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Woods Hole Oceanographic Institution

Trans-Equatorial Bottom Water Flow in the Western Atlantic, Volume XLVI in a series of reports presenting data from moored current meters.

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Susan A. Tarbell, John A. Whitehead, Melinda M. Hall and Michael S. McCartney

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Technical Report

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Approved for Distribution:

Philip L. Richardson, Chair
Department of Physical Oceanography

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Abstract

Current and temperature measurements from Vector Averaging Current Meters (VACMs) deployed from September 1992 to June 1994 as part of the Deep Basin Experiment (DBE) measuring the trans-equatorial water flow are presented. Salinity and temperature measurements from Conductivity/Temperature/Depth (CTD) casts taken during the mooring deployment and recovery cruises are also presented.

Six mooring sites were occupied with a total of 24 vector averaging current meters and 4 Aanderaa current meters. Three nominal depths (3900, 4100 and 4300 m.) were occupied on each mooring. Three of the 6 moorings had current meters at additional depths.

Basic data from the vector averaging current meters are presented both in statistical tables and graphically as histograms, scatter plots, progressive vector diagrams and spectral diagrams. One day Gaussian filtered plots are shown in composite displays of variables versus time.

Temperature and salinity profiles and θ/S plots for 22 CTD stations are presented.

Acknowledgments

The principal responsibility for the current meter preparations, deployment, and recovery was borne by Scott E. Worrilow. We thank him for outstanding performance of the sensors with over 99% data recovery. Richard Limeburner conducted the data acquisition and processing for both cruises. The quality of the data is superb and we thank him for an excellent job. We also must thank the officers and crew of the R/V Columbus Iselin, Michael Dick, Master, and the officers and crew of the R/V Knorr, Captain Carl F. Swanson, Master, for smooth operations and wonderful cooperation. Research supported by the Division of Ocean Sciences, National Science Foundation grant OCE-9105834.

Preface

This volume is the 46th in a series of technical reports presenting moored current meter and associated data collected by the WHOI Buoy Group.

Associated reports include a data directory and bibliography for the years 1963-1978 which has been published as WHOI technical report 79-88 and a technical memorandum, WHOI-3-88 which describes the WHOI Buoy Group current meter data processing system for VAX /VMS operating system.

Volume No.	WHOI ref. No.	Author	Years	Experiment Name
I	65-44	Webster, F., and N. P. Fofonoff	1963	miscellaneous
II	66-60	Webster, F., and N. P. Fofonoff	1962-4	near Bermuda
III	67-66	Webster, F., and N. P. Fofonoff	1964	miscellaneous
IV	70-40	Pollard, R.	1965	miscellaneous
V	71-50	Tarbell, S., and F. Webster	1966	miscellaneous
VI	74-4	Tarbell, S.	1967	miscellaneous
VII	74-52	Chausse, D., and S. Tarbell	1968	miscellaneous
VIII	75-7	Pollard, R., and S. Tarbell	1970	Site D array
IX	75-68	Tarbell, S., M. G. Briscoe and D. Chausse	1973	IWEX
X	76-40	Tarbell, S.	1969	misc. early 1969
XI	76-41	Tarbell, S.	1969	misc. late 1969
XII	76-101	Chausse, D., and S. Tarbell	1973	MODE
XIII	77-18	Tarbell, S., and A. Whitlatch	1970	miscellaneous
XIV	77-41	Tarbell, S., R. Payne, and R. Walden	1976	Mooring 952
XV	77-56	Tarbell, S., and A. Whitlatch	1971	miscellaneous
XVI	78-5	Tarbell S., and A. Spencer	1971-5	MODE-Site
XVII	78-49	Tarbell S., A. Spencer and R. Payne	1975-7	POLYMODE Array II
XVIII	79-65	Tarbell, S., M. G. Briscoe and R. A. Weller	1978	JASIN
XIX	79-34	Spencer, A., C. Mills and R. Payne	1974-5	POLYMODE Array I
XX	79-56	Spencer, A.	1974	Rise Array
XXI	79-85	Mills, C., and P. Rhines	1978	W.B.U.C
XXII	79-87	Tarbell, S. and R. Payne	1973	miscellaneous
XXIII	80-40	Tarbell, S.	1977-9	POLYMODE Array III
XXIV	80-41	Spencer, A., K. O'Neill and J. Luyten	1976	Indian Ocean Array
XXV	81-12	Spencer, A., E. D'Asaro and L. Armi	1966-7	benthic boundary
XXVI	81-45	Chausse, D., and R. Payne	1972	miscellaneous
XXVII	81-68	McKee, T., E. Francis, and N. Hogg	1975-7	miscellaneous
XXVIII	81-73	Mills, C., S. Tarbell, and R. Payne	1978	L.D.E
XXIX	82-16	Levy, E. et al.	1979	INDEX
XXX	82-43	Levy, E., S. Tarbell and N. P. Fofonoff	1979-80	GSE/NSOI
XXXI	83-30	Levy, E. and S. Tarbell	1980-2	WESPAC
XXXII	83-46	Levy, E.	1979	Vema Channel
XXXIII	84-6	Spencer, A., D. Chausse and W. B. Owens	1981	N.P.B.C.

