Woods Hole Oceanographic Institution

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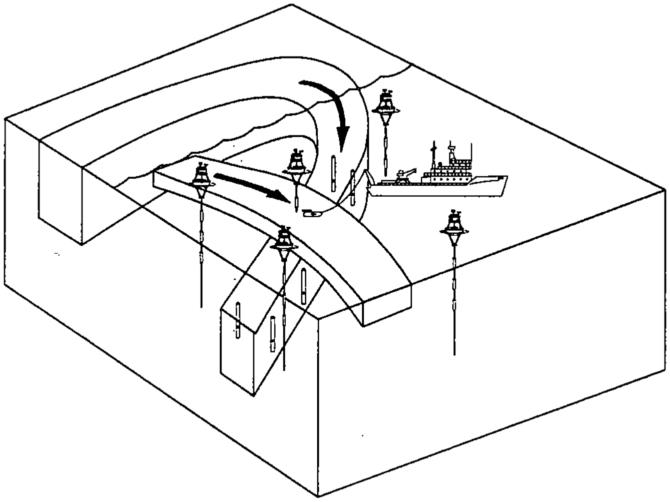
Technical Report

December 1993

The Subduction Experiment



Cruise Report
R/V *Knorr*
Cruise Number 138 Leg XV
Subduction 3 Mooring Recovery Cruise
13 – 30 June 1993

by

Richard P. Trask
Nancy Galbraith
Paul Robbins
William Ostrom
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Glenn Pezzoli
Neil McPhee

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Abstract

Subduction is the mechanism by which water masses formed in the mixed layer and near the surface of the ocean find their way into the upper thermocline. The subduction process and its underlying mechanisms were studied through a combination of Eulerian and Langrangian measurements of velocity, measurements of tracer distributions and hydrographic properties and modeling.

An array of five surface moorings carrying meteorological and oceanographic instrumentation were deployed for a period of two years beginning in June 1991 as part of an Office of Naval Research (ONR) funded Subduction experiment. Three eight month deployments were planned. The moorings were deployed at 18°N 34°W, 18°N 22°W, 25.5°N 29°W, 33°N 22°W and 33°N 34°W.

A Vector Averaging Wind Recorder (VAWR) and an Improved Meteorological Recorder (IMET) collected wind speed and wind direction, sea surface temperature, air temperature, short wave radiation, barometric pressure and relative humidity. The IMET also measured precipitation. The moorings were heavily instrumented below the surface with Vector Measuring Current Meters (VMCM) and single point temperature recorders.

Expendable bathythermograph (XBT) data were collected and meteorological observations were made while transitting between mooring locations.

This report describes the work that took place during R/V Knorr cruise number 138 leg XV which was the fourth scheduled Subduction mooring cruise. During this cruise the moorings previously deployed for a third and final eight month period were recovered. This report includes a description of the moorings and instrumentation that were recovered, has information about the underway measurements (XBT and meteorological observations) that were made including plots of the data, and presents a chronology of the cruise events.

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Section 1: Introduction

R/V Knorr cruise number 138 (KN138) Leg XV departed Ponta Delgada, Azores, at 0855 UTC on Sunday, 13 June 1993, to recover an array of five surface moorings as part of the Office of Naval Research (ONR) funded Subduction experiment. This cruise was the fourth of four scheduled mooring cruises planned for this experiment (figure 1). Hourly XBTs and meteorological observations were made while in transit between mooring locations.

The cruise involved personnel and equipment from both the Woods Hole Oceanographic Institution (WHOI) and Scripps Institution of Oceanography (SIO). Appendix 1 lists the cruise participants. Figure 2 shows the cruise track and the mooring locations.

The moored array was originally deployed in June 1991 and recovered and redeployed in both February and October 1992. The moorings recovered during this cruise were from the third setting of the array and were known as Subduction 3. Table 1 lists the Subduction 3 mooring positions and the dates they were deployed and recovered. For completeness, the Subduction 1 and 2 (the first and second settings of the moored array) mooring positions and deployment dates are included in tables 2 and 3 respectively.

This report has, in addition to this introduction, two other sections. The second section provides a description of the moorings, buoys, and instrumentation that were recovered, as well as the underway measurements that were made, including XBT profiles and meteorological observations. The third section is a chronology of the entire cruise.

