Echosounder.

##### **Operation**

The Simrad Echosounder was used during the cruise for bottom detection and determining the height of the CTD off the bottom during casts. While in bottom detection mode the depth values were passed via a RVS level A interface to the level C system for processing. Data were logged at a 30 second interval.

The transducers were connected to the Simrad equipment via an external switch. An uniform sound velocity of 1500 meters/sec was used during the cruise.

A visual display of the return echo was displayed on the Simrad VDU. Hardcopy output was produced on a colour inkjet printer and a Waverley thermal linescan recorder.

## Performance

While on station and steaming during the initial few weeks of the cruise, the PES fish transducer was used. This gave good return signals on station and adequate return signals whilst steaming at 10 knots. After the second week the return signal when steaming deteriorated rapidly and the hull transducer was used whilst underway. Upon recovery of the fish on day 025 prior to steaming for Capetown, it was found that the lowest section of fairing was split in two. This was probably hitting the fish and the cause of noise whilst steaming. The fairing was replaced before being re-deployed on day 028, and a good signals were obtained whilst underway for the remainder of the cruise.

When coming on station the PES fish sank considerably from its steaming depth: this resulted in a 17m offset between the PES fish and the hull transducer on the graphic display. The fish returned a lower depth than the hull transducer. The amount of cable submerged whilst on station was measured to be approximately 22m, thereby accounting for the offset.

The Hewlett Packard inkjet printer developed a fault after one week and was replaced by the Waverley linescan recorder. This was quite unreliable and was itself replaced, when a new inkjet printer was delivered by the Capetown pilot on 27 January.

As is well known the automatic depth finder performance is adversely affected when the signal to noise ratio is small. In these circumstances the digitally recorded data is frequently unreliable. Given strip-chart records the situation can be recognised and rectified. Except for the first few and the last few days, such records are unavailable on cruise 199. Consequently the overall quality of the depth measurements is very disappointing. (Note added by P.M.Saunders, 9 Feb '93).

### **b) Meteorological Measurements**

by: K.J. Heywood and P.K. Smith

The meteorological monitoring system used on RRS *Discovery* comprises the following instruments:-

an R.M. Young Instruments Type 05103 wind velocity propeller - vane sensor, located on the foremast to port.

two Vector Instruments psychrometers, located on the foremast to starboard (serial numbers 1072 and 1073).

(1073 was replaced by 1071 during the cruise).

two Didcot cosine collector PAR sensors (spectral range 400-700nm) located port and starboard on the foremast (serial numbers 0150 and 0151 respectively).

two Kipp and Zonen total irradiance sensors located on the foremast to port and starboard (serial numbers 92015 and 92016 respectively).

- an Eppley longwave pyrogeometer located on the foremast top pole (serial number 26207F3).
- a hull-mounted RVS/RS Components platinum resistance thermometer, recording sea surface temperatures.
- a Väisälä DPA21 aneroid barometer, located in the main lab.
- a Gill sonic anemometer located on the foremast to starboard.
- a shipborne wave recorder.

Unlike most shipboard instruments that have a dedicated Level A interface, the metlogger PC emulates a standard Level A interface and transmits the data directly to the Level B in Ship Message Protocol (SMP). The data are transferred to the Level C and then reformatted from Level C to PSTAR format to allow processing under Unix, using a series of pexec scripts based on the set of scripts used for the IOSDL Multimet system. Data were recorded as 1 minute averages.

#### Processing

The Unix shell script metexec0 was used to retrieve data from the Level C and convert them into PSTAR format. Metexec1 was used to calibrate all instruments apart from the aneroid barometer and wind direction output from the wind velocity sensor. Ship's navigation data including gyro heading (bestnav, derived from GPS and dead-reckoning) were merged with the met file by metexec2. Metexec3 and metexec4 were not normally used for this cruise. A combination of the ship's velocity components and heading was used in metexec5 for the conversion from relative to absolute wind velocities. Metexec6, an appending script was used to generate a full time series from the individual files, metexecp was used to produce plots, and the Pstar program metflx was used to derive wind stress and heat fluxes.

#### Calibration

With the exception of the aneroid barometer and wind direction output from the wind velocity sensor where any conversion or calibration is performed by the metlogger PC and were therefore logged through to the Level B as calibrated output, all instruments were calibrated during PSTAR processing of the met. data. The calibration algorithms applied were derived either from manufacturers calibration certificates or from calibrations undertaken by RVS and IOSDL prior to the cruise. Details are given in Table M1.

#### Problems encountered

##### Air temperatures

The RVS PC display system showed slightly higher readings than expected. This was due to the calibration coefficients being only nominal values. Also the calibration file used a 2nd order

polynomial, whereas the IOS calibration uses a 3rd order polynomial. Using the calibration data for each psychrometer, new values were calculated and entered into the calibration file. These gave good readings on the display. The correct 3 order coefficients were in the Pstar calibration file.

On 29/12/92 (day 364) the port psychrometer data became very noisy. It was replaced and new calibration coefficients entered into the calibration file (/pstar/src/extras/cal/met 199. cal). There is a gap in the port data between 1600 hrs and 1845 hrs. No further problems occurred during the cruise.

#### Long Wave Radiometer

This gave good readings at the start of the cruise, but began giving some low readings during 1st January (day 367). The signal slowly deteriorated becoming more erratic. The battery was replaced on 16th January (day 382) and good readings were obtained for the rest of the cruise.

#### Sonic Anemometer

The Asymmetric Sonic Anemometer was mounted on the foremast with North facing forward. The system gave good readings. The system stores processed data on both hard disk and floppy disk. To store the raw data an optical disk was installed with a capacity of 20 days' data. There was some difficulty in setting up the software but eventually the optical disk recorded raw data. There was some complex interaction between the system clock and the optical disk software. As the software needs the time and date information in the data files and in naming the files, the software halts if the internal clock is in error. This error occurred between once in 3 days to 3 times in a day. Re-booting and resetting the time and date resumed normal operation.

#### Ship Borne Wave Recorder

The computer and associated software worked well during the cruise with very few errors. The signal amplification/conditioning unit showed a large d.c. offset and low amplitude signal for the Port Pressure Transducer. This transducer was flushed, which considerably reduced the d.c. offset and increased the signal amplitude. Further flushing produced a further improvement but there was still a small d.c. offset and the amplitude remained slightly smaller than the starboard pressure transducer. The last calibration was at the refit and a d.c. offset was noted then.

#### Met Observations during the cruise

Weather conditions during the cruise were remarkably clement, with the exception of a storm in mid January. The maximum wind speed observed was  $28 \text{ ms}^{-1}$  on 13th January, producing the largest waveheights.

**TABLE M1**  
**Calibration coefficients for the met. sensors**

Measurement	Calibration coeffs				source if not IOS
	a	b	c	d	
Wind speed	0	0.1	0	0	mfr
Wind dirm	0	1.0	0	0	mfr
swet	-21.63646	2.580562e-3	7.893778e-6	0.660868e-9	
sdry	-20.18834	9.733870e-4	7.835114e-6	0.525038e-9	
up to day 364					
pwet	-23.71101	6.848060e-3	5.626587e-6	1.077627e-9	
pdry	-23.84735	5.788879e-3	5.648462e-6	0.907665e-9	
after day 364					
pwet	-24.38268	6.720888e-3	5.840227e-6	0.969597e-9	
pdry	-23.36777	5.245053e-3	5.784058e-6	0.882978e-9	
sea	0.26705	0.99189	2.9755e-4	0	RVS
longwave	0	0.23364486	0	0	

$y=x/(ab)$

pPAR	5	12.86e-6
sPAR	5	12.87e-6
pirr	2	48.49e-3
sirr	2	43.63e-3

**c) Thermosalinograph measurements**

by: S. Cunningham

Instrument and Technique

Continuous underway measurements of surface salinity and temperature were made with a Falmouth Scientific Inc. (FSI) shipboard mounted thermosalinograph (TSG). Salinity samples were

drawn from the non-toxic sea water supply at four hourly intervals, and used to calibrate conductivities obtained from the TSG. The instrument was run continuously throughout the cruise.

The TSG comprises of two FSI sensor 'modules', an Ocean Conductivity Module (OCM) and an Ocean Temperature Module (OTM) both fitted within the same laboratory housing. Sea surface temperature is measured by a second OTM situated on the suction side of the non-toxic supply in the forward hold. The non-toxic intake is 5 m below the sea surface.

Data from the OCM and OTM modules are passed to a personal computer (pc). The pc imitates the traditional Level A system, passing it to Level B at 30 second intervals.

#### Sensor Calibrations

The temperature modules are installed pre-calibrated to a laboratory standard and laboratory calibration data are used to obtain four polynomial coefficients. A similar procedure is employed for the conductivity module.

#### Underway Salinity Sampling

Salinity samples were drawn from the non-toxic supply at four hourly intervals. These samples were then analysed on a Guildline 8400 using standard sea water batch P120.

#### Calibration of TSG Salinities against Underway Salinity Samples

TSG conductivity measurements at 30 second interval were median despiked, discarding data more than 0.01 mmho/cm from a mean computed over 5 adjacent data values. Conductivity of the bottle samples was calculated at a pressure of 0 dbar and at the temperatures of the TSG OTM. The TSG data were merged onto the bottle data and the conductivity difference between the bottles and TSG calculated. After excluding outliers, a linear regression between the conductivities was determined and applied to the TSG values. TSG salinities were computed along with the difference from the bottle salinities. This difference was filtered with a Gaussian filter of half width 12 hours and normalised peak height of 0.38. TSG salinities were then corrected by adding the filtered difference. A plot of the corrected salinity and temperature at the surface for the entire cruise is shown in Figure 7.

#### Estimate of the TSG accuracy and salinity residuals

Due to particular difficulties with the instrument, the estimate of salinity residuals has been split into two portions. For the period day of year=359 to day=23 (389) the mean difference between the bottle and TSG salinities was -0.0009 with a standard deviation of 0.0145. For the period day=23 to day=32 the mean salinity difference was 0.0005 with a standard deviation of 0.02.

Over the period from 23 0000Z to 27 0825Z the housing temperature sensor produced unreliable results. A current leakage was found between the platinum resistance thermometer and the

surrounding seawater. This caused the probe to oxidise and eventually fail. At about the same time the pumps for the non-toxic supply failed and an alternative set were switched on. This caused a decrease in the flow rate and a corresponding increase in lag time for water from the non-toxic intake to reach the TSG, from approximately 5 to 10 minutes. Degradation of the conductivity results is likely. On day=26 at 0555Z the housing OTM was replaced. For the period 23 0000Z to 26 0555Z a reconstructed housing temperature was derived from the remote temperatures. Given the uncertainties in lag time and the alternative heating and cooling of the non-toxic supply through the ship (during this period for surface temperatures less than 20.2°C the supply is warmed and above that cooled) the reconstructed temperatures are not likely to be better than 0.2°C. The uncertainty probably accounts for most of the spread in the salinity residuals over this latter period.

**d) Satellite Image Acquisition and Processing**

by: M.P. Meredith and V.C. Cornell

Equipment and function

On this cruise equipment was installed for the capture, display and processing of polar-orbiting weather satellite imagery. This consisted of an omnidirectional VHF antenna mounted on the main mast, a pre-amplifier to compensate for feeder cable losses of up to 10db, a Dartcom system II receiver, an 8-bit 15MHz microcontrolled interface to control the frequency and mode of the receiver, and an Apple Macintosh IIxi computer with the MacSat 2.1 software supplied jointly by Dartcom and Newcastle Computer Services.

The equipment was used to receive data sent from the NOAA satellites 10, 11 and 12 via the Automatic Picture Transmission (APT) system at 137.50 and 137.62 MHz. Although the software allows the capture of geostationary weather satellite images, the hardware necessary for this was not present. No attempt was made to capture images from polar-orbiting satellites other than the NOAA series.