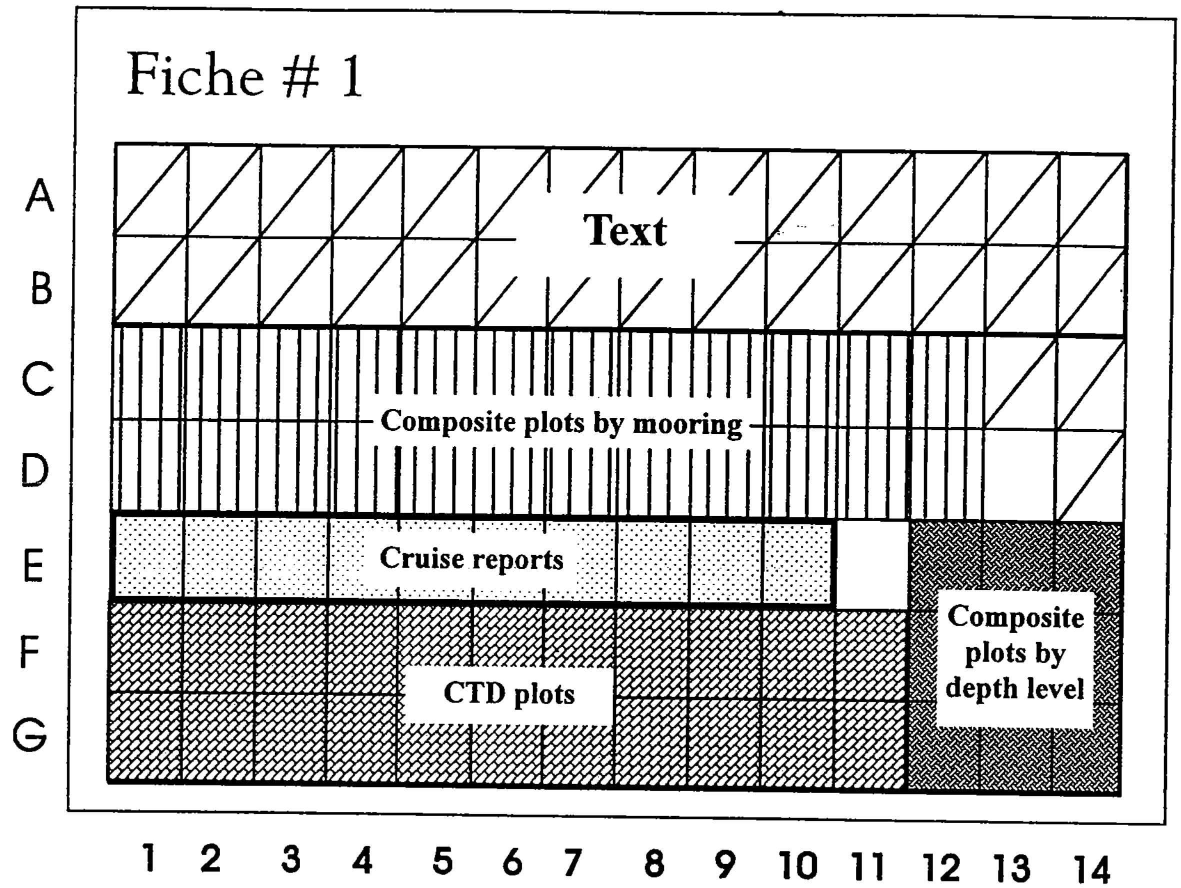
XXXIV	84-16	Levy, E. and P. L. Richardson	1983	SEQUAL I
XXXV	84-36	Tarbell, S., N. J. Pennington and M. G. Briscoe	1982-4	LOTUS
XXXVI	84-37	Levy, E., and P. L. Richardson	1983-4	SEQUAL II
XXXVII	85-7	Levy, E., and P. L. Richardson	1984	SEQUAL III
XXXVIII	85-39	Tarbell, S., E. T. Montgomery & M. G. Briscoe	1983-4	LOTUS
XXXIX	86-14	Levy, E., and S. Tarbell	1983-4	HEBBLE
XL	87-19	Tarbell, S., P. L. Richardson and J. Price	1984-6	Canary Basin
XLI	87-20	Levy, E., and S. Tarbell	1983-5	Zonal Pacific
XLII	90-30	Luyten, J., et al.	1985-7	Agulhas
XLIII	90-18	Crescenti, G. H., S. Tarbell and R. A. Weller	1988-9	SESMOOR
XLIV	93-01	Tarbell, S., S. Worrilow and N. Hogg	1987-91	SYNOP
XLV	94-07	Tarbell, S., R. Meyer, N. Hogg, and W. Zenk	1991-2	Deep Basin

Presentation

The printed portion of this report contains introductory text, information about the instruments, data processing procedures, data quality assessments and composite plots of data. Tables and figures give information on moorings, instruments and CTDs.

All of the printed pages are included on the first page of the microfiche. Also included on the first fiche are the cruise reports for the deployment and recovery of the current meter moorings. Pagination of the fiche consists of a three part field, the fiche number, the row letter and the column number.

The second and third pages of fiche present data for the individual current meters. Each row of the fiche presents a different type of display, for instance, statistics are shown in row 'A'. Each column shows the variety of displays for the time series from a single instrument. Figure 1 shows the layout of the three fiche pages. Fiche 2 and 3, shown in the lower panel, have the same layout.