Figure 1. Mooring Cruise Schedule

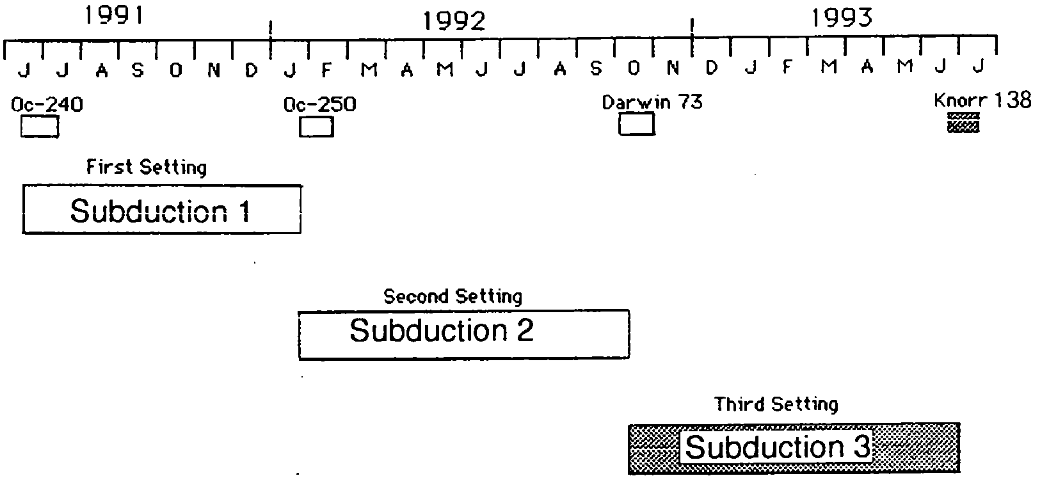


Figure 2. KN138 Leg XV cruise track and mooring positions

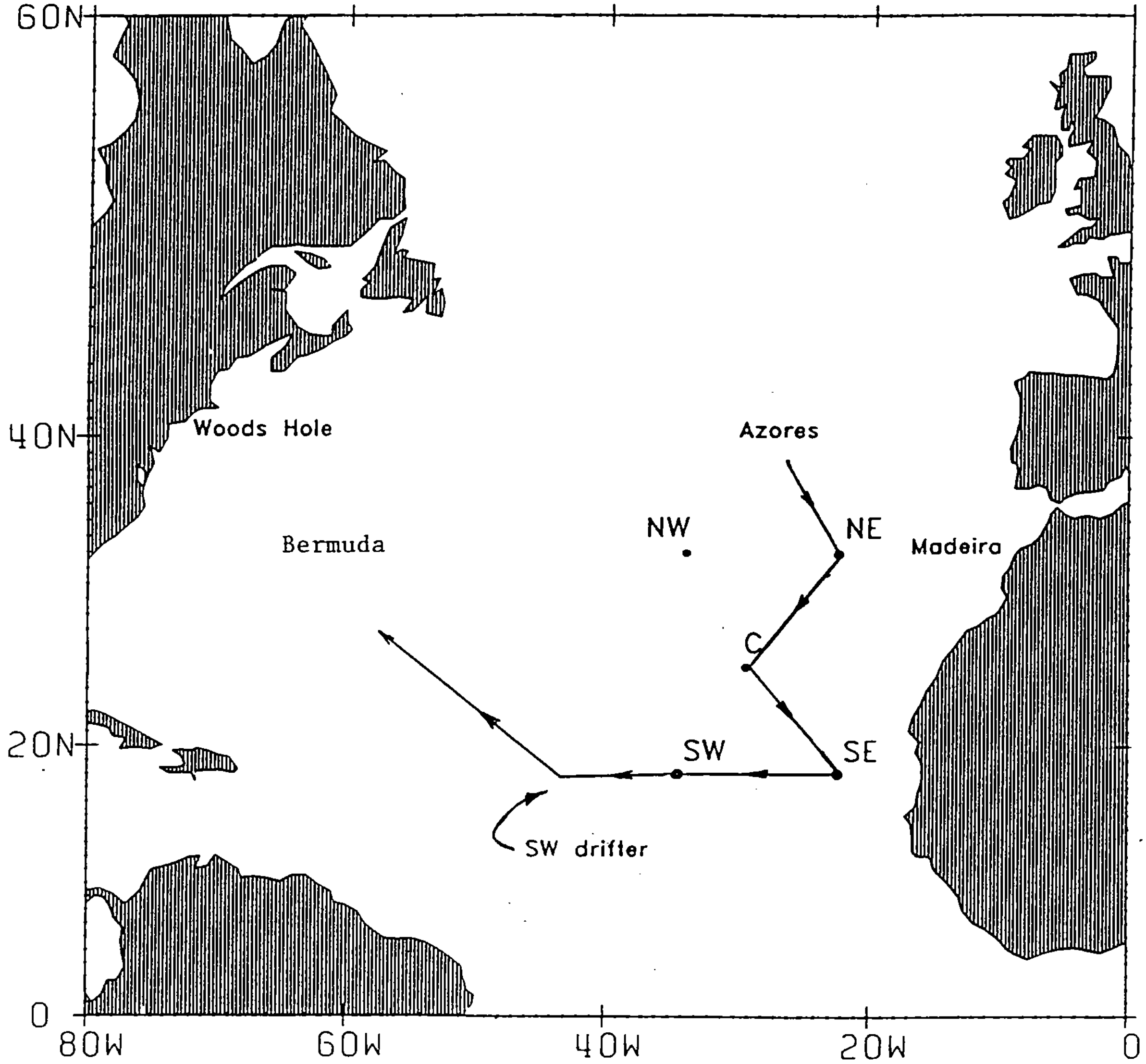


Table 1
Subduction 3 Mooring Deployments and Positions

Buoy	Mooring #	Deployment Date Time (UTC)	Recovery Date Time (UTC)	Position(GPS)
SW**	954	11 Oct1992 @ 1846	21 Jun 1993 @ 1506	18° 05.57'N 33° 53.97'W
SE	953	7 Oct 1992 @ 1157	19 Jun 1993 @ 0526	17° 57.71'W 22° 02.77'W
C	955	15 Oct 1992 @ 1023	16 Jun 1993 @ 2009	25° 31.93'N 28° 56.52'W
NE	952	2 Oct 1992 @ 1449	14 Jun 1993 @ 1528	33° 01.80'N 21° 59.39'W
NW*	956	24 Oct 1992 @ 0017	15 Jun 1993 @ 0300	32° 54.38'N 33° 53.58'W

* NW parted13 March 1993, Discus with upper instruments recovered 11April 1993.
Remainder recovered 15 June 1993.
** SW parted 22 May 1993. Top 10 meters recovered 25 June 1993.
Remainder recovered 21 June 1993.