The data collected were from the Advanced Very High Resolution Radiometer (AVHRR), a five-channel radiometer featuring one visible, two near-infra red and two thermal infra-red channels, though the APT system only allows for the visible channel plus one infra-red channel to be received. The APT system also reduces the spatial resolution of the data from its maximum of 1.1 km square at nadir to approximately 4 km square. Data from almost all the radiometers' swath width is captured with MacSat; an 800 x 800 pixel image covers approximately 3000 km square, and has a maximum of 256 digitisation levels per pixel.

Procedure

During the cruise, most of the longer satellite passes (>12 minutes) were captured. Shorter passes generally did not contain enough noise-free data to warrant their capture. The vast majority of images were from the infra-red channel, since the previous cruise experienced serial error problems

with the Auto Save function (the function enabling both channels to be acquired simultaneously), which led to the loss of the images. Thus only one of the two channels was available, and the infra-red data were deemed more useful than the visible for our purposes.

Once captured, the time/date, ship's position, and whether the satellite was in an ascending or descending pass was recorded, and a geographical overlay created for the image. This shows lines of latitude and longitude, ship's position at time of acquisition, and, if relevant, a coarse coastline. Three standard colour palettes were created to enable depiction of sea brightness temperature. One would not suffice since the manual contrast stretch facilities of MacSat (adjusting the RGB response curves for the image) were found to be very cumbersome, and the Auto Contrast function is only useful for grey scale images.

Colour hardcopies were produced for each image by using the Mac's screendump tool. This creates a TeachText picture of the screen, which can then be printed to a postscript file, transferred to the Sun workstations using ftp, converted to a PCL file and outputted to the HP Paintjet printer. This was considered a better procedure than using MacSat's print option, since not only can the whole image be displayed on one A4 sheet, but the geographical overlay can be also be printed on the image.

Some images were transferred to more sophisticated image processing software on the Suns; this, along with the image file format and file archiving, is discussed elsewhere.

#### Problems

Difficulties encountered on the previous cruise concerning the gross inaccuracy of the geographical overlay were to a large extent resolved. Updated files containing the Keplerian orbital elements for the satellites were obtained by fax from Newcastle Computer Services on two occasions as a matter of course, and on a third (1st Jan), when an error in the orbital element calculations became apparent. Also, the Mac's internal clock was corrected each day, since it gains approximately one second per day on GMT. Such an error is not insignificant for satellites travelling at 27,000 km/h, and would greatly affect the positioning of the overlay if left unaltered for a number of days. However, even with these measures being taken, the overlay could still be as much as a degree or two out, and the uncertainty should be borne in mind when considering images without coastline in them.

Noise contamination of images was a frequent problem, and although MacSat has a noise reduction filter, this is of use only for presentation purposes and obviously cannot replace missing data values. Whether the problem was caused by atmospheric conditions, insufficient signal amplification or faulty hardware remains unknown.

A further unsolved problem is the overlay tool's failure to plot lines of latitude for descending satellite passes. We think this can only be attributable to a bug in the program.

Initially, difficulties were encountered with the loss of images due to serial errors during acquisition. This was caused by a slowing of the Mac to the point where it could not keep up with the

incoming data stream, and was solved by ensuring that there were no telnet connections active, no print jobs queued and no appleshare volumes present on the workspace at the time of capturing an image.

#### Observations

Several significant oceanographic features were observed in the satellite imagery captured during the course of the cruise. The retroflexion of the Falkland Current at the Brazil Current was clearly visible, and when the thermosalinograph (TSG) showed an increase in temperature, the MacSat image revealed a warm ring shed from the conflict of the two currents. Many of the images showed the position of the Subtropical Front to the north of the cruise track, and, towards the end of the cruise, the coastal upwelling region associated with the Benguela Current is clearly visible. An Agulhas ring was possibly observed, but not certainly, since cloud contamination partially obscures the feature. The cloud images also proved illuminating, especially during the severe storm encountered on the 13/14th January 1993.

#### 2.11 Shipboard computing

by: M.G. Beney and V.C. Cornell

##### RVS logging System 'ABC'

The RVS logging system comprises of 3 distinguishable parts or levels. Each level is referred to by one of the following letters A, B or C, and the whole system is called the 'ABC' system.

A Level A consists of a microprocessor based intelligent interface with firmware which collects data from a piece of scientific equipment, checks and filters it, and outputs it as SMP (ship message protocol) formatted messages.

There are two versions of dedicated Level A's, a MkI based on a 8085 processor using CEXEC as the operating system, and a MkII based on a 68000 processor running OS9 as the operating system. In addition there are pseudo Level A's which are PC's around which a piece of equipment is based, which are also capable of generating SMP messages.

The Level B collects each of the Level A SMP messages and writes them to disk and backup cartridge tape. The Level B monitors the frequency of these messages, and besides providing a central display for the data messages also warns the operator when messages fail to appear. The Level B, which is based on a 68030 processor using OS9 as the operating system, collates the data and outputs it to the network.

The Level C, which is a SUN IPC (4/40), takes this data and parses it into RVS datafiles. These datafiles are constructed on a RVS styled database for speed of access.

The following list shows the instrument Level As and the variables which were logged by the Level C. The first column shows the name used by the Level A. Brackets after the Level A name indicate whether it was a MkI (1), MkII (2) or IBM compatible PC (PC), based Level A. The "adcp" data was collected directly by the Level C through one of its serial ports (ttya). The data was written to the datafile named in column 2 with the variable names shown in column 3.

Level A	Datafile	Variables
BOTTLES(1)	bottles	code
CTD_17C(2)	ctd_17	press temp cond trans alt oxyc oxyt temp2 cond2 deltat nframes
GPS_ATT(2)	gps_att	hdg pitch roll mrms brms attf sec
GPS_TRIM(2)	gps_trim	lat lon pdop hvel hdg svc sl-s5
GYRO_RVS(2)	gyro_rvs	heading
LOG_CHF(2)	log_chf	speedfa speedps
METLOGGR(PC)	metloggr	winspd windir pwettemp pdrytemp swettemp sdrytemp seatemp ppar ptir spar stir lwave baro
MX1107(1)	mx1107	lat lon slt sln el it ct dist dir sat r status
SIM500(2)	sim500	uncdepth rpow angfa angps
SURFLOG(PC)	surflog	temp_h temp_m cond
WAVE(1)	wave	height
WINCH(PC)	winch	cabltype cablout rate tension btension comp angle

The following list shows datafiles which contained data directly collected by the Level C

adcp_raw	rawamp1 beamno bindepth
adcp	bindepth heading temp velew velns velvert velerr ampl good bottomew bottomns depth
xbt	depth temp

The following datafiles were archived:- relmov gps mx1107 bestnav bestdrf winch wave metloggr surflog adcp adcp\_raw ctd and xbt. These RVS archives have only limited life and are only intended as (fall-) backups.

#### Processing of data

Virtually all of the data processing was performed using the interactive "pstar" suite of about 300 documented programs (Alderson et al,1991). This continuously updated system is installed on RVS ships as well as at labs ashore. RVS datafiles were converted to "pstar" datafiles using the program 'datapup'.

#### Archiving of pstar files

Archiving took place on a daily basis. Copies were made of all processed files on Sony erasable magneto-optical disks. These were mounted as standard unix file systems. In addition files were copied to Quarter Inch Cartridge (QIC) tape in both raw sequential and unix tar format. Six sides of optical disk data were taken ashore at the end of the cruise, totalling about 1.5 Gigabytes.

#### Equipment available on cruise 199:-

##### Personal Computers (Operating under Apple system 7.01)

3 Apple Macintosh Classics (40Mb Hard Disc, 4Mb RAM)

1 Apple Macintosh ClassicII (40Mb Hard Disc, 4Mb RAM)

1 Apple Macintosh II si (80 Mb Hard Disc, 5Mb RAM)

The last was connected to a Dartcom System II satellite image receiver.

##### Sun Workstations (Operating under Sunsoft's version 4.1.1)

Nodename	Type	Ram	Hard Disc	Peripherals
			(Mb)	(Mb)
discovery1	IPC	12	2x327	Exabyte drive
			1x207	QIC 150 tape
discovery2	IPC	12	1x207	Magneto/optic
			1x1200	QIC 150 tape
discovery3	Sparc stn	8	2x327	
discovery4	Sparc stn	8	2x237	

Output devices:-

Apple LaserWriter II (Mono Laser Printer).

Hewlett Packard Paintjet XL (InkJet Colour Plotter).

Tektronix 4693RGB (Thermal transfer plotter).

Hewlett Packard LaserJet III (Mono Laser Printer).

NEC Pinwriter P5 (Dot Matrix line printer).

Bruning Drum-type Pen Plotter.

### Networking

All PCs, workstations and a number of output devices were connected to a thin ethernet (10Base2) local area network. The Sun workstations have integral ethernet interfaces, the Apple Macintoshes were connected via external SCSI ethernet interfaces.

### References

ALDERSON, S.G., GRIFFITHS, M.J., READ, J.F. and R.T. POLLARD, 1991. PEXEX PROCESSING SYSTEM, Internal document, Institute of Oceanographic Sciences Deacon Laboratory, about 450 pp.

### 2.12 Cruise diary

by: P.M. Saunders

22 December Day 357/1992

RRS *Discovery* left Punta Arenas at 1700P (1400Z) with a pilot aboard, about 9 hours later than planned. All times are given as ship's time and the relation of ship's time to GMT stated whenever the relationship is altered. The delay was occasioned by the late arrival of the customs paperwork for the various items of air freight. Amongst these was the CFC equipment which came on board, late on the 20 December. A new emlog was installed and an arbitrary calibration applied to yield reasonable ship's speed. The navigation and the Acoustic Doppler current Profiler (ADCP) were logged from departure.

23 December Day 358

Calm seas, some pitching motion as course is set 050° across the Argentine shelf 0430 (0730Z). At 0900 the first officer gave a safety briefing and this was followed by a science briefing by the PSO.

At 1030 there was fire and boat drill, followed by a tour of the ship pointing out escape routes etc. Around 0130P (0430Z) the thermosalinograph was started up. At 0200 the Echosounder fish was streamed and after repairs to the fairing clips RRS *Discovery* resumed speed.

24 December Day 359

Given continuing fair weather it was decided to undertake an ADCP calibration exercise; this was performed between 1300 and 1600P. The results were satisfactory. See the ADCP account in this report.

25 December Day 360

A trial of the midship winch was undertaken as station 12238 between 0628 and 0729P. A depth of 500m was reached and, after recovery, repairs were made to the winch scrolling gear and to the CTD, so that the exercise proved fruitful. Whilst the RRS *Discovery* continued northwards towards the latitude 45°S, crew and scientific party celebrated the festive occasion.

26 December Day 361

A test station 12239 was started in approximately 4000m of water at 0830P and was concluded about 1130P. The Rosette jammed after 5 firings and the ctd display was very noisy. The new altimeter unit worked well. Lanyard tensions were reduced and some cables replaced. An XBT was launched. A second station at the same location (45° 00'S 47° 30'W) 12240 to a depth of 2500m was more successful. With the wind 25-30kts samples were drawn on station, and at 1810P the ship turned west into an ADCP/XBT section. Some light rolling ensued.

27 December Day 362

A murky drizzly foggy morning turned into a bright sunny afternoon as 8 XBT/ADCP stations (12240-12247) were occupied in all. The wind died away and during passage, a tongue of cool surface water circa 8.5°C was encountered with warmer water 11.5°C to both west and east; it was the Falklands current.

#### **COMMENCEMENT OF THE A11 SECTION (45°S, 60°W)**

At 2000P station 122047, the first in the transoceanic section was begun: the water depth was about 250m and the initial objective was the Mid Atlantic Ridge nearly 1900 miles away. In order to assure good ADCP data, stations in the western boundary current were assigned a minimum duration of 2 hours.