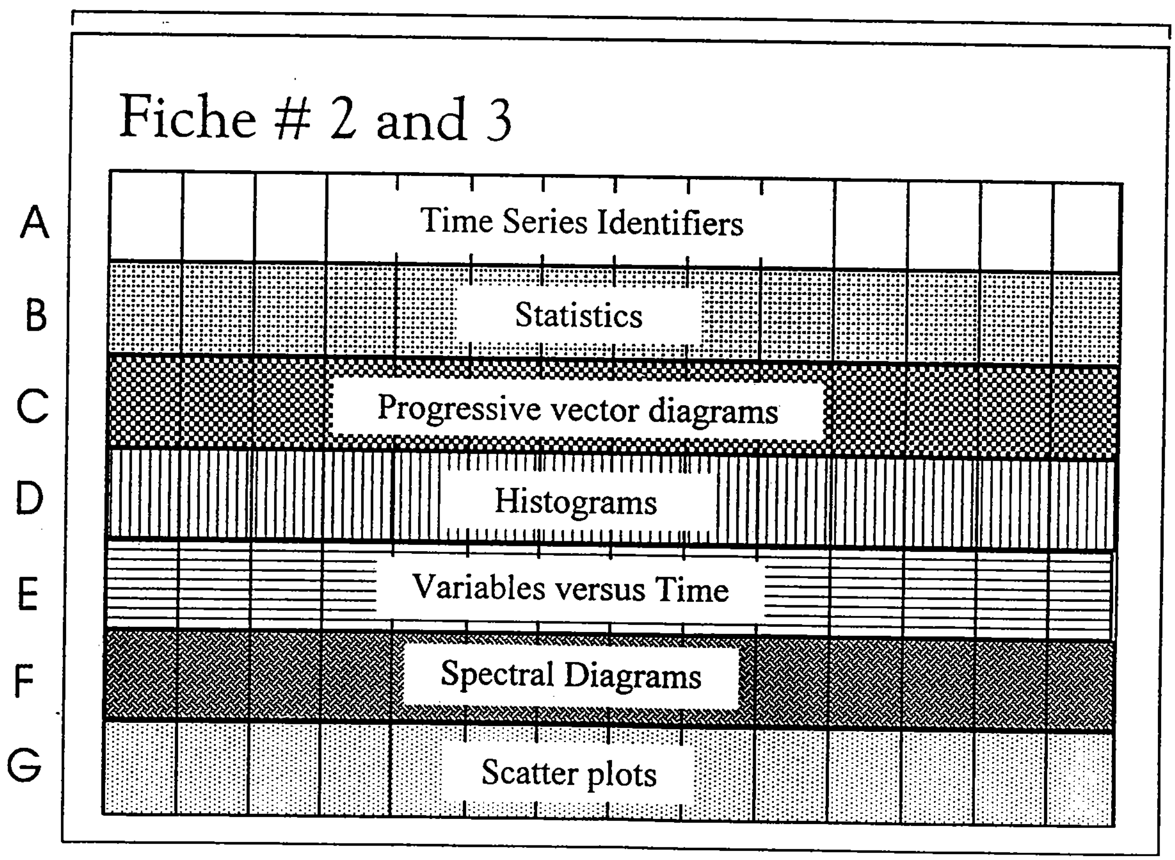


Figure 1 Fiche diagrams

Introduction

This program is a part of the Deep Basin Experiment of the World Ocean Circulation Experiment (WOCE). A description of the overall objectives of the experiment is given by Hogg et al., 1996. The objective of this part of the program was to measure the northward flow of Antarctic Bottom Water (AABW) out of the Brazil Basin in the South Atlantic and into the Guiana Basin in the North Atlantic. A current meter array of six moorings was set for about 600 days across the opening at the Equator between the Brazil Basin and the Guiana Basin west of the Mid-Atlantic Ridge. CTD profiles were taken near each mooring and between mooring locations to measure water properties during the current meter deployment cruise, approximately one month prior to mooring recovery (Smethie, 1996), and during the recovery cruise.

The mooring array was designed to extend in a north-south direction at 36° W with 6 moorings equally spaced between 1° N and 1°30' S (Figure 2). These locations evenly filled the passage between the Brazil and Guiana Basins from north to south, and put the array at approximately the east-west center of the almost perfectly zonal gap that steers the Antarctic Bottom Water. The depths of the Vector Averaging Current Meters (VACMs) were chosen to optimize measurement of the AABW. All six moorings had current meters placed at roughly 3900, 4100 and 4300 meter depths. The two moorings at roughly 1° N and S of the equator each had an additional VACM close to 3300 meters in depth to provide more information about the vertical shear and levels of no motion. One mooring, placed almost exactly on the equator, had VACMs at 2993, 3593 and 4485 meters in addition to the nominal depths mentioned above. Also on the equatorial mooring were four Aanderaa current meters, placed at shallower levels for use by scientists at the Institute für Meereskunde, Kiel, Germany (Fischer and Schott, 1997).

The deployment cruise on R/V Columbus Iselin, cruise CI 92-10, left Bridgetown, Barbados on September 18, 1992 and arrived in Recife, Brazil on October 9, 1992. Six moorings (#936 to #941) with a total of 24 VACMs were deployed. The mooring deployments went as planned for moorings 936, 937 and 939. Mooring 938 anchored about 5 miles west of the planned location due to a strong surface current. The designated location of mooring 940 at 01° 00' S was a little shallower than desired so the mooring was placed about 3 miles NW of the planned location. Mooring 941 was placed near 01° 20' S and 36° 05'W rather than 1° 30' S to place the mooring out of Brazilian waters as the government of Brazil did not grant clearance to deploy within their waters. Eleven CTD stations were taken near and between the mooring positions.