Table 2
Subduction 1 Mooring Deployments and Positions

Buoy	Mooring #	Deployment Time (UTC)	Recovery Time (UTC)	Position(GPS)
NE	914	18 Jun1991 1642	14 Feb 1992 2315	33° 00.07'N 21° 59.75'W
C	915	23 Jun 1991 0026	11 Feb 1992 1120	25° 31.90'N 28° 57.17'W
SW	916	25 Jun 1991 1312	2 Feb 1992 0727 4 Feb 1992 1844 *	18° 00.03'N 33° 59.96'W
SE	917	29 Jun 1991 0137	30 Oct 1991 0000 8 Feb 1992 0843**	18° 00.13'N 22° 00.00'W
NW	918	3 Jul 1991 1323	15 Sept 1991 2035 23 Feb 1992 1022***	32° 54.61'N 33° 53.50'W

* SW Mooring broke free on 3 November 1991. Top 110m recovered 2 February 1992
remainder of mooring recovered 4 February 1992.

** SE Mooring broke free on 10 October 1991. Top 50m recovered on 30 October 1991
remainder of mooring recovered 8 February 1992

*** NW Mooring broke free on 3 August 1991. Top 400m recovered 15 September 1991
remainder of mooring recovered 23 February 1992

Table 3
Subduction 2 Mooring Deployment Dates and Positions

Buoy	Mooring Number	Deployment Date and Time (UTC)	Recovery Date and Time (UTC)	Position (GPS)
SW*	924	5 Feb 92 @1318	23 June 93	17°59.93'N 34°00.65'W
SE	925	9 Feb 92 @ 0244	6 Oct 92 @1759	17°59.72'W 22°00.29'W
C	926	12 Feb 92 @ 1915	14 Oct 92 @1203	25°31.95'N 28°57.23'W
NE	927	20 Feb 92 @ 1547	1 Oct 92 @ 1857	33°01.98'N 22°00.27'W
NW	928	23 Feb92 @ 2328	23 Oct 92 @ 0912	32°54.42'N 33°53.35'W

*SW Parted 4 June 92, Toroid with upper instrument cage recovered 17 July 92
Unsuccessful dragging attempt during DARWIN cruise 73.
A second attempt to drag for the mooring during Kn 138 was successful. Bottom recovered 23 June 1993.

Section 2: The Mooring Program

A. Mooring and Buoys

The mooring work carried out during KN138 Leg XV consisted of recovering five moorings that were deployed during earlier Subduction cruises. Five surface moorings were deployed for a third time in October 1992 during RRS Charles Darwin cruise number 73. The surface moorings included two WHOI moorings designated Central and Northeast and three SIO moorings designated Southeast, Southwest and Northwest. Figure 3 schematically shows all five moorings and the distribution of the Subduction 3 subsurface instrumentation. For details about the buoys and their tower configurations deployed during Subduction 3, see Trask et al. 1993a. Appendix 2 has a complete discussion on the surface mooring recovery operations that took place during KN138 Leg XV.

Two moorings failed during the third setting of the Subduction array. The first to fail was the Northwest mooring followed soon thereafter by the Southwest mooring. On 13 March 1993, the Northwest mooring parted and the discus buoy went adrift. The buoy was tracked via satellite and was recovered by the Canadian research vessel Hudson on 11 April 1993. Recovered with the buoy was the upper 104 meters of the mooring. Figure 4 is a mooring schematic of the Subduction 3 Northwest mooring. The deepest component recovered by the CSS Hudson was a pear ring. The shackle and everything below was missing.