28 December Day 363

Overnight stations in 500m, 1000m, and 1500m were occupied in calm seas the last within and close to the western edge of the Falklands current. Stations continued at 500m spacing down the slope, with spacing that varied between 3 and 30 n-miles.

29 December Day 364

Overnight the wind increased sharply and reached 35kts but by 0800P it decreased to 20kts under cloudless skies. Approximately 125kg of lead was removed from the rosette to reduce wire tension for the deeper casts. On station 12256 started near noon and completed at 1600P the deep western boundary current was detected; a nepheloid layer of thickness 400m defined it, at a depth below 4350m. The weather was fine enough for maintenance of the psychrometers on the foremast to be carried out.

30 December Day 365

Overnight the wind increased from the west to 30kts and the sea began to build. Station 12258 was begun at 0250P and after the cast had reached 2500m the ship's bow-thruster malfunctioned and the CTD/Rosette were recovered by 0450P. After repairs a second cast to the station was begun; it reached 5500m and was completed by 1240. (Subsequently it was learned that one of the motors that rotated the thruster needed parts which were not available on board.) Use was made of the railway to move the rosette to a protected position for sampling. This proved helpful.

Station 12259 was carried out between 1650. and 2150 to a depth of 5630m; by now seas had built and some difficulties were encountered in hauling at the bottom of the cast. Fire and boat drill engaged those not involved directly in station work.

31 December Day 366

At 0000 the ship's master-clock decided it had started a new year and clock day was reset to 0. Some difficulties are to be expected in the subsequent processing of the data!!

At this same time a station was started in about 5770m of water with strong SW squalls and high seas. This proved unwise. About two hours later it became quite evident that coupled with a strong current shear, the wire could no longer be controlled. Accordingly stn 12260 was abandoned at a depth of about 2800m. During the day wind and sea subsided and soon after midday stn 12261 was begun in 5900m of water. The station reached within 20m of the bottom where a very strong nepheloid layer was encountered and all gear was recovered by 1700. The performance of the winch in these circumstances was very satisfactory. At 2200 station 12262 was begun, again in nearly 5900m of water; the maximum expected water depth for the section was found between these latter casts.

#### 1 January Day 001/1993

The new year was welcomed whilst completing the station. Again a very strong nepheloid layer was seen. Unfortunately apart from this success little else went right on the day.

At 0600 the ship hove to on station; RRS *Discovery* remained in this vicinity for the remainder of the day as both the engineers on board and those at the RVS base, over 6000n-mi away, attempted to diagnose and repair a defunct winch. The timing was inopportune, occurring on a bank holiday followed by a weekend. To ensure a quiet night, there was no work programme.

#### 2 January Day 002

After considerable effort overnight the problem was identified. A faulty electrical component in the control logic circuit was found and replaced with an identical unit from the main winch, which was unserviceable. At about 0630 a series of shallow lowerings was begun: these were employed to fix the winch control settings, which were quite different from those prior to the breakdown. At 1620 station 12263 was begun in approximately 5750m of water, in the location arrived at approximately 36 hours earlier. The weather for this entire period had been (gallingly) fine. Immediately after launch the transmissometer failed, due to a cable connection adrift, but the cast was continued to full depth. On subsequent stations the transmissometer performed well.

#### 3 January Day 003

The normal routine of station work was resumed with XBTs at a location midway between CTD casts. Mud waves were spotted and the chart recorder of the Echosounder which had been malfunctioning repaired and activated. At 1204 the level B system stopped logging and approximately 8 minutes of data was lost. This was during station 12265. The CTD data was recovered from the deck unit PS2, but other data was lost. On the following station 12266 a strong nepheloid layer was again seen, suggesting strong currents on the abyssal plain.

#### 4 January Day 004

Fine weather and a flat calm prevailed and the depth of the abyssal plain continued to shallow. A large school of pilot whales investigated RRS *Discovery* on station 12269, which was also noteworthy because the rosette jammed in position 13 and all shallow samples were lost. As the ship steamed away from the station the flanks of the Zapiola ridge were encountered at 2000P. The action of the Echosounder chart recorder continued erratically. CFC measurements were halted because of contamination.

#### 5 January Day 005

On station 12270, 0100 - 0500P, the Rosette jammed at or near position 13 and samples were not collected at shallow depths. Since the previous station had experienced a similar sample loss, the failure to add a second shallow cast was unfortunate. Samples were collected in the rain but the protection of umbrellas was deemed unnecessary. After station 12271 a NEly wind came up and the ships progress was hindered. The ADCP lost penetration and subsequent analysis revealed the presence of the bogus "current following the ship" of  $50-80 \text{ cms}^{-1}$  always(?) seen when heading into a sea. On station 12272 the rosette again jammed at mid bottle so a second cast was made to 1500m depth.

#### 6 January Day 006

On the overnight station 12273 bottles 9 10 11 were not cocked but the Rosette again malfunctioned so that after the samples were drawn the Rosette was stripped of all equipment for an overhaul. The spare Rosette (No 2) was mobilised and functioned satisfactorily for the next station. The wind and sea were subsiding but low temperatures prevailed as the *RRS Discovery* re-entered the sub-Antarctic zone.

#### 7 January Day 007

On the overnight and morning stations the rosette performed satisfactorily but on station 12277 all bottles were closed below 1500m so a second cast was undertaken. Together the casts lasted from 1115 to 1745. After the Zapiola ridge with crests near 4900m, stations were now on the abyssal plain with depths over 5300m. At 1615 there was fire and boat drill. The performance of the ADCP continued poor and air was bled from the sensor pod without significant improvement.

#### 8 January Day 008

The clocks were advanced 1 hour at 0001P so that ship time was now GMT-2. Station 12278 at 3545W which was completed at 0200 in a flat calm had a depth of 5470m and was the maximum reached between the Zapiola ridge and the mid Atlantic ridge; on this and subsequent stations the measurements differed substantially from the GEBCO chart. Mud waves continued to be seen.

At 1530 in continuing flat calm seas the emlog, which had shown a cross track drift of about 1.3 kts, was rotated anticlockwise about  $5^\circ$  to a more nearly correct direction. On the completion of station 12280 at 1740 a second ADCP zig-zag calibration exercise was begun to attempt to verify the gyro drift measured by the Ashtech GPS receiver. The experiment concluded at 2100 still in very calm seas.

9 January Day 009

In the early hours of the following morning a seal was spotted close to the ship and the barometer began to fall. At 0900 ships time the wind began to freshen from the Southeast and the barometer fell precipitately. At the start of station 12283 the wind was 45 kts from the south; almost immediately it began to diminish and by the end of the station it was only 25 kts. The lowering and handling of the ctd was straightforward despite the conditions.

A comparison was made between measurements made on leg5 of SAVE near 45S and 41W (stns 290-293) and those on this cruise (12269-74). The salts and nitrates were in good agreement, the oxygens about 1.5% low and the silicates 3% low.

10 January Day 010

During the night the wind continued to come westerly and the considerable swell caused heavy rolling. This was uncomfortable for the ship's complement and on station led to very heavy snatch loadings. For the first time significant irregularities arose in the lay of the wire on the storage drum. At about 0745 station 12285 was commenced. About 4m down a high swell caught the Rosette and the wire was instantaneously so slack that it jumped off the sheave pair at the foot of the gantry. The wire was stopped off on the top of the Gantry, and inboard the wire was paid out, correctly rerouted and the load taken up again. The package was recovered on deck and a large kink located; about 20m of wire was cut off and the end reterminated.

At the same time the Rosette No 1 was restored since No 2 had starting registering numerous misfires. The station was then restarted at 1000 after a delay of 2hours 15 minutes, and proceeded normally until about 3500m on recovery when attempts were made to improve the lay of the wire on the drum. Eventually the station was completed at 1500. Meanwhile the sea was subsiding. BAK reported a green flash at sunset.

11 January Day 011

The day started fair and concern for the CTD performance proved unnecessary. The regulation 3 stations were performed and the first coloured macsat images with a grid of lat and lon lines and the position of the ship were printed. Some but not all of these features had been available previously. Prior to station 12289 two lead weights (125kg) were restored to the Rosette in order to improve the shallow descent rate on the down cast.

12 January Day 012

A stiff northerly blew up during stn 12291 (1040- 1400) now in only 4400m of water. The next stations were accompanied by increasing rigour of the conditions. On both of them the Rosette was

moved forward on the railway and sampling was undertaken on station. The wind and sea increased although during the evening the sky cleared.

#### 13 January Day 013

At midnight the ship's clock, on which time this log is based, was advanced one hour to become GMT-1. On station 12293 in 3500m of water (0130-0430) conditions deteriorated markedly and by recovery the wind was blowing 45kts gusting to 55. The wind was now from west north-west and despite clear skies continued to blow a gale; the seas were the largest seen on the cruise so far. We remained jogging, ie going slowly upwind, for the rest of the day. The ADCP functioned well and remarkable inertial oscillations were seen with an amplitude exceeding 50 cms<sup>-1</sup>.

#### 14 January Day 014

After midnight the wind began to build again and by 0400 reached 50-60 kts, slowly backing to the south of west. The seas were, without exaggeration, mountainous with continuous spume blown from the crests. The pitching of the ship was severe but tolerable but the occasional heavy rolling was very uncomfortable. Not surprisingly the ADCP functioned only poorly. During daylight hours wind and seas moderated only very slowly and not until 2000 was the ship able to run before the seas towards the next station position.

#### 15 January Day 015

At 0320 RRS *Discovery* arrived on station and the work programme was resumed. The seas were moderate - as was the performance of the Rosette. A second cast was made to 1000m to collect samples in the upper ocean. The decision was made to increase station spacing to 50 nautical miles for the foreseeable future.

#### 16 January Day 016

A series of routine stations were made in shallowing water depths, until on station 12298 (1050-1300) in 2500m of water the crest of the Mid Atlantic Ridge was reached. A mid-cruise break and PES survey had been planned but in view of the recent enforced delay this was no longer possible. By now the sea had quieted down and the skies were clear.

#### THE TURNING POINT ON THE A11 SECTION (45°S, 15°W).

At 1300 RRS *Discovery* steamed away on a course 059° towards the coast of South Africa and the conclusion of the section just over 1700 miles away. Within a short time a large iceberg was sighted (!) and at 1500 was passed at a range of 6 miles.

17 January Day 017

A day of calm seas and routine station work. Having crossed the ridge warmer water is encountered at all levels. A new inductive FSI conductivity cell is fitted to the CTD and yields encouraging results. A substitute Echosounder chart recorder is in action at last. Light rain fell about 1930.

18 January Day 018

At 0000 ships time the clocks are advanced 1 hour so that ships time and GMT now agree. A sunny morning gives way to a rainy cloudy afternoon; by 1900 the wind is northerly blowing 25-30 kts. The umbrellas and their clamps on the Rosette frame are in use for the first time. The transmissometer develops intermittent and persistent noise; it is not clear whether the noise is oceanic or instrumental. Casts continue at a 50 mile spacing up to station 12306 (2015 - 2345). The surface temperature remains near 13-14°C. I had expected it would rise before now.

19 January Day 019

An eventful day. After the station it was decided to resume a 42 mile spacing which had been characteristic of the leg on 45S. During steaming between stations 12307 and -8 two remarkable topographic features were encountered. The first of these was seen at 0930 (XBT 72) at location 40 58S and 6 01W; a seamount was detected rising to about 2300m from a sea floor near 3700m. This was tentatively identified as the flanks of the Admiral Zenker seamount. As the proposed site of the CTD station was neared, a second seamount was observed. This rose to a depth of 750m at 1054 at which point XBT 73 was dropped, 40° 48'S 5° 40'W. The seamount was flat topped (a Guyot) and for a distance of about 6 miles the depth was less than 1000m. A further 8 miles on, station 12308 was completed in 3700m of water. There is no indication of the seamount on any charts available to us; the name *New Discovery Seamount* is proposed. An overcast morning gave way to a sunny day although a brisk NWly wind persisted.