The recovery cruise, from Salvador, Brazil to Bridgetown, Barbados, took place from 27 May to 13 June, 1994 on RV Knorr, cruise 142-4. Every current meter was recovered, although mooring 941 had a failed release, due to a fractured end cap, and had to be recovered by dragging grappling hooks and depressor weights to snag the mooring. As before, a complete bathymetric profile was taken and eleven CTD casts were made at and between each mooring site. The CTD casts at mooring sites were made before mooring recovery so that VACM recorded temperatures and CTD temperature profiles could be compared.

The principal topic of this report will be the graphical displays of up to 610 days of current meter measurements per VACM. In addition, CTD station data plots will be presented.

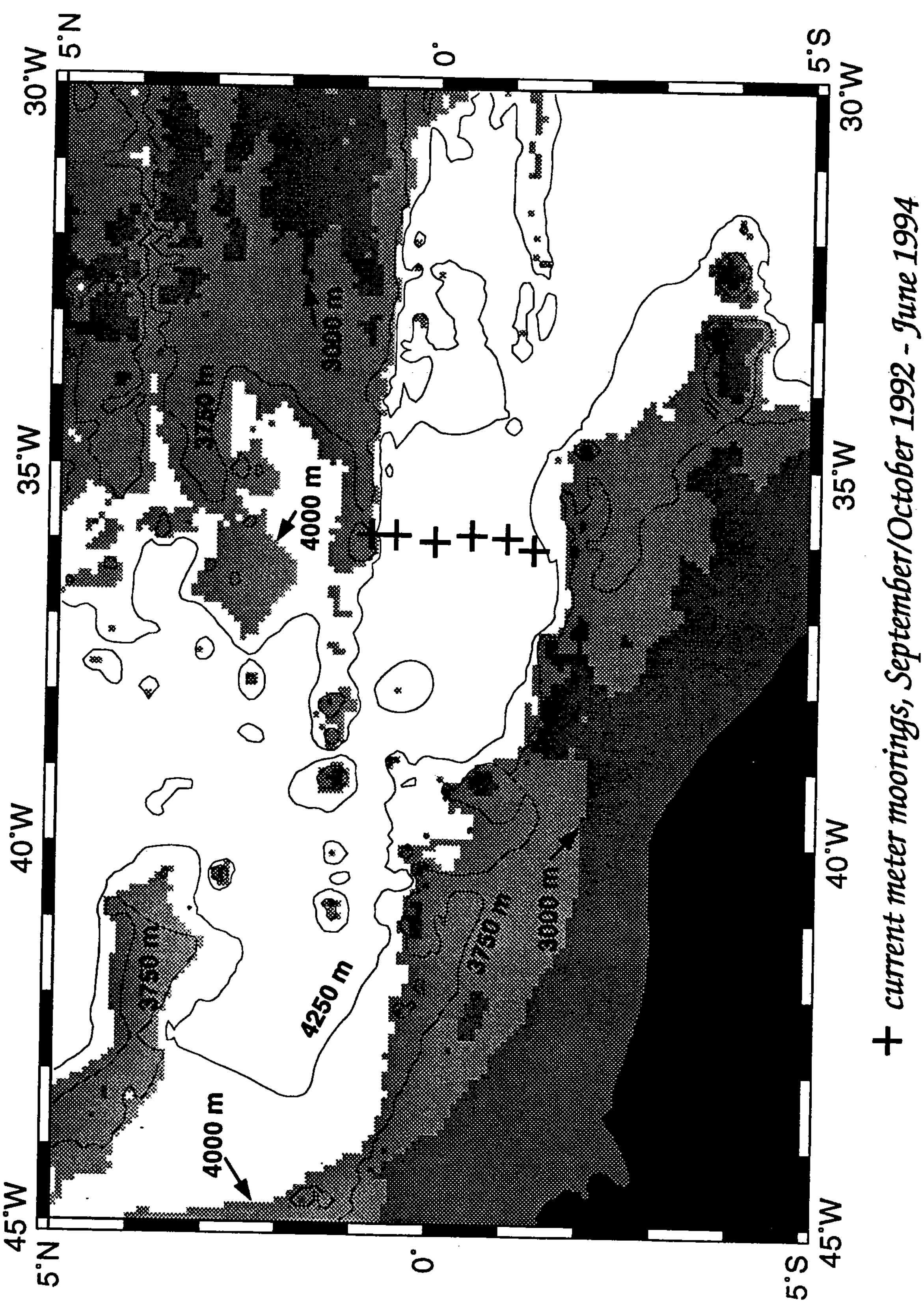


Figure 2 **Mooring positions for the Trans-Equatorial water flow**

The principal scientific results of the experiment are described by Hall, McCartney and Whitehead (1997) and can be summarized as follows:

1) Below θ=1.8° C. an average of $2.0 \times 10^6 m^3 sec^{-1}$ of AABW passes westward during the ~600 day array duration.

2) The westward AABW flow is persistent and strong at and south of the equator, but north of the equator the AABW flow is weak (neither persistent in direction, nor organized) and is negligible in transport.

3) Immediately above the AABW the Lower North Atlantic Deep Water flows strongly eastward in a boundary layer approximately 200 km wide, with eastward flow intensified to the south at the Parnaiba Ridge.

4) There is a quasi-annual signal in the AABW transports, with maxima occurring in September/October and minima occurring in February/March. The Lower North Atlantic Deep Water (LNADW) also displays quasi-annual variability, with strong flow episodes in April/May.