Figure 3. Subduction 3 Moored Instrument Positions

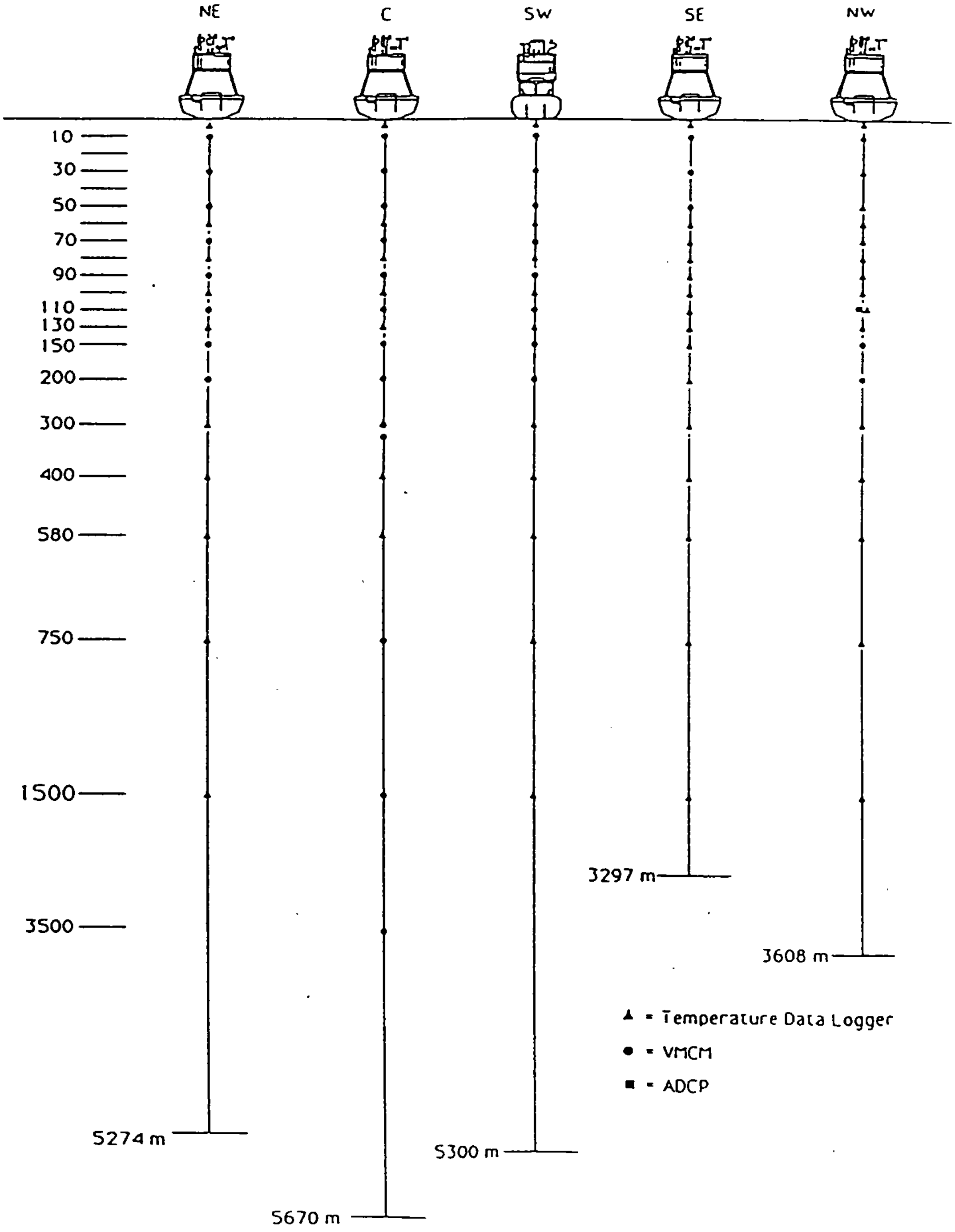
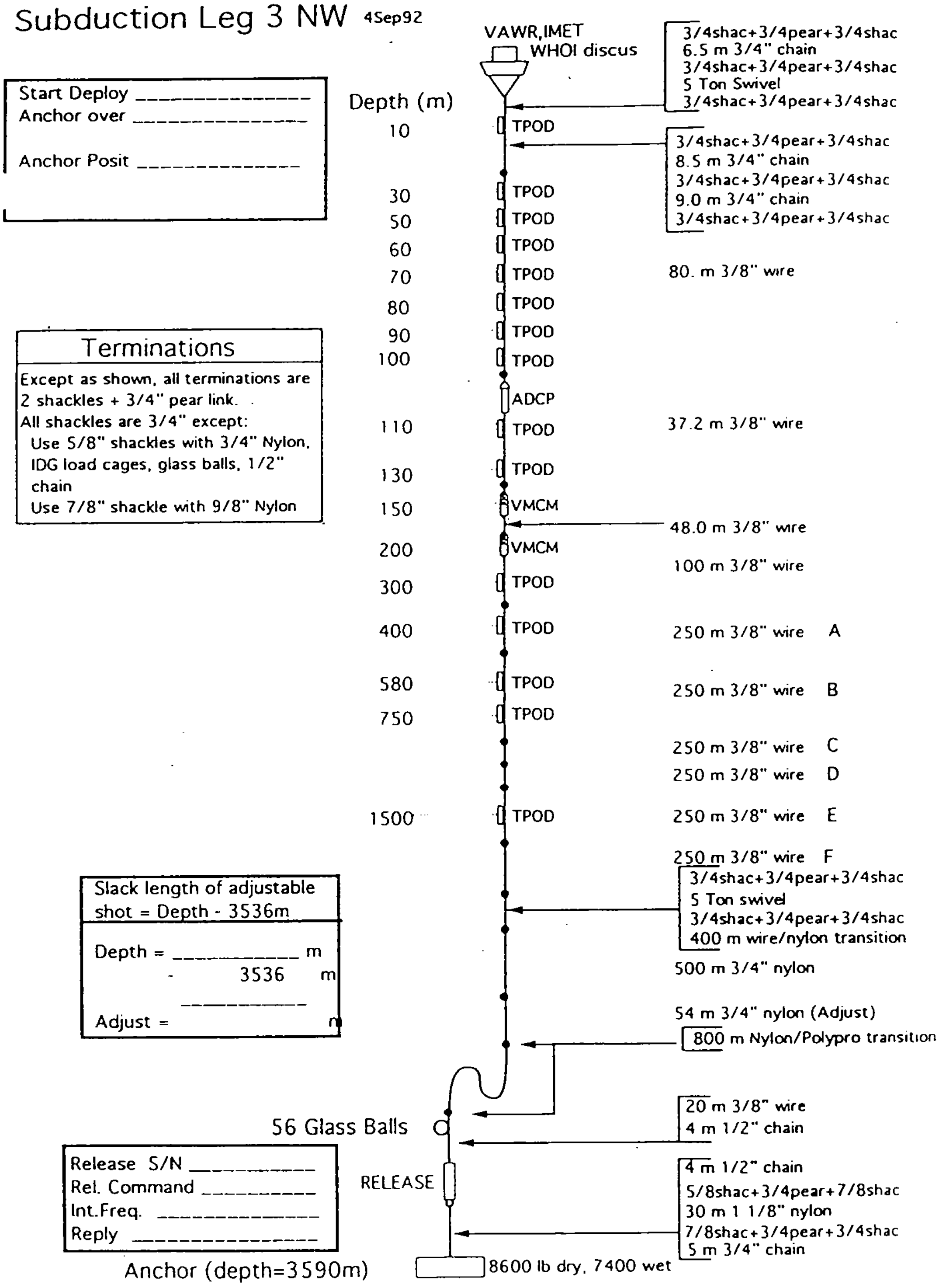