20 January Day 020

Station 12310 started in conventional fashion just before 0100, but as the Rosette was raised towards the surface a wave carried it upwards, the wire went slack and jumped off the sheave pair at the foot of the Gantry. This was a repeat of the event of station 12285 on the 10th of January. Eventually the package was recovered, 35m of wire removed, a new termination made and the cast restarted about 0300.

For much of the day a moderate Westerly swell persisted and made the station work slightly difficult for the winch drivers. At the end of station 12311 when the package was recovered a kink was

found in the wire which required cutting off about 10m of wire and a retermination - for the second time in the day.

21 January Day 021

During the night the swell diminished and station 12313 in over 5000m of water allowed the wire lay on the drum to be improved substantially. Surface water temperatures have now risen to 16°C but the absence of a marked subtropical convergence (RRS *Discovery* at 0700 is at 38.7S) has surprised a number on board. After station number 12315 we crossed the Greenwich Meridian at 2025, a minor milestone. The crossing was made at the start of the third ADCP calibration exercise 2020 -2300 in which alternate courses were 015° and 105°.

22 January Day 022

The station work continues. After station 12316 maintenance work was carried out on the rosette and CTD cabling was replaced. Nevertheless a noisy transmissometer record was obtained. Shortly before station 12318 the surface salinity exceeded 35 for the first time (near 37°S 2°E).

23 January Day 023

Calm seas continue but the station spacing is augmented to 60 miles in order to anticipate a potential medical emergency and permit a dash to Cape Town if required. During the course of the day a remarkable lens of cool saline water is seen by XBTs 85-88 and CTD station 12320 and approximately 100 miles across. This takes the form of a 600m deep thermostad of temperature 13.5°C and salinity 35.2 which is capped by warmer fresher water. There is speculation that this is the remnant of an Agulhas ring, shed in the retroflection zone which has overwintered south of the convergence. But it is much cooler and fresher than any observed before. After passage through the ring the water freshens to 34.95 and temperature 18.5°C; perhaps Deacon's assertion (1937) that the seasonal migration of the sub-tropical convergence is large in this area with a maximum northwards location in summer is being verified on the cruise. At about 1930 there is an abrupt jump on the thermosalinograph. The salinity rises to 36 and the temperature to 20°C. Hallelujah! The latitude is 35° 40'S and the longitude 5° 00'E.

24 January Day 024

The routine continues in calm clear subtropical weather with 60 mile spacing of the stations. Even underway the ADCP penetration is 300m. For the past few days the winch operation under light loads has been erratic; lets hope it lasts to Cape Town. In the late afternoon a Barbecue on the after deck whist the ship was on station 12324 was a pleasant social occasion.

25 January Day 025

Today we passed through what is certainly an Agulhas ring. It took 20 hours and involved stations 12325 and 12326 and XBTs 097 - 102. The 15°C isotherm went from a depth of 100m or less outside the ring to over 350m within the ring. The extreme locations were 33° 49'S, 8 48°E to 33° 07'S, 10° 44'E, a distance of 105 n-miles. Both of the stations involved had problems. On station 12325 the rosette firing hung up at bottle 11; there were no samples above 1500m. Consequently a second cast was made to 1500m. On station 12326 a number of the hydraulic units shut down after start-up, attributed to a frozen cable-hauler, and the cast was delayed 30 minutes. During this cast the decision was made to proceed to Cape Town to put ashore the PSO whose medical condition was causing him and others concern. Prior to departure the Echosounding fish was brought on board. It was decided to launch XBTs every 2 hours on the way in. Dr. King agreed to act as PSO.

26 January Day 026

XBTs continued as RRS *Discovery* steamed into a stiff SE'ly wind, and later a 3 kt current. For only the second time in the cruise the ADCP data return was zero. The thermosalinograph failed due to a defective temperature element, which was replaced. It had given poor data for 3 days.

27 January Day 027

Clocks were advanced one hour to bring ships time to GMT + 2. Just outside Cape Town harbour, 2 miles off Green Point and at about 1200, the ship was met by a small boat and the PSO was put aboard. By 1330 the ship was underway and a speedy northward passage at an average speed of 13.5 kt was then made, with XBTs at 4 hourly intervals, to reach the eastern of the line and work southwestward from there toward station 12326. The ADCP housing was bled of air and repairs were made to clips on the Echosounder fairing. A new printer was installed for the Echosounder and for the first time excellent records were obtained

28 January Day 028

Station 12327 was commenced in 230m of water at 0730 and by 0800 was completed. Because of the pressure of time the decision was made NOT to remain for a minimum of two hours on station to obtain good ADCP records as we had in the WBC. On the following station in just under 500m of water, at 1045 the Echosounding fish was deployed. Thereafter stations were occupied at water-depth increments of 500m and at distances of between 10 and 40 n-miles, down the slope. The last station occupied on this day was 12332 in 2500m of water.

29 January Day 029

A superb calm day with a green flash at sunrise. Four stations were occupied today with the last, 12336, in a depth of water just under 4000m.

30 January Day 030

Today between 0530 and 0900 the last station 12337 was occupied at a distance of only 43 n-miles from station 12326. Thus the line is satisfactorily completed - a tribute not only to the entire scientific party but also to the entire ship's complement.

**END OF ALL SECTION**

Between 1200 and 1530 winch trials were carried out with the aim of improving the performance of the inboard compensation unit, and also to test the performance of the Mk 5 CTD. Unfortunately neither was successful, and at the end of them the Echosounding fish was recovered and course was set for Cape Town. Underway data logging was concluded at 2400 and watches were stood down at 1600.

31 January Day 031

In light winds the ship made good speed so that by 1720 it was possible to start the fourth ADCP calibration exercise of the cruise. The zig-zags were conducted on courses 105° and 015° respectively and ended at 2040.

1 February Day 032

The ship docked in Cape Town at 0830, concluding a most successful cruise.

**ACKNOWLEDGEMENTS**

This cruise, a UK contribution to the World Ocean Circulation Experiment (WOCE), was made possible by the parent body of (almost) all of the participants, namely The Natural Environment Research Council. Substantial support was also furnished by Ministry of Defence through the MoD/Research Council's joint scheme and by the generous provision of XBTs from DNOM, Taunton.

The scientific party is grateful to the professional dedication of the Master, Captain Keith Avery, the officers and entire crew of RRS *Discovery*, - especially for the smooth running of a long cruise encompassing both Xmas and the New Year. We also wish to acknowledge the support of the shore-side staff of the Research Vessels Base (Barry) and Mr. R.Bonner (IOSDL) for their expertise in the mobilisation and demobilisation of the cruise in distant ports.

CTD STATION LIST

Stn	Cast	date mmddyy	time, gmt				latitude	longitude	depth, m				Samples		
			start	bottom	end	uncwtr			ht	off	wire	max	p	no	notes
12247	1	122792	2300	2312	2340	44 58.99	S	60 00.12	W	237	5	233	235	6	CFC
12248	1	122892	0143	0206	0229	44 59.66	S	59 56.35	W	476	8	455	461	9	CFC
12249	1	122892	0424	0458	0532	44 58.98	S	59 46.96	W	1007	9	963	971	10	
12250	1	122892	0936	1018	1109	44 58.85	S	59 07.14	W	1504	11	1480	1481	11	
12251	1	122892	1429	1516	1622	44 59.38	S	58 33.03	W	1908	10	1860	1891	7	CFC
12252	1	122892	1739	1831	1948	44 59.28	S	58 24.85	W	2603	10	2563	2613	18	
12253	1	122892	2112	2216	2338	44 59.93	S	58 21.71	W	3139	14	3080	3137	19	
12254	1	122992	0216	0325	0511	44 59.68	S	57 49.19	W	3447	9	3399	3455	19	
12255	1	122992	0915	1050	1258	45 00.59	S	57 24.73	W	4011	7	3965	4049	19	I
12256	1	122992	1509	1652	1844	45 01.16	S	56 59.79	W	4773	11	4755	4841	23	CFC
12257	1	123092	2209	0012	0240	45 01.26	S	56 29.90	W	5304	11	5313	5399	22	CFC
12258	2	123092	0817	1018	1239	45 01.47	S	55 45.28	W	5497	14	5555	5609	24	
12259	1	123092	1659	1904	2144	44 58.85	S	54 47.41	W	5648	28	5836	5765	24	CFC
12260	1	123192	0323	0501	0630	45 01.23	S	53 50.68	W	5784	-99	3121	2763	9	
12261	1	123192	1529	1739	1955	44 56.33	S	52 49.00	W	5901	21	5977	6037	24	CFC
12262	1	010193	0108	0320	0528	45 02.14	S	51 44.47	W	5916	18	5950	6051	23	
12263	1	010293	1919	2118	2331	45 02.34	S	50 44.74	W	5763	19	5795	5893	24	CFC
12264	1	010393	0324	0512	0710	45 01.47	S	49 45.10	W	5562	11	5547	5685	24	
12265	1	010393	1108	1259	1510	45 00.23	S	48 46.16	W	5390	10	5373	5499	24	CFC
12266	1	010393	1857	2047	2246	44 59.84	S	47 45.75	W	5271	18	5245	5367	23	
12267	1	010493	0248	0436	0639	45 00.58	S	46 45.22	W	5206	4	5185	5311	20	
12268	1	010493	1027	1208	1402	45 00.17	S	45 45.26	W	5127	12	5100	5223	23	
12269	1	010493	1750	1931	2124	44 59.33	S	44 44.39	W	5088	6	5065	5179	13	
12270	1	010593	0110	0256	0452	44 59.89	S	43 45.12	W	4899	12	4866	4977	15	
12271	1	010593	0855	1050	1253	44 59.98	S	42 45.23	W	5201	5	5205	5305	24	CFC
12272	1	010593	1808	2001	2208	44 59.62	S	41 45.07	W	4964	16	4946	5019	9	
12272	2	010593	2235	2315	0006	44 57.87	S	41 45.72	W	4924	-99	1500	1513	16	
12273	1	010693	0541	0740	0948	45 00.10	S	40 45.44	W	4980	13	4960	5055	24	CFC
12274	1	010693	1427	1606	1801	44 58.87	S	39 45.79	W	4990	6	4996	5075	23	
12275	1	010793	2229	0010	0202	44 58.90	S	38 43.82	W	4866	8	4842	4941	23	CFC
12276	1	010793	0612	0805	1011	45 00.55	S	37 42.91	W	5123	12	5155	5215	23	
12277	1	010793	1419	1611	1821	44 59.23	S	36 44.71	W	5328	6	5334	5457	24	
12277	2	010793	1925	2002	2037	44 59.72	S	36 45.03	W	5328	-99	1250	1264	12	
12278	1	010893	0027	0214	0417	44 59.43	S	35 45.06	W	5490	11	5470	5607	24	
12279	1	010893	0824	1013	1209	44 59.82	S	34 45.83	W	5311	8	5290	5413	23	CFC
12280	1	010893	1557	1742	1936	44 59.47	S	33 46.29	W	5172	4	5155	5267	24	
12281	1	010993	0115	0258	0450	45 00.88	S	32 46.44	W	5124	9	5092	5209	23	CFC
12282	1	010993	0850	1035	1232	45 00.11	S	31 43.23	W	5187	8	5170	5281	23	
12283	1	010993	1649	1847	2043	44 59.33	S	30 45.53	W	5096	12	5070	5185	24	CFC
12284	1	011093	0140	0346	0545	44 59.93	S	29 46.54	W	4933	15	4938	5009	22	
12285	1	011093	1209	1410	1659	44 59.87	S	28 44.49	W	4726	8	4695	4795	22	CFC
12286	1	011093	2048	2234	0021	45 00.32	S	27 46.34	W	4532	10	4510	4587	21	
12287	1	011193	0420	0603	0758	45 00.49	S	26 44.13	W	4764	9	4755	4853	23	CFC
12288	1	011193	1133	1326	1515	44 59.58	S	25 43.88	W	4648	8	4612	4717	21	I
12289	1	011193	1904	2040	2225	45 01.11	S	24 44.97	W	4523	11	4570	4605	21	CFC
12290	1	011293	0201	0334	0513	44 59.25	S	23 43.44	W	4221	12	4200	4259	20	
12291	1	011293	0848	1019	1158	44 59.65	S	22 45.72	W	4438	14	4405	4471	22	CFC
12292	1	011293	1608	1743	1918	45 00.89	S	21 44.24	W	3981	7	4108	4185	20	
12293	1	011393	0028	0156	0321	44 59.69	S	20 42.84	W	3527	17	3534	3599	22	CFC
12294	1	011593	0425	0554	0727	44 59.28	S	19 44.55	W	3830	15	3850	3895	10	
12294	2	011593	0810	0844	0917	44 58.70	S	19 45.83	W	3931	-99	1000	1008	12	
12295	1	011593	1338	1522	1656	45 00.91	S	18 34.32	W	3760	17	3906	3929	20	CFC
12296	1	011593	2106	2229	2353	45 00.03	S	17 23.82	W	-999	23	3710	3787	21	
12297	1	011693	0419	0547	0708	44 59.30	S	16 13.50	W	3322	10	3290	3327	19	CFC
12298	1	011693	1145	1253	1357	45 00.39	S	15 00.50	W	2757	23	2715	2747	17	
12299	1	011693	1824	1953	2114	44 32.66	S	14 00.18	W	3300	10	3335	3399	18	CFC
12300	1	011793	0133	0258	0421	44 06.73	S	13 00.66	W	3727	12	3658	3733	19	
12301	1	011793	0823	0946	1115	43 40.01	S	12 01.24	W	3612	12	3650	3709	20	CFC
12302	1	011793	1518	1644	1815	43 14.00	S	11 02.67	W	4006	10	3970	4049	19	CFC
12303	1	011793	2233	2355	0124	42 49.20	S	10 05.30	W	3840	11	3810	3877	22	CFC