5) Both the hydrographic surveys and the temperature time series from the moored current meters show that the water below 3900m warms over the observation period (equivalently, isotherms lowered 50 to 80 meters).

Other scientific activities were undertaken on the cruises that set and recovered the moorings. For the cruise of the R/V Columbus Iselin these include the recovery of six SOFAR float listening stations that were part of the 1989-1992 Tropical Atlantic Experiment (Richardson et al., 1994). In addition sixteen RAFOS floats and three sound source moorings were launched as part of the WOCE Deep Basin Experiment (contact B. Owens, N. Hogg at W.H.O.I.). During the R/V Knorr cruise an unsuccessful attempt was made to recover a sediment trap during the steam to Barbados. In addition, the shipboard ADCP was calibrated in shallow waters off Barbados.

CTDs

Conductivity/Temperature/Depth (CTD) profiles were taken in the vicinity of and between each mooring during both the mooring launch and mooring recovery cruises. Table 1 lists the CTD station locations and the associated mooring number.

On the deployment cruise the hydrographic profiles were made using the R/V Iselin's NBIS Mark III CTD underwater unit, an NBIS Mark V deck unit in an 1150 configuration and a General Oceanics Rosette sampling system with 12 ten liter Niskin bottles. An acoustic pinger was used for bottom ranging with depths corrected for sound speed using Matthew's Tables and adding 3m for transducer depth.

The profiles taken on the recovery cruise used an NBIS Mark III underwater unit, an NBIS Mark III deck unit and a General Oceanics 1015 Rosette sampling system with 12 1.2 liter Niskin bottles. A Guildline salinometer was used to calibrate the salinities from the CTD. An acoustic pinger was used for bottom ranging with the depths corrected for sound speed; the corrections were calculated from the CTD data.

The CTD data represent full water column measurements of the temperature and salinity structure of the equatorial system near 36°W. Figures 3 a, b and c show the potential temperature distribution below 3000 meters for the three CTD sections with superimposed current meter locations. Discussions of older hydrographic data at and near this location may be found in articles by McCartney (1993), McCartney and Curry (1993), and Rhein, et al. (1995,1996).

Table 1 CTD Stations

R/V Columbus (cruise 92 10)

The temperature and salinity plots from these CTD stations are printed at the end of this report.

Station	Latitude	Longitude	Date 1992	Station Depth	Associated Mooring #
4	0 51.14 N	35 53.86 W	Sept. 28	4463	936
5	0 30.72 N	35 54.39 W	Sept. 28	4525	937
6	0 41.04 N	35 52.79 W	Sept. 29	4523	
7	0 00.34 N	35 54.24 W	Sept. 29	4525	938
8	0 15.84 N	35 54.58 W	Sept. 30	4527	
9	0 15.03 S	35 53.79 W	Sept. 30	4515	
10	0 30.08 S	35 55.13 W	Sept. 30	4490	939
11	0 44.74 S	35 54.59 W	Sept. 30	4413	
12	0 59.82 S	35 53.51 W	Oct. 1	4281	940
13	1 14.77 S	35 54.42 W	Oct. 1	4424	
14	1 19.14 S	36 04.32 W	Oct. 1	4441	941

Table 1 continued

R/V Knorr (cruise 142-3)

The temperature and salinity plots from these CTD stations are <u>not</u> shown in this report.

Station	Latitude	Longitude	Month 1994	Station Depth
-----	-----------	--------------	-------	--------
10	1 31.95 S	35 56.90 W	Apr.	4058
11	1 39.51 S	35 57.10 W	Apr.	4243
12	1 20.04 S	35 56.79 W	Apr.	4381
13	0 59.04 S	35 57.12 W	Apr.	4460
16	0 14.95 S	35 57.21 W	Apr.	4582
17	0 00.01 N	35 56.97 W	Apr.	4597
18	0 14.97 N	35 57.00 W	Apr.	4596
19	0 30.00 N	35 56.99 W	Apr.	4606
20	0 39.97 N	35 56.94 W	Apr.	4600
21	0 51.91 N	35 56.87 W	Apr.	4527

R/V Knorr (cruise 142-4)

The temperature and salinity plots from these CTD stations are printed at the end of this report.

Station	Latitude	Longitude	Date 1994	Station Depth	Associated Mooring #
-----	-----------	--------------	----------	---------	-------------
1	1 37.28 S	36 02.33 W	May 30	4205	
2	1 19.57 S	36 05.29 W	May 31	4439	941
3	0 58.81 S	35 55.96 W	May 31	4381	940
4	0 29.91 S	35 53.95 W	May 31	4470	939
5	0 14.86 S	35 59.70 W	June 1	4494	
6	0 00.02 S	35 55.17 W	June 1	4517	938
7	0 15.29 N	35 59.75 W	June 1	4519	
8	0 29.94 N	35 54.17 W	June 1	4525	937
9	0 45.17 N	35 59.54 W	June 2	4519	
10	0 50.26 N	35 50.62 W	June 2	4468	936
11	0 44.93 S	35 54.06 W	June 2	4451	