Figure 4. Subduction 3 Northwest Mooring Schematic



Start Deploy ______________
Anchor over ______________

Anchor Posit ______________

Terminations

Except as shown, all terminations are 2 shackles + 3/4" pear link.
All shackles are 3/4" except:
Use 5/8" shackles with 3/4" Nylon, IDG load cages, glass balls, 1/2" chain
Use 7/8" shackle with 9/8" Nylon

Slack length of adjustable shot = Depth - 3536m

Depth = __________ m
- 3536 m
____
Adjust = m

Release S/N __________
Rel. Command __________
Int.Freq. __________
Reply __________

Dr. James Luyten (WHOI), chief scientist during R/V Oceanus cruise number 258 Leg 3 agreed to try to recover the lower part of the Northwest mooring if time permitted during his cruise. Two days after the Knorr had left Ponta Delgada the Oceanus reported that they had successfully recovered the bottom portion of the failed Northwest mooring. The upper most part of the mooring recovered by the Oceanus consisted of the lower bail of the ADCP cage. Somehow the ADCP cage failed, and the shackle in the top bail either failed on its own, rattled loose or was removed. It remains a mystery as to the sequence of events that led to the loss of the Acoustic Doppler Current Profiler (ADCP).

Since the Oceanus was able to recover the bottom of the Northwest mooring, there was no need for the Knorr to transit to that site. The shiptime saved by not having to transit to the Northwest site was used to drag for a previously lost mooring at the Southwest site.

On 22 May 1993, the Subduction 3 Southwest mooring parted and its toroid surface buoy went adrift. The lower portion of the Southwest mooring was successfully recovered during KN138 Leg XV (see Section 3). The surface buoy was tracked via satellite and recovered during the same cruise on 25 June 1993, at 0924 UTC.

On 4 June 1992, the Southwest mooring from the second setting of the Subduction array parted. The top of the mooring was recovered on 17 July 1992, by the NOAA vessel Malcolm Baldridge. Attempts to recover the lower portion of the mooring during Darwin cruise 73 were unsuccessful (see Trask et al. 1993a). A dragging operation conducted during KN138 resulted in the successful recovery of all mooring components from the Subduction 2 Southwest mooring. For details about the dragging operation see Section 3 and Appendix 3.

Hardware and wire rope samples were collected from the Northeast and Central moorings. The shackles and pear rings that were deployed together were kept together and labelled. The label included the mooring number and the numbers of the two items that the hardware had connected. The item numbers were taken from the mooring logs. For example, on the Northeast mooring the label on the hardware that connected the buoy to the upper shot of chain would read "952 Item 1-2". The wire rope samples were labelled with the mooring number, their item number from the mooring log and either the word "top" or "bottom" depending upon the end of the wire shot (as oriented on the mooring) from which the sample was taken. For example, the tag on a wire sample from the top of the first shot of wire on the Northeast mooring would read "952 Item 4 TOP". The swaged ends of the wire plus approximately 5 feet of wire were saved as a sample. This will permit re-swaging on the cut end so that the samples can be tested. To inhibit further corrosion, the samples were submerged in seawater for the transit back to Woods Hole. Both the hardware and wire rope samples will be used in future cyclic fatique tests.

B. Instrumentation

A total of 102 recording instruments were deployed on the five Subduction 3 moorings. There were nine meteorological packages, 34 current meters, 58 temperature data loggers, and one ADCP. The specific instrumentation deployed during the third setting of the Subduction array is shown in table 4. For reference purposes the instrumentation on the first and second settings are shown in tables 5 and 6 respectively. wind speed and direction, air temperature, relative humidity, barometric pressure, sea surface temperature, short wave radiation, and long wave radiation. Additional information about the VAWR can be found in Trask et. al. 1989. The other meteorological package was an IMET system which made measurements of the same variables as the VAWR plus precipitation. Both the VAWR and IMET systems individually recorded all data internally as well as telemetered their data via Argos. The VAWR stored its data on cassette tape every 15 minutes, and the IMET system recorded on optical disk every minute.

For both the discus and toroid buoys the VAWR sensors (except sea temperature) and electronics with battery pack were attached to the tower top. The sea surface temperature sensors for both the VAWR and IMET systems were attached to the buoy bridle approximately 1 meter below the surface. During the third Subduction setting the Southwest toroid did not have an IMET system. The IMET sensors on all the discus buoys are configured the same and mounted on the tower top. The IMET electronics and rechargeable batteries are housed in the discus buoy watertight instrument well.

Since there was no capability to read the IMET optical disk on board ship, it was impossible to back-up the moored IMET data. The VAWR data was read on a model 12B Sea Data reader and transcribed to floppy disk. An exabyte tar tape was also made of the VAWR data. Appendix 4 lists for each VAWR the number of data records, and parity, long and tape errors encountered during the initial tape reading. Appendix 5 describes the condition of each of the IMET systems at the time of recovery.