CTD STATION LIST (continued)

Stn	Cast	date mmddyy	time, gmt				latitude	longitude	depth, m				Samples	
			start	bottom	end	uncwtr			ht	off	wire	max	p	no
12304	1	011893	0547	0712	0847	42 22.27	S	9 05.17	W	3841	7	3765	3843	19
12305	1	011893	1302	1430	1558	41 55.79	S	8 10.09	W	3991	10	3964	4043	21
12306	1	011893	2023	2151	2320	41 31.40	S	7 12.31	W	3715	68	3730	3769	19
12307	1	011993	0311	0449	0624	41 09.32	S	6 24.00	W	4066	2	4065	4123	20
12308	1	011993	1218	1343	1512	40 42.26	S	5 26.50	W	3718	10	3680	3755	20
12309	1	011993	1809	1938	2102	40 25.38	S	4 49.82	W	3979	10	3964	4023	19
12310	1	012093	0252	0449	0638	40 04.98	S	4 02.44	W	4627	6	4605	4709	22
12311	1	012093	1030	1229	1414	39 43.22	S	3 15.24	W	4488	11	4507	4593	24
12312	1	012093	1758	1941	2133	39 21.31	S	2 28.67	W	4561	12	4535	4631	23
12313	1	012193	0107	0255	0443	38 58.22	S	1 41.36	W	4924	11	5038	5151	23
12314	1	012193	0814	1012	1207	38 36.46	S	0 56.54	W	4983	11	4996	5107	22
12315	1	012193	1539	1733	1933	38 14.88	S	0 09.74	W	5184	10	5180	5299	23
12316	1	012293	0013	0202	0359	37 52.89	S	0 35.51	E	5013	10	4997	5107	22
12317	1	012293	0733	0918	1107	37 31.26	S	1 21.00	E	5074	10	5080	5193	22
12318	1	012293	1435	1627	1825	37 09.08	S	2 06.23	E	5106	5	5135	5209	23
12319	1	012293	2146	2335	0127	36 47.42	S	2 51.51	E	5154	10	5155	5267	24
12320	1	012393	0623	0815	1019	36 16.60	S	3 55.53	E	5190	12	5195	5305	23
12321	1	012393	1522	1715	1903	35 44.79	S	5 00.15	E	5201	12	5220	5307	23
12322	1	012493	2357	0200	0404	35 12.76	S	6 02.17	E	5257	10	5270	5369	24
12323	1	012493	0915	1058	1247	34 42.33	S	7 04.20	E	5219	10	5220	5337	24
12324	1	012493	1751	1943	2159	34 09.16	S	8 07.24	E	4989	9	5035	5103	22
12325	1	012593	0301	0457	0638	33 40.82	S	9 08.81	E	5017	5	5065	5135	23
12325	2	012593	0820	0903	0955	33 40.25	S	9 07.97	E	5019	-99	1500	1502	23
12326	1	012593	1547	1750	1944	33 05.25	S	10 08.97	E	4999	4	5075	5103	23
12327	1	012893	0533	0550	0604	30 13.59	S	15 37.16	E	238	4	230	233	6
12328	1	012893	0849	0915	0939	30 28.27	S	15 08.12	E	471	8	465	465	9
12329	1	012893	1101	1138	1209	30 34.23	S	14 58.84	E	999	9	992	997	12
12330	1	012893	1325	1411	1454	30 40.29	S	14 47.44	E	1497	10	1505	1495	12
12331	1	012893	1612	1703	1759	30 45.31	S	14 38.59	E	1986	10	1965	1985	14
12332	1	012893	1948	2047	2145	30 53.45	S	14 22.05	E	2498	10	2460	2503	16
12333	1	012993	0046	0151	0301	31 14.14	S	13 44.98	E	3044	9	3012	3063	18
12334	1	012993	0611	0733	0856	31 32.54	S	13 09.65	E	3497	10	3475	3531	18
12335	1	012993	1303	1427	1553	31 57.82	S	12 21.75	E	4002	7	3980	4055	21
12336	1	012993	1955	2127	2305	32 19.16	S	11 38.47	E	4412	9	4400	4483	22
12337	1	013093	0330	0521	0700	32 42.47	S	10 53.87	E	4809	9	4795	4901	22

Notes 1) Position is reported for the time at the bottom of the cast  
 2) Salinity, oxygen, silicate, phosphate, nitrate+nitrite were sampled for all bottles  
 3) CFC denotes CFC-11,12 and 113 and I denotes Iodine

XBT STATION LIST

Stn	Cast	date mmddyy	time, gmt				latitude	longitude	depth, m				Samples	
			start	bottom	end	uncwtr			ht	off	wire	max	no	notes
1	1	122692	1444				45 01.15 S	57 30.29 W	3872	-99	-999	1833		T5
2	1	122792	0025				45 00.03 S	57 59.88 W	3206	-99	-999	1833		T5
3	1	122792	0501				44 59.52 S	58 29.94 W	2059	-99	-999	1833		T5
4	1	122792	0924				44 59.76 S	58 59.97 W	1558	-99	-999	1793		T5
5	1	122792	1304				44 59.81 S	59 14.85 W	1412	-99	-999	1431		T5
6	1	122792	1617				44 59.68 S	59 30.39 W	1222	-99	-999	1241		T5
7	1	122792	1937				44 59.22 S	59 45.30 W	1047	-99	-999	1063		T5
8	1	122792	2248				44 59.28 S	59 59.68 W	238	-99	-999	237		
9	1	122892	0719				44 57.28 S	59 33.73 W	1200	-99	-999	763		
10	1	122892	0826				44 58.87 S	59 18.64 W	1389	-99	-999	763		
11	1	122892	1229				44 57.48 S	58 57.00 W	1610	-99	-999	763		
14	1	122892	2011				44 59.49 S	58 23.29 W	2705	-99	-999	763		
15	1	122992	0032				44 59.40 S	58 10.75 W	3376	-99	-999	763		
16	1	122992	0111				44 59.72 S	58 01.56 W	3110	-99	-999	763		
17	1	122992	0753				44 58.68 S	57 36.32 W	4200	-99	-999	763		
18	1	122992	1404				45 00.70 S	57 11.82 W	4333	-99	-999	763		
19	1	122992	2011				45 00.97 S	56 44.38 W	5073	-99	-999	763		
20	1	123092	0408				45 01.40 S	56 07.95 W	5380	-99	-999	763		
21	1	123092	1510				45 00.75 S	55 07.73 W	5550	-99	-999	923		
22	1	123192	0020				44 58.77 S	54 14.43 W	5731	-99	-999	763		
23	1	123192	1236				44 59.45 S	53 14.63 W	5846	-99	-999	763		
24	1	123192	2244				44 54.19 S	52 15.82 W	5954	-99	-999	763		
25	1	010193	0727				45 02.18 S	51 15.42 W	5844	-99	-999	763		
26	1	010393	0119				45 02.76 S	50 17.40 W	5685	-99	-999	763		
27	1	010393	0909				45 00.68 S	49 15.04 W	5440	-99	-999	763		
28	1	010393	1717				45 00.19 S	48 12.44 W	5300	-99	-999	763		
29	1	010493	0049				44 59.50 S	47 14.55 W	5572	-99	-999	763		
30	1	010493	0833				44 59.57 S	46 14.03 W	5860	-99	-999	763		
31	1	010493	1600				45 00.22 S	45 14.28 W	5026	-99	-999	763		
32	1	010493	2313				44 59.68 S	44 15.05 W	4946	-99	-999	763		
33	1	010593	0626				45 00.00 S	43 15.00 W	4980	-99	-999	763		
34	1	010593	1551				44 59.83 S	42 11.74 W	5060	-99	-999	763		
35	1	010693	0325				44 58.86 S	41 12.86 W	4919	-99	-999	763		
36	1	010693	1238				44 58.62 S	40 05.32 W	4804	-99	-999	763		
37	1	010693	2024				44 59.05 S	39 14.19 W	5000	-99	-999	763		
38	1	010793	0424				44 59.00 S	38 11.16 W	4752	-99	-999	763		
39	1	010793	1207				45 01.85 S	37 13.04 W	5151	-99	-999	763		
40	1	010793	2233				44 59.11 S	36 15.31 W	5460	-99	-999	763		
41	1	010893	0616				44 59.75 S	35 14.73 W	5475	-99	-999	763		
42	1	010893	1406				44 59.89 S	34 16.15 W	5220	-99	-999	763		
43	1	010893	2302				44 56.96 S	33 15.18 W	5051	-99	-999	763		
44	1	010993	0657				45 00.48 S	32 14.31 W	5050	-99	-999	763		
45	1	010993	1424				44 59.78 S	31 13.73 W	5170	-99	-999	763		
46	1	010993	2321				44 56.24 S	30 15.39 W	4945	-99	-999	763		
49	1	011093	0801				45 00.27 S	29 10.79 W	4638	-99	-999	763		
50	1	011093	1847				44 59.53 S	28 14.82 W	4650	-99	-999	763		
51	1	011193	0236				45 00.69 S	27 12.41 W	4684	-99	-999	763		
52	1	011193	0936				44 58.39 S	26 14.51 W	4780	-99	-999	763		
53	1	011193	1657				44 59.70 S	25 17.14 W	-999	-99	-999	763		
54	1	011293	0013				45 01.56 S	24 14.14 W	4620	-99	-999	763		
55	1	011293	0649				44 58.98 S	23 15.42 W	4550	-99	-999	763		
56	1	011293	1410				45 00.38 S	22 13.35 W	3638	-99	-999	763		
57	1	011293	2207				45 00.06 S	21 15.61 W	4134	-99	-999	763		
58	1	011593	0237				44 59.22 S	20 13.85 W	3003	-99	-999	763		
59	1	011593	1136				44 59.68 S	19 08.56 W	3756	-99	-999	763		
60	1	011593	1851				45 00.33 S	18 00.20 W	3500	-99	-999	763		
61	1	011693	0215				44 59.82 S	16 45.68 W	3800	-99	-999	763		
62	1	011693	0934				44 58.69 S	15 36.62 W	1863	-99	-999	763		
63	1	011693	1601				44 47.01 S	14 31.47 W	3500	-99	-999	763		
64	1	011693	2318				44 20.51 S	13 30.92 W	3237	-99	-999	763		
65	1	011793	0614				43 54.69 S	12 32.06 W	3456	-99	-999	763		
66	1	011793	1308				43 27.77 S	11 33.83 W	3675	-99	-999	763		
67	1	011793	2022				43 01.46 S	10 34.51 W	3740	-99	-999	763		
68	1	011893	0333				42 35.99 S	9 36.56 W	3670	-99	-999	763		