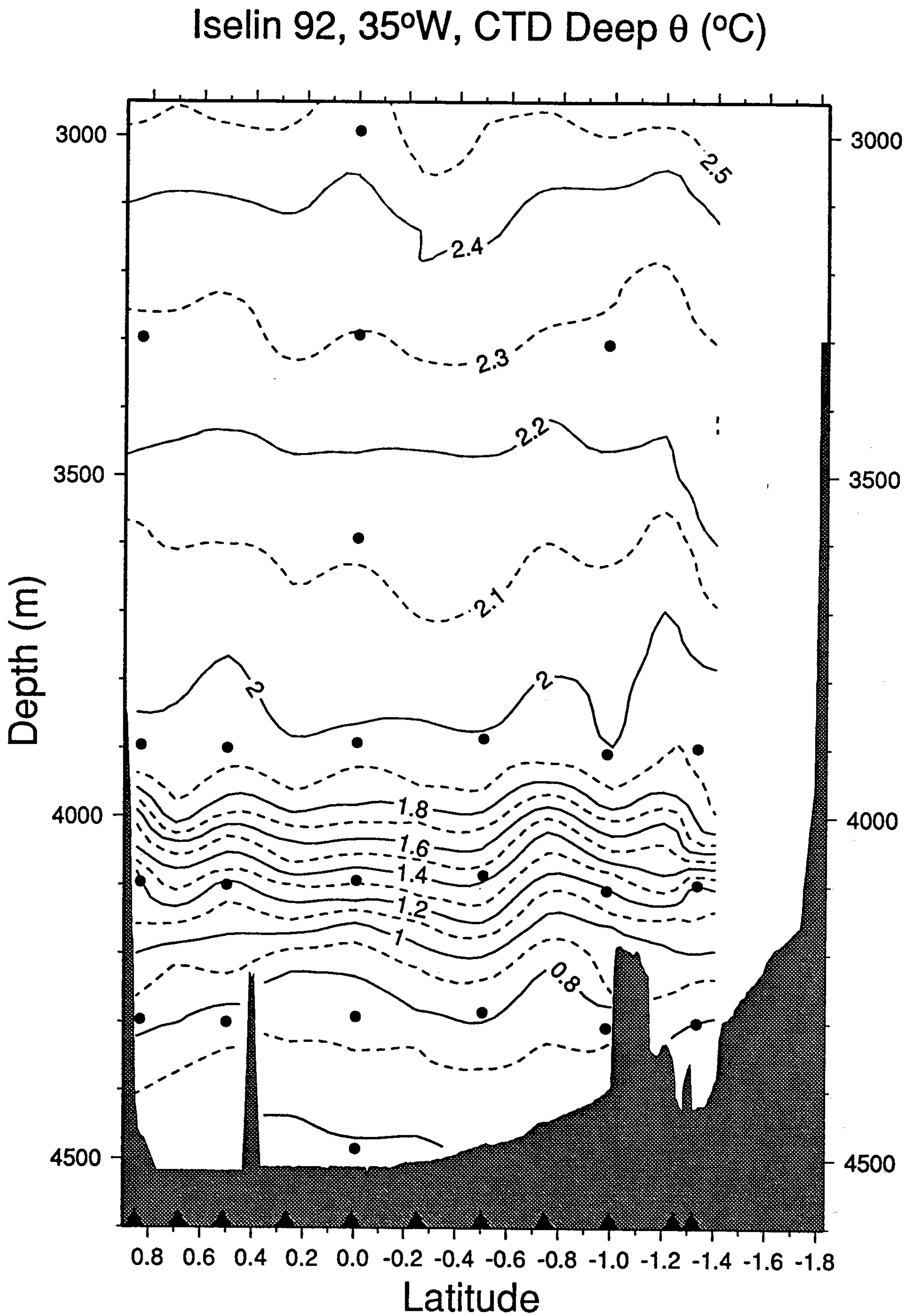


figure 3a - sections of deep θ taken during the mooring deployment cruise in September 1992. Filled circles indicate current meter locations; filled triangles indicate CTD casts