Current Meters

A total of 34 Vector Measuring Current Meters (VMCM) provided by both WHOI and SIO were deployed on the five Subduction 3 surface moorings. The 23 WHOI VMCMs were a modified version of the EG&G Sea Link instrument, whereas the 11 SIO VMCMs were built by Scripps personnel. The sampling interval for the WHOI VMCMs was 7.5 minutes, and for the majority of the SIO VMCMs it was 15 minutes. Two SIO instruments (numbers 23 and 24 at 70 and 150 meters respectively on the Southwest mooring) had flash card memory and new electronics which permitted them to store 4 minute averages.

The WHOI VMCMs incorporate several changes to the standard EG&G Sea Link product. These include different propeller bearings, a different plastic for the propeller blades, an external temperature pod for faster temperature response, and a redesign of the instrument cage. The cage redesign and external temperature pods are described in Trask et al (1989) as is some historical information on propeller bearings and blade materials.

Meteorological Instrumentation

Each discus buoy was outfitted with two separate meteorological instruments. One system was a Vector Averaging Wind Recorder (VAWR) which recorded measurements of

Table 4
Subduction 3 Instrumentation

Depth	NE	C	SW	SE	NW
VAWR IMET	V-721WR	V-121WR	V-720WR	V-704WR	V-722WR
1	W-3283	W-3279	W-3297	W-3305	W-3262
10	VM-038	VM-032	SVM-02	SVM-06	S-3306
30	VM-021	VM-018	SVM-22	VM-022	W-3341
50	VM-012	VM-024	SVM-07	SVM-20	W-4492
60	W-4488	W-3303	S-2432	W-4481	W-2541
70	VM-033	VM-030	SVM-23	S-2418	W-2537
80	W-3259	W-4489	W-2539	S-2436	W-3665
90	VM-037	VM-028	SVM-13	S-2428	W-2533
100	W-4485	W-3265	W-4487	S-2422	W-3274
110	VM-041	VM-039	SVM-4	S-2420	ADCP-185 W-3309
130	W-4482	W-3280	S-2421	S-2424	S-3710
150	VM-015	VM-009	SVM-24	S-2437	VM-014
200	VM-016	VM-034	SVM-19	S-2433	SVM-03
300	W-4493	VM-035	S-2435	S-2425	S-3270
310		VM-027			
400	S-3302	W-4491	S-3295	S-3312	S-3314
580	S-3311	W-3662	W-2542	W-4490	S-3307
750	S-3278	VM-036	S-3292	S-3275	S-3708
1500	S-3281	VM-011	W-4483	W-3271	S-3304
3500		VM-045			

W-# = WHOI Brancker Temperature Recorder
S-#= SIO Brancker Temperature Recorder
VM-# = WHOI Vector Measuring Current Meter
SVM-#= SIO Vector Measuring Current Meter

Table 5
Subduction 1 Instrumentation

Depth	NE	C	SW	SE	NW
VAWR IMET	V-704WR	V-722WR	V-720WR	V-721WR	V-121WR
10	VM-041	VM-035	SVM-04	SVM-12	S-3285
20	TEST STING1			TEST STING2	
30	VM-021	VM-033	SVM-07	VM-007	S-3315
40	TEST STING3				
50	VM-039	VM-024	SVM-06	SVM-16	S-3294
60	W-3274	W-3309	S-3314	W-3297	W-3262
70	VM-032	VM-012	SVM-22	S-3282	S-3313
80	W-3265	W-3308	W-3279	S-3270	S-3260
90	VM-022	VM-038	SVM-02	S-3298	S-3261
100	W-3288	W-3296	W-3303	S-3284	W-3258
110	VM-030	VM-009	SVM-05	S-2425	ADCP S-3277
130	W-3269	W-3280	S-2427	S-2432	S-2434
150	VM-028	VM-037	SVM-20	S-2418	SVM-11
200	VM-018	VM-016	SVM-13	S-2424	SVM-10
206	COND				
300	W-3300	W-3289	S-2435	S-2433	S-2421
400	W-3305	W-3283	S-2437	S-2422	S-2431
580	W-3268	W-3271	W-3341	W-3290	W-3272
750	W-3286	VM-015	S-2436	S-2426	S-2420
1500	W-3293	VM-034	W-3287	W-3259	W-3273
3490		TENS 1029			
3500		VM-011			

W-# = WHOI Brancker Temperature Recorder
S-#= SIO Brancker Temperature Recorder
VM-# = WHOI Vector Measuring Current Meter
SVM-#= SIO Vector Measuring Current Meter

Table 6
Subduction 2 Instrumentation

Depth	NE	C	SW	SE	NW
VAWR IMET	V-380WR	V-712WR	V-713WR	V-707WR	V-717WR
1	W-3507	W-3506	W-3665	W-3704	W-3508
10	VM-034	VM-002	SVM-01	SVM-03	S-3709
30	VM-027	VM-023	SVM-16	VM-010	W-3274
50	VM-036	VM-020	SVM-08	SVM-17	W-3288
60	W-2539	W-2541	S-3285	W-3279	W-3296
70	VM-014	VM-013	SVM-15	S-3707	W-3309
80	W-2542	W-2534	W-3263	S-3261	W-3269
90	VM-045	VM-019	SVM-14	S-3706	W-2536
100	W-3280	W-2537	W-3291	S-3714	W-2540
110	VM-035	VM-008	SVM-12	S-3710	ADCP-195 W-2535
130	W-3265	W-2538	S-3310	S-3294	S-3313
150	VM-009	VM-026	SVM-11	S-3715	SVM-09
200	VM-011	VM-025	SVM-18	S-3708	SVM-21
300	S-3260	VM-017	S-3713	S-3712	S-3276
310		VM-031			
400	S-3711	W-2533	S-2430	S-2423	S-3277
580	S-3298	W-3262	W-3299	W-3303	S-3316
750	S-2426	VM-029	S-2429	S-2434	S-3282
1500	S-2427	VM-001	W-3258	W-3341	S-3296
3500		VM-003			

W-# = WHOI Brancker Temperature Recorder
S-#= SIO Brancker Temperature Recorder
VM-# = WHOI Vector Measuring Current Meter
SVM-#= SIO Vector Measuring Current Meter

For the Subduction experiment the WHOI VMCMs in the upper 100 meters were outfitted with cages that have 3/4" diameter cage rods. The deeper instruments had cages with 1/2" cage rods. All cages had a single cross brace to support the sting between the two sets of propellers.