Stn	Cast	date mmddyy	time, gmt			latitude	longitude	depth, m			Samples		
			start	bottom	end			uncwtr	ht	off	wire	max	no
69	1	011893	1056	42	08.83	S	8	37.80	W	3888	-99	-999	763
70	1	011893	1808	41	42.77	S	7	42.57	W	3748	-99	-999	763
71	1	011993	0115	41	20.75	S	6	49.00	W	3822	-99	-999	763
72	1	011993	0920	40	57.97	S	6	00.83	W	3507	-99	-999	763
73	1	011993	1056	40	48.49	S	5	39.99	W	800	-99	-999	763
74	1	011993	1620	40	36.56	S	5	13.18	W	3804	-99	-999	763
75	1	011993	2254	40	14.11	S	4	26.07	W	3559	-99	-999	763
76	1	012093	0843	39	53.47	S	3	38.92	W	4327	-99	-999	763
77	1	012093	1607	39	31.75	S	2	49.93	W	4400	-99	-999	763
78	1	012093	2320	39	09.62	S	2	05.28	W	4520	-99	-999	763
79	1	012193	0627	38	46.25	S	1	19.64	W	5306	-99	-999	763
80	1	012193	1351	38	25.54	S	0	33.41	W	5800	-99	-999	763
81	1	012193	2151	38	05.02	S	0	12.46	E	5147	-99	-999	763
82	1	012293	0544	37	40.57	S	0	58.21	E	5250	-99	-999	763
83	1	012293	1252	37	20.15	S	1	42.27	E	5050	-99	-999	763
84	1	012293	2005	36	57.74	S	2	27.23	E	4901	-99	-999	763
85	1	012393	0304	36	35.92	S	3	12.92	E	5200	-99	-999	763
86	1	012393	0448	36	24.64	S	3	35.94	E	5185	-99	-999	811
87	1	012393	0456	36	23.71	S	3	37.77	E	5185	-99	-999	763
88	1	012393	1152	36	05.99	S	4	14.75	E	5086	-99	-999	763
89	1	012393	1344	35	54.63	S	4	38.80	E	5086	-99	-999	763
90	1	012393	2039	35	34.53	S	5	18.52	E	5196	-99	-999	763
91	1	012393	2216	35	23.98	S	5	40.47	E	5218	-99	-999	763
92	1	012493	0543	35	01.66	S	6	20.62	E	5350	-99	-999	763
93	1	012493	0732	34	51.83	S	6	43.58	E	5230	-99	-999	763
94	1	012493	1429	34	31.35	S	7	24.46	E	5128	-99	-999	763
95	1	012493	1603	34	20.72	S	7	44.96	E	5197	-99	-999	763
96	1	012493	2336	33	59.47	S	8	26.69	E	-999	-99	-999	763
97	1	012593	0123	33	48.81	S	8	48.91	E	5047	-99	-999	763
98	1	012593	1144	33	28.67	S	9	27.81	E	4968	-99	-999	763
99	1	012593	1325	33	17.37	S	9	48.52	E	4994	-99	-999	1127
100	1	012593	1335	33	16.45	S	9	50.40	E	4988	-99	-999	1832
101	1	012593	2104	33	05.15	S	10	25.95	E	4800	-99	-999	1832
102	1	012593	2240	33	07.38	S	10	44.54	E	4752	-99	-999	763
103	1	012693	0002	33	09.10	S	11	03.09	E	4850	-99	-999	763
104	1	012693	0203	33	11.80	S	11	30.40	E	4800	-99	-999	763
105	1	012693	0400	33	14.49	S	11	54.79	E	-999	-99	-999	763
106	1	012693	0559	33	16.76	S	12	18.73	E	-999	-99	-999	763
108	1	012693	0802	33	18.47	S	12	43.31	E	4695	-99	-999	763
109	1	012693	0957	33	20.03	S	13	06.57	E	-999	-99	-999	763
110	1	012693	1204	33	22.71	S	13	32.09	E	5000	-99	-999	763
111	1	012693	1400	33	25.48	S	13	56.13	E	-999	-99	-999	763
112	1	012693	1559	33	27.22	S	14	21.13	E	4350	-99	-999	763
113	1	012693	1800	33	29.98	S	14	46.22	E	4350	-99	-999	763
114	1	012693	1959	33	32.10	S	15	11.23	E	-999	-99	-999	763
115	1	012693	2204	33	34.89	S	15	36.97	E	3460	-99	-999	763
116	1	012793	0006	33	37.37	S	16	00.34	E	3407	-99	-999	763
117	1	012793	0200	33	40.10	S	16	25.13	E	3000	-99	-999	763
118	1	012793	0400	33	42.98	S	16	54.44	E	1800	-99	-999	763
119	1	012793	0600	33	45.64	S	17	25.31	E	530	-99	-999	599
120	1	012793	1309	33	22.96	S	17	50.72	E	163	-99	-999	204
121	1	012793	1500	33	01.59	S	17	35.71	E	250	-99	-999	305
123	1	012793	1908	32	13.98	S	16	59.59	E	281	-99	-999	443
124	1	012793	2259	31	28.25	S	16	28.93	E	363	-99	-999	405
125	1	012893	0300	30	39.45	S	15	54.50	E	190	-99	-999	255
126	1	012893	0732	30	21.31	S	15	21.89	E	280	-99	-999	340
127	1	012893	0814	30	25.43	S	15	13.43	E	353	-99	-999	405
128	1	012893	1036	30	32.45	S	15	01.53	E	750	-99	-999	763
129	1	012893	1248	30	37.04	S	14	52.74	E	1288	-99	-999	1195
130	1	012893	1552	30	44.33	S	14	39.77	E	1890	-99	-999	1216
131	1	012893	1837	30	48.51	S	14	33.04	E	2250	-99	-999	1832
132	1	012893	2308	31	02.28	S	14	05.94	E	2750	-99	-999	1260
133	1	012993	0417	31	22.17	S	13	31.87	E	3250	-99	-999	1832
134	1	012993	1104	31	46.48	S	12	44.51	E	3800	-99	-999	1207
135	1	012993	1755	32	08.56	S	12	00.10	E	4160	-99	-999	1832
136	1	013093	0112	32	30.27	S	11	16.38	E	4620	-99	-999	1832

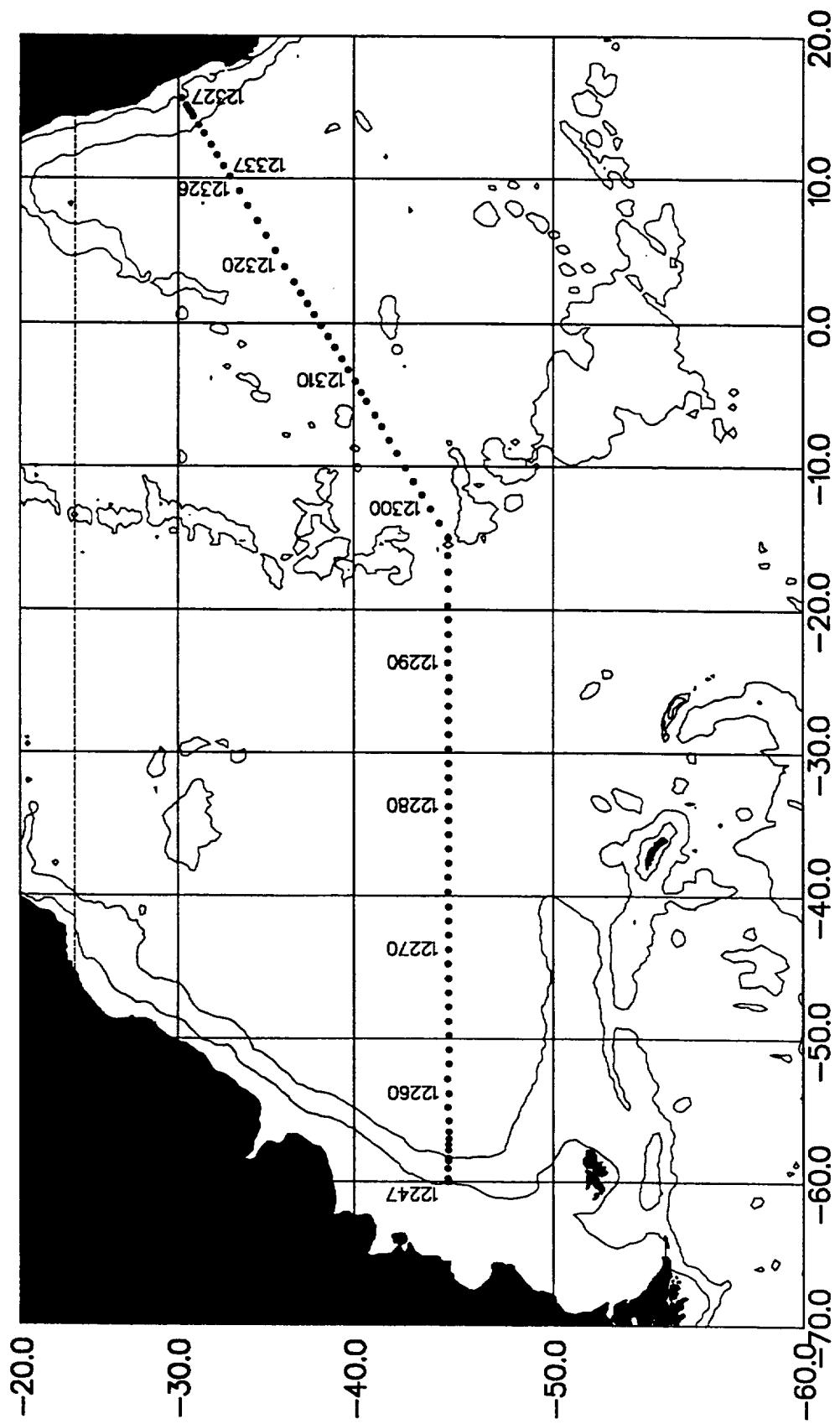


Figure 1. Track Chart: RRS Discovery Cruise 199, 22 Dec 1992 - 01 Feb 1993.  
Station numbers and isobaths of 200m and 3000m are superimposed.