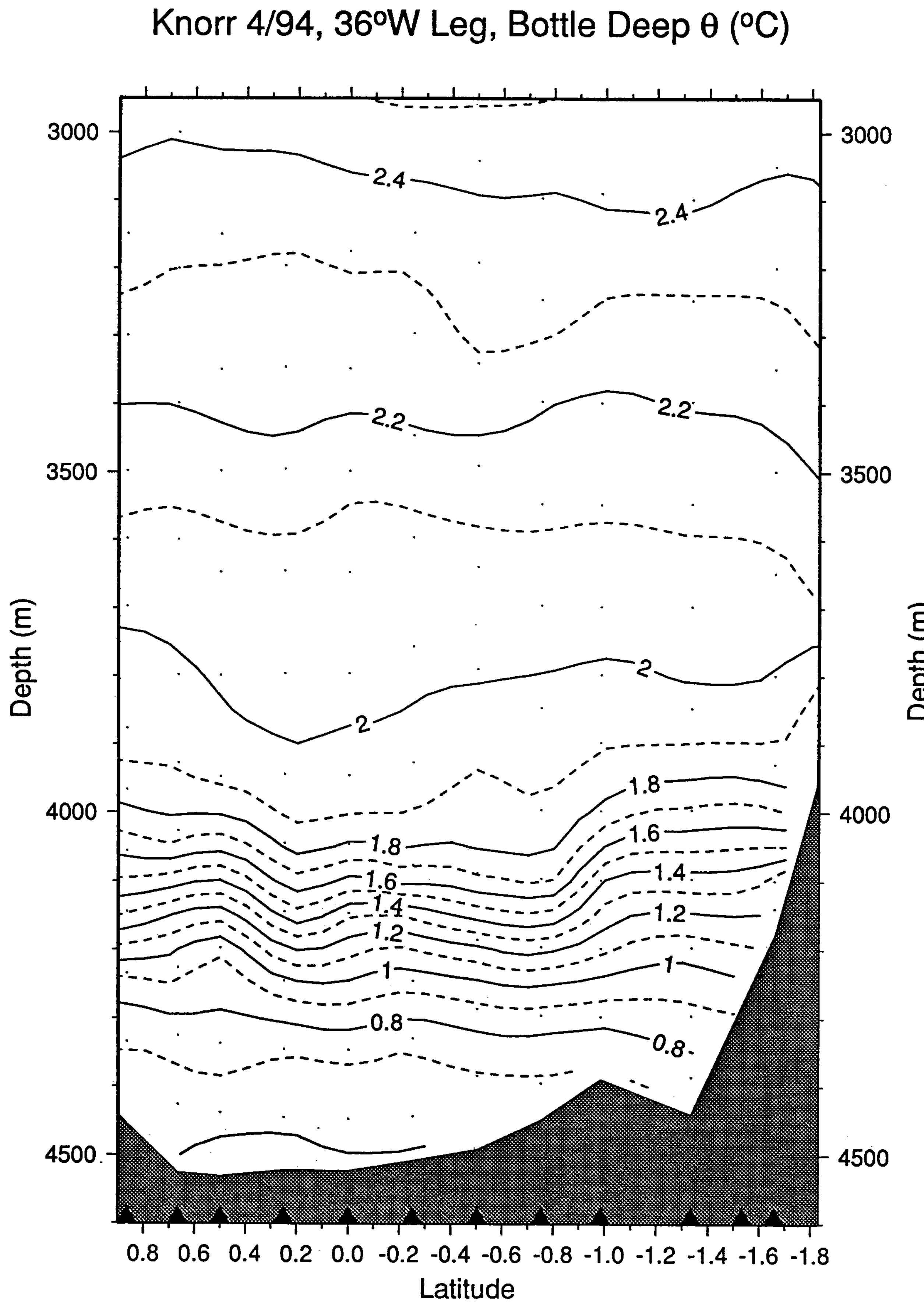


figure 3b - sections of deep θ taken in April 1994

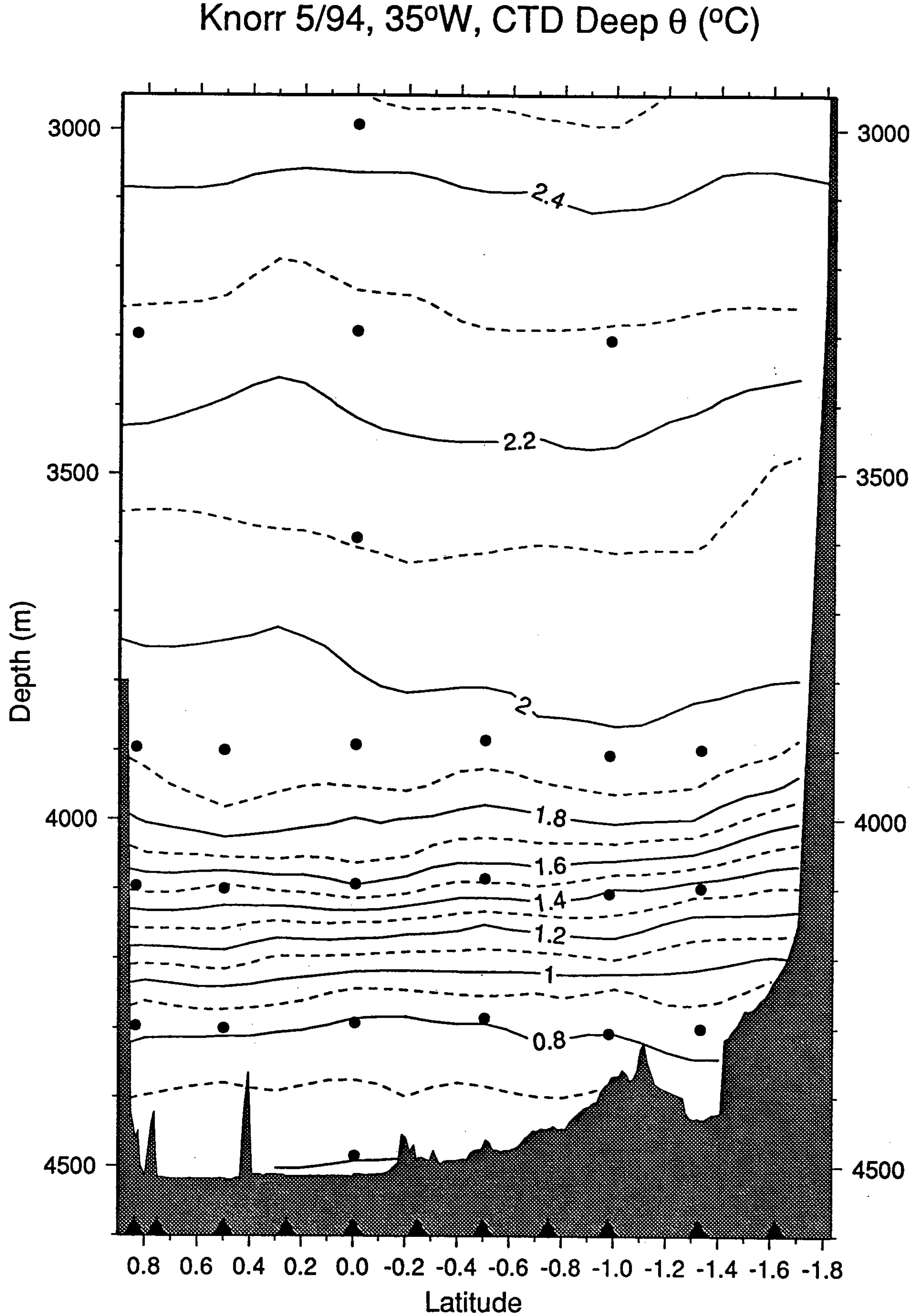


figure 3c - sections of deep θ taken during the mooring recovery cruise in May-June 1994