An alternative propeller bearing chosen for use in the Subduction experiment is an all silicon nitride ball bearing (SiNi balls and races with a Duroid ball retainer) available from Miniature Precision Bearing (MPB), of Keene, New Hampshire, part number J0001-809. This was selected over the typical stainless steel bearing based on previous test results, actual deployments and the fact that the 8-month Subduction deployments would be 30% longer than most previous deployments. The VMCM propellers used in the Subduction experiment are made of an unpigmented Delrin 100 ST which is impact modified.

The Subduction 3 WHOI VMCMs that were recovered during KN138 were, for the most part, in excellent condition with respect to propeller bearings and blades. None of the propellers had broken blades and the silicon nitride bearings were like new. Two instruments (at 30 and 50 meters depth) on the Northeast mooring had commercial fishing line entangling the propellers. Once removed both rotors on both instruments spun freely. The one WHOI instrument on the Southeast mooring had a sluggish top rotor, and the propeller shaft appeared bent. Two instruments (VM009 and VM011) that were recovered from the Central mooring had been in the water during Subduction 1, 2 and 3 with their original stings (propeller sensor assemblies). These instruments had a total deployment time of 24 months and were found to still be in excellent mechanical condition. See Appendix 6 for specific details noted as both the WHOI and SIO instruments were recovered. Appendix 7 contains more detailed information about the SIO instruments and other notes pertaining to the cruise.

The original data cassettes were read using a Sea Data reader model 12 B, and the data were transcribed to floppy disks. In addition the data were transferred to the ship's SUN computer and stored on an exabyte tar tape. VMCM number 009 (Central mooring at 150 meters depth) was the only instrument that had a noticeably shorter record than the others. Appendix 4 lists for each WHOI current meter the number of data records, parity, long and tape errors encountered during the initial tape reading.

Temperature Loggers

A total of 58 temperature data loggers manufactured by Richard Brancker Research Ltd. were provided by both WHOI and SIO for the five Subduction moorings. The locations of the loggers are shown in figure 3 and table 4. The loggers provided by WHOI were attached to the mooring line using a hinge-type clamp that was tightened around the wire. The SIO clamping arrangement consisted of two, 2-piece monel blocks which were machined to accept the mooring wire. The two pieces were clamped around the wire with .25" hardware.

Several different temperature recorder models were deployed. The SIO 2000-series instruments sampled at 30-minute intervals. The WHOI 2000-series instruments which were modified for extra memory, sampled at 15 minutes; and both the SIO and WHOI 3000-series instruments were sampling at 15-minute intervals. The SIO 2000-series instruments had SIO fabricated pressure cases and endcaps. The WHOI 4000-series instruments were rebuilt XX-105 units that flooded during Subduction 1 and had new EPROMS installed. The sampling interval for the 4000-series instruments was the same as the 3000-series units.

The Subduction 1 deployment of the Brancker temperature loggers had 15 instruments that leaked a small quantity of water, and, as a result, their data could not be read. See Trask et al 1993a and 1993b for details about the flooding Brancker temperature loggers. In preparation for the third setting of instruments several changes were made to the temperature loggers. In addition to the procedures that were adopted from SIO during the second setting, which included extreme tightening of the endcaps and drawing a vacuum, a new flexible nut assembly was incorporated into all the temperature loggers prepared in Woods Hole. The intent of the flexible nut was to correct for an out-of-square condition between the removable endcap and its threaded rod used to secure the endcap to the pressure case. The preparation of instruments also included spray coating all electronic boards with Dow Corning 1-2577 conformal coating to offer some resistance to moisture should the instruments leak a small quantity of water. The following Brancker serial numbers were modified to have the flexible nut assembly, and coated electronics boards: 3662, 4491, 4489, 3283, 4488, 3259, 4485, 4487, 3297, 3305, 4481, 4482, 4493, 4490, 4483, 3271, 4492, 3665.

Two temperature loggers (at 80 and 580 meters) recovered from the failed Subduction 3 Southwest mooring had pressure cases that were rated for 1000-meters depth. When the mooring failed the instrumentation went to the bottom (5300 meters) where the pressure exceeded the instruments' operating pressure and crushed their pressure cases.

Other than the two crushed instruments none of the WHOI Subduction 3 temperature loggers recovered during KN138 had any indication of leaking, and all instruments recorded data for the entire deployment. The five WHOI temperature instruments recovered from the failed Subduction 2 Southwest mooring showed no signs of leaking and all recorded data. For a complete listing of all Brancker temperature recorders and their previous deployments during the three Subduction settings, see Trask et al 1993a.

The temperature logger data was read from the instruments and stored on floppy disks. Copies of those floppies were made and a copy of the data was also stored on an exabyte tar tape.