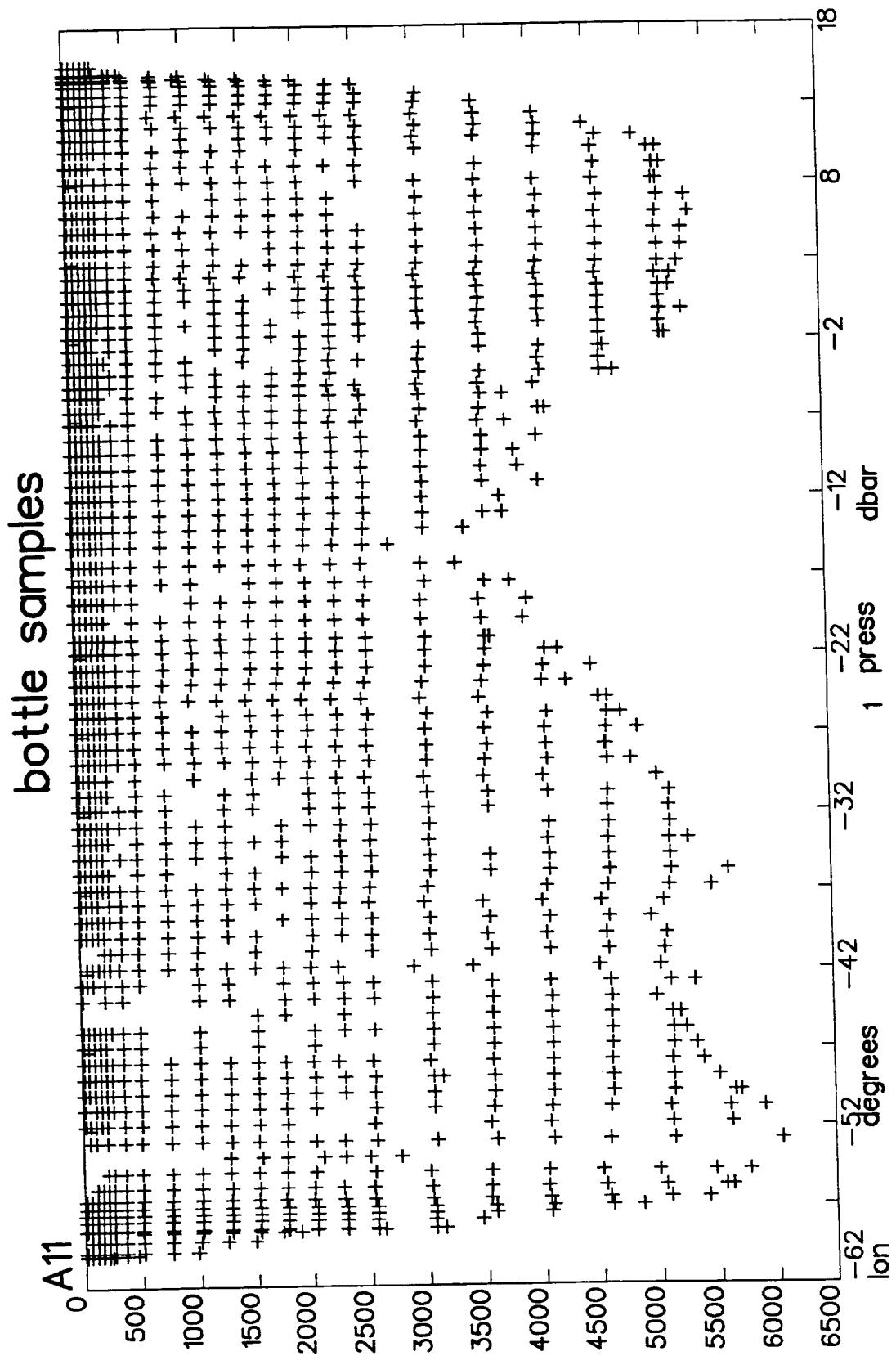


Figure 2. The location of 10 litre water samples collected on cruise A11. Depth is in dbar.

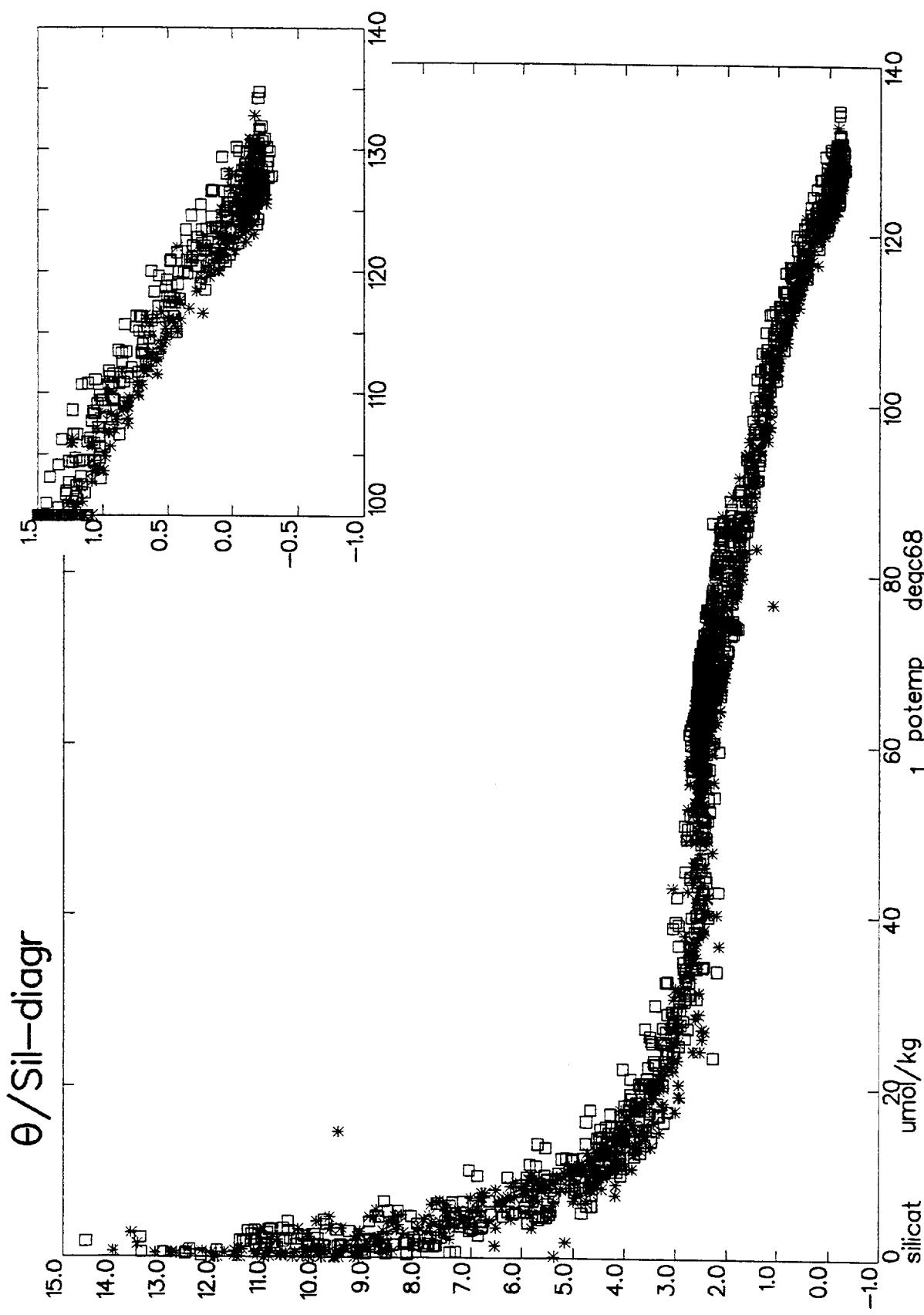


Figure 3. Silicate concentration versus potential temperature for A11 \* and S4 data: both are in the Argentine basin and for the whole water column. The inset, for the deepest levels, shows the small discrepancy between the data sets.

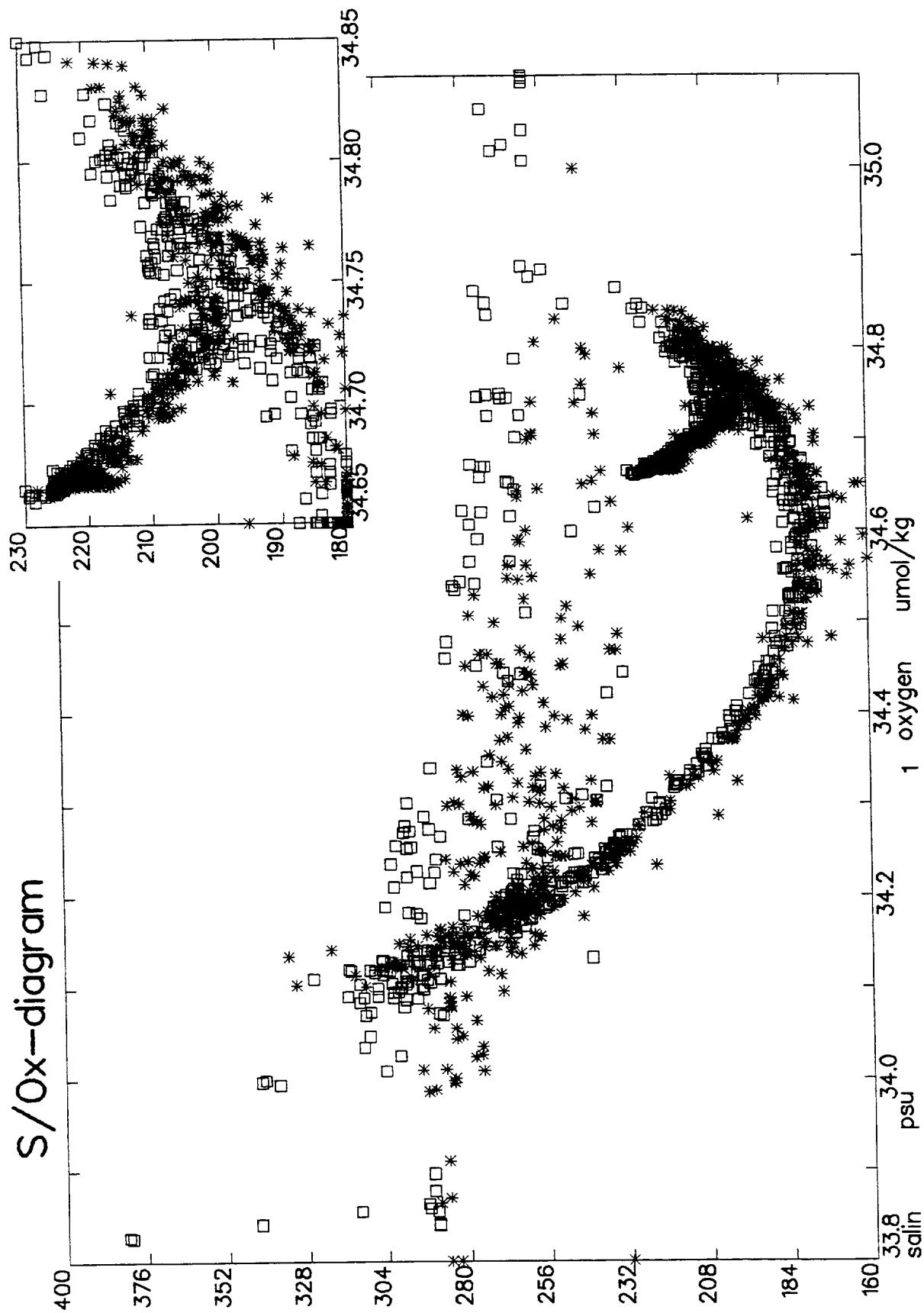


Figure 4. Dissolved oxygen concentration versus salinity for All \* and SAV 4 data: both are in the Argentine basin and for the whole water column. The inset, where the deepest levels form the left branch of the Y, shows the small discrepancy between the data sets.