Moorings

Mooring locations are shown in Figure 2. Mooring latitude, longitude, deployment and recovery times are listed in Table 2. The moorings were set and recovered by Scott Worrilow using the R/V Iselin (cruise CI 92-10) from the University of Miami for the deployment cruise and the R/V Knorr (cruise 142-4) from the Woods Hole Oceanographic Institution for the recovery cruise. Mooring 938 was located about 5 miles west of the planned site due to a swift surface countercurrent affecting the deployment. The site for mooring 940 was deliberately shifted due to a bump in the sea floor, and the site for 941 was repositioned to be outside Brazilian waters.

Table 2 Mooring location and duration

Mooring #	Latitude	Longitude	Mag. Var.	Set 1992 mon,day,hr	Recovery 1994 mon,day,hr	Water Depth (m)
936	0 50.16 N	35 54.02 W	21w	Sep. 28, 14	Jun. 2, 09	4486
937	0 30.10 N	35 54.17 W	21w	Sep. 28, 22	Jun. 1, 19	4540
938	0 00.28 S	35 59.46 W	21w	Sep. 29, 21	Jun. 1, 10	4536
939	0 30.05 S	35 54.06 W	21w	Sep. 30, 16	May 31, 20	4485
940	0 58.80 S	35 55.95 W	21w	Oct. 1, 03	May 31, 12	4396
941	1 19.90 S	36 04.94 W	21w	Oct. 1, 19	Jun. 3, 21	4449

Times are in GMT.

The moorings in this experiment were standard WHOI Buoy Group subsurface moorings as described by Heinmiller (1976). Details of the mooring configurations are shown in Table 3.

Table 3 Itemized list of mooring components for each mooring

Item	936	937	936	939	940	941
--------------------	----	-----	-----	-----	-----	----
3 ball float depth	3251m	3854m	1256m	3839m	3261m	3854m
1/2" chain	3.	3.	3.	3.	3.	3.
transponder	.5	.5	.5	.5	.5	.5
17" glass balls	19.	19.	33.	19.	19.	19.
Aanderaa CM			1.			
3/16" wire			198.			
Aanderaa CM			1.			
3/16" wire			198.			
Aanderaa CM			1.			
3/16" wire			193.			
17" glass balls			5.			
Aanderaa CM			1.			
3/16" wire			1000.			
3/16" wire			85.			
17" glass balls			5.			
VACM @3000			1.8			
3/16" wire	20.	20.	296.	20.	20.	20.
VACM @3300	1.8		1.8		1.8	
3/16" wire			292.		590.	
17" glass balls			4.			
VACM @3600			1.8			
3/16" wire	590.		295.			
17" glass balls	5.				5.	
VACM @3900	1.8	1.8	1.8	1.8	1.8	1.8
3/16" wire	197.	197.	193.	197.	197.	197.
17" glass balls			4.			
VACM 4100	1.8	1.8	1.8	1.8	1.8	1.8
3/16" wire	179.	179.	176.	179.	179.	179.
17" glass balls	15.	15.		15.	15.	15.
3/8" chain	3.	3.		3.	3.	3.
VACM 4300	1.8	1.8	1.8	1.8	1.8	1.8
3/16" wire			100.			
3/16" wire			50.			
3/16" wire			20.			
17" glass balls			16.			
1/2" chain	3.	3.	3.			
VACM @4500			1.8			
1.2" chain			3.	3.	3.	3.
Release	1.8	1.8	1.8	1.8	1.8	1.8
1/2" chain	5.	5.	5.	5.	5.	5.
1/4" wire	100.	100.		100.	50.	100.
1/4" wire	50.	50.		50.		10.
1/4" wire		30.		10.		
1/4" wire		20.	11.			
3/4" nylon	20.	20.	20.	20.	20.	20.
1/2" chain	5.	5.	5.	5.	5.	5.
Anchor with Danforth						
Water depth	4486m	4540m	4536m	4485m	4396m	4449m

Instrument depths

Instruments depths are achieved by determining the water depth at the anticipated anchor launch site, then adding, or deleting, short components of mooring line at the bottom of the mooring string to adjust the overall mooring length (height). The mooring components are all input into program NOYFB (Moller, 1976) which calculates not only the instrument depths but also the buoyancy and mooring performance in different current conditions. Table 4 contains the instrument depths (in meters) for the VACM time series presented in this technical report.

Table 4 Instrument Placement

Mooring #	Instrument depth in meters						
936		3297		3896	4096	4297	
937				3900	4100	4300	
938 *	2993	3293	3593	3892	4093	4292	4485
939				3885	4085	4285	
940		3307		3907	4107	4307	
941				3899	4099	4300	

NOTE: * Four Aanderaa current meters, not described in this report, were included on this mooring at depths of 1293, 1493, 1693, and 1893 meters (Fischer and Schott, 1997)