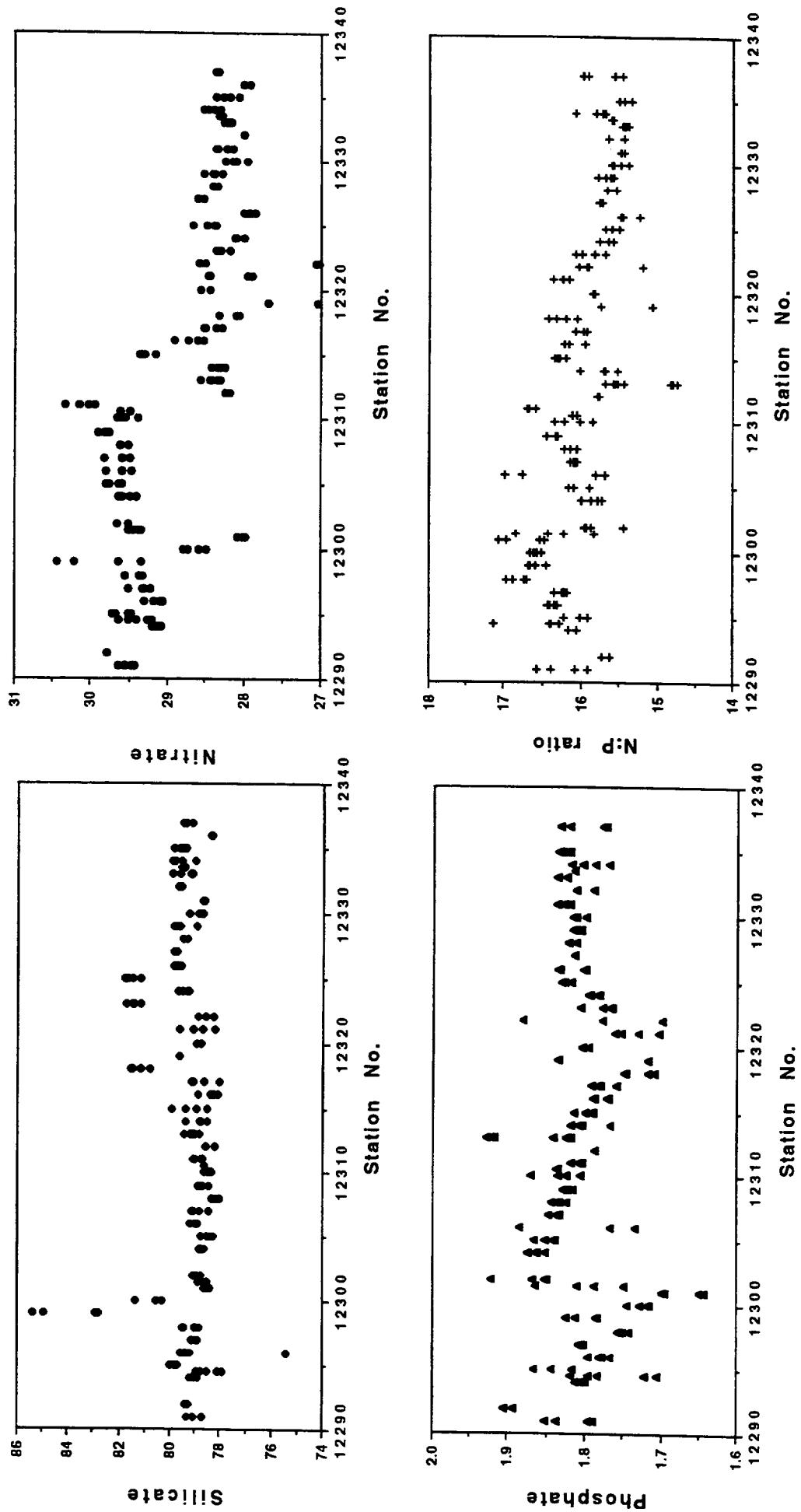


Figure 5. Deep water collected on station 12240 from 2500m was used as quality control for the nutrient measurements: results are shown for the last 50 stations of the cruise.

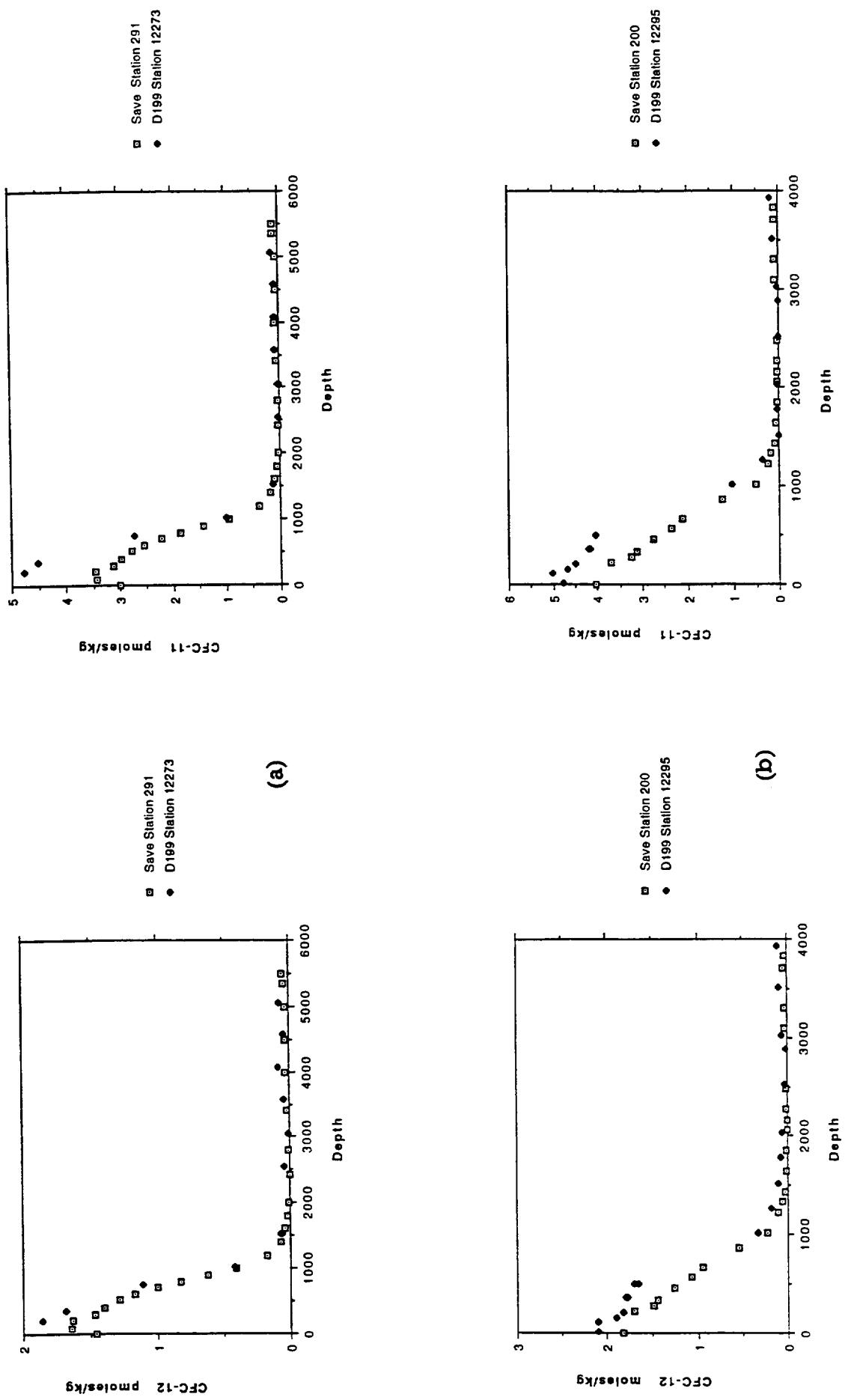


Figure 6. A comparison of CFC-11 and CFC-12 data from (a) SAVE station 291 and A11 station 12273 and (b) SAVE station 200 and A11 station 12295.

### A11 Thermosalinograph

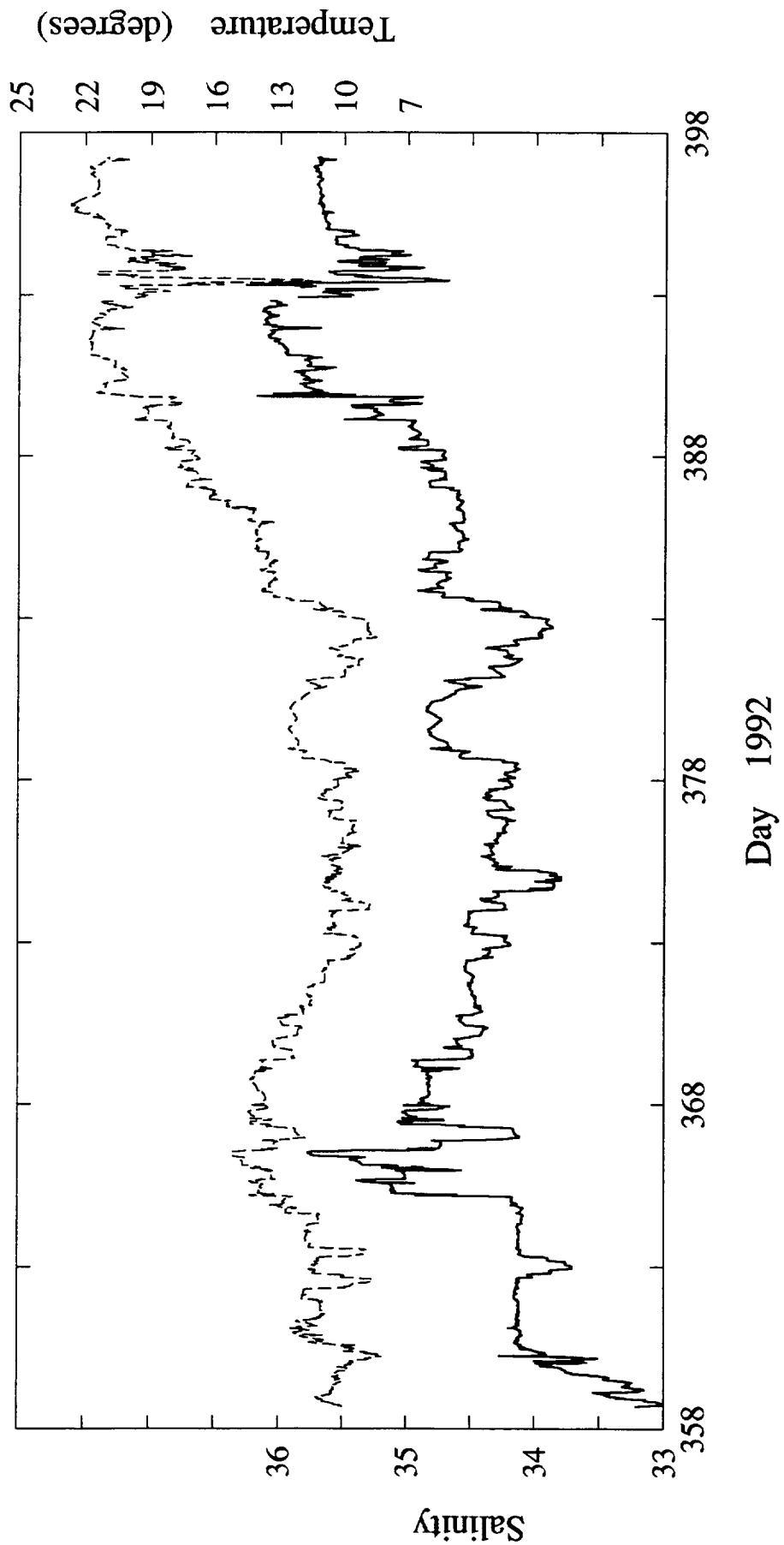


Figure 7. Surface salinity (bold) and temperature (broken) on cruise A11. The cruise begins on the Argentine shelf, passes through the Falkland current (day 363), enters the Brazil current retroflection (day 365), traverses the Subantarctic Zone until somewhere between day 386 and 390 it enters the subtropical gyre. The cruise ends in S. Africa.