C. Underway Measurements

Expendable Bathythermographs (XBT)

Two hundred and three XBTs were deployed during KN138 Leg XV. The T-7 probes were purchased from Spartan of Canada. The XBT data were logged on a personal computer outfitted with the Sippican MK-12 Oceanographic Data Acquisition System (version 1.3). With this system the digitized XBT data were plotted in real time on the PC monitor, and at the conclusion of the profile the data was stored on disk.

Hourly XBTs were taken on the hour while the ship was underway. When the ship was within 10 miles of a surface mooring site, XBTs were temporarily suspended. XBT positions and overplots of the XBT data, as well as contoured sections, can be found in Appendix 8.

The original XBT data was stored on floppy disks. Copies of those floppies were made, as well as an exabyte tar tape.

Meteorological Measurements

IMET sensors shipped from Woods Hole were installed on the bow mast and connected to the shipboard logging system prior to departure from Ponta Delgada. The meteorological parameters measured by the IMET system included wind speed and direction (oceanographic convention relative to the ship), air temperature, relative humidity, short wave radiation, barometric pressure, sea surface temperature and precipitation The IMET sea surface temperature module was installed some time prior to KN138 Leg XV.

IMET data aboard Knorr were exported to a data base management system called Minotaur, which runs on a PC. Minotaur uses Network File System to export data to the shipboard SunSparc 1, named Mike. Once on the Sun, data are available across the network. Minotaur includes a user selectable export list which allowed us to tailor the data storage on the Sun. On KN138, we chose to store all IMET variables and all GPS data to the Sun. The system was easy to use, although an unknown password on the Sun prevented data logging at the start of the cruise.

Using PCDC Telnet, we were able to access the data on the Sun from the PCs in the main lab. Using shell scripts, we could locate the most recent Minotaur data file and extract the fields of interest for the watch's meteorological log. We were also able to access the data directly on the Sun for plotting and archiving.

The instantaneous access to the IMET and GPS data was valuable because it saved time and provided constant verification of successful data storage. Data were extracted from Minotaur data files and tarred to exabyte tape to be brought home for later use. See Appendix 9 for a sample Minotaur log file from KN138. Appendix 9 also includes the shell scripts used to access the Minotaur files in order to print out the most recent IMET data at the terminal.

Manual meteorological observations were taken hourly on the half hour. The manual observations consisted of recording the time, position, ship's speed, ship's heading, wind speed and wind direction from the bridge readout; barometric pressure in the main lab using an AIR hand-held sensor; and from the bridge's barometer, air temperature and relative humidity using a hand-held Vaisala sensor; sea surface temperature from a bucket thermometer, and cloud type and cloud coverage in octas. These observations, plus the corresponding IMET data, were manually recorded in the underway meteorological log.

The manual observations of barometric pressure by the AIR hand-held sensor, Vaisala relative humidity and air temperature and bucket temperature were entered and stored on floppy disk. A copy of the data was made on the exabyte tar tape.

Another meteorological data recording system utilizing a Tattletale 7 and IMET modules as sensors was undergoing testing during KN138 Leg XV. Four parameters were being recorded by the TT-7 system. They included barometric pressure, relative humidity, air temperature and shortwave radiation. The data from these sensors were also recorded by hand in the underway meteorological log. A partial record of the data was stored on floppy disk, and a complete record exists on the instrument's hard disk and was read in Woods Hole.

Appendix 10 contains time series plots of meteorological data collected during a two-week period of the cruise. The plots are a comparison of the shipboard IMET system, the TT-7 system, and the hand-held data. The variables plotted are barometric pressure, relative humidity, air temperature and shortwave radiation.

Wind speed and direction from an RM Young anemometer mounted on a 10-foot mast above the flying bridge were also recorded. Since this sensor was mounted 20 feet in front of the ship's mast, there were certain directions relative to the ship that yielded questionable results.

Three independent measurements of sea surface temperature (SST) were collected during the cruise. They included IMET shipboard SST at 4-meters depth, XBT temperature and bucket temperature. IMET SST, and bucket temperature were recorded hourly on the hour in conjunction with the XBTs. Appendix 11 has a comparison of the data collected during the cruise.

Intensive Meteorological Observations

As the ship arrived at each buoy, four hours of intense meteorological observations (IMO) were carried out while the ship maintained a position approximately 1/4 mile downwind of the buoy. During this period, shipboard IMET data were logged by hand every 5 minutes. Every half hour, sea surface temperature readings were taken with a bucket thermometer, and air temperature and relative humidity readings were taken with the Vaisala. Anemometer, gyro, speed log and barometer readings were also taken on the bridge every half hour.

During the IMO periods, VAWR and IMET Argos data telemetered from the buoys were logged using a Telonics receiver and laptop computer for comparison with the shipboard observations. VAWR Argos data were processed on the PC using a suite of programs including picktel and vawrtel. Data were then transferred to the shipboard Sun for plotting. Comparison plots of VAWR and shipboard IMET data were done with Matlab. Table 7 shows the IMO periods for the four buoys recovered during Kn 138 Leg XV.

Table 7
Intense Meteorological Observation Periods KN138 Leg XV.

BUOY	VAWR	DATE	Yr DAY	I.M.O.TIMES. (UTC)
NE	721	14 June	165	1050 - 1450
C	121	16 June	167	1600 - 2000
SE	704	19 June	170	0130 - 0530
SW	720	25 June	176	0400 - 0800

Section 3: Cruise Chronology

The R/V Knorr left Ponta Delgada, Azores, on 13 June 1993, at 0855 UTC. While enroute to the Northeast mooring, hourly XBTs and meteorological observations were taken starting at 1200 UTC on 13 June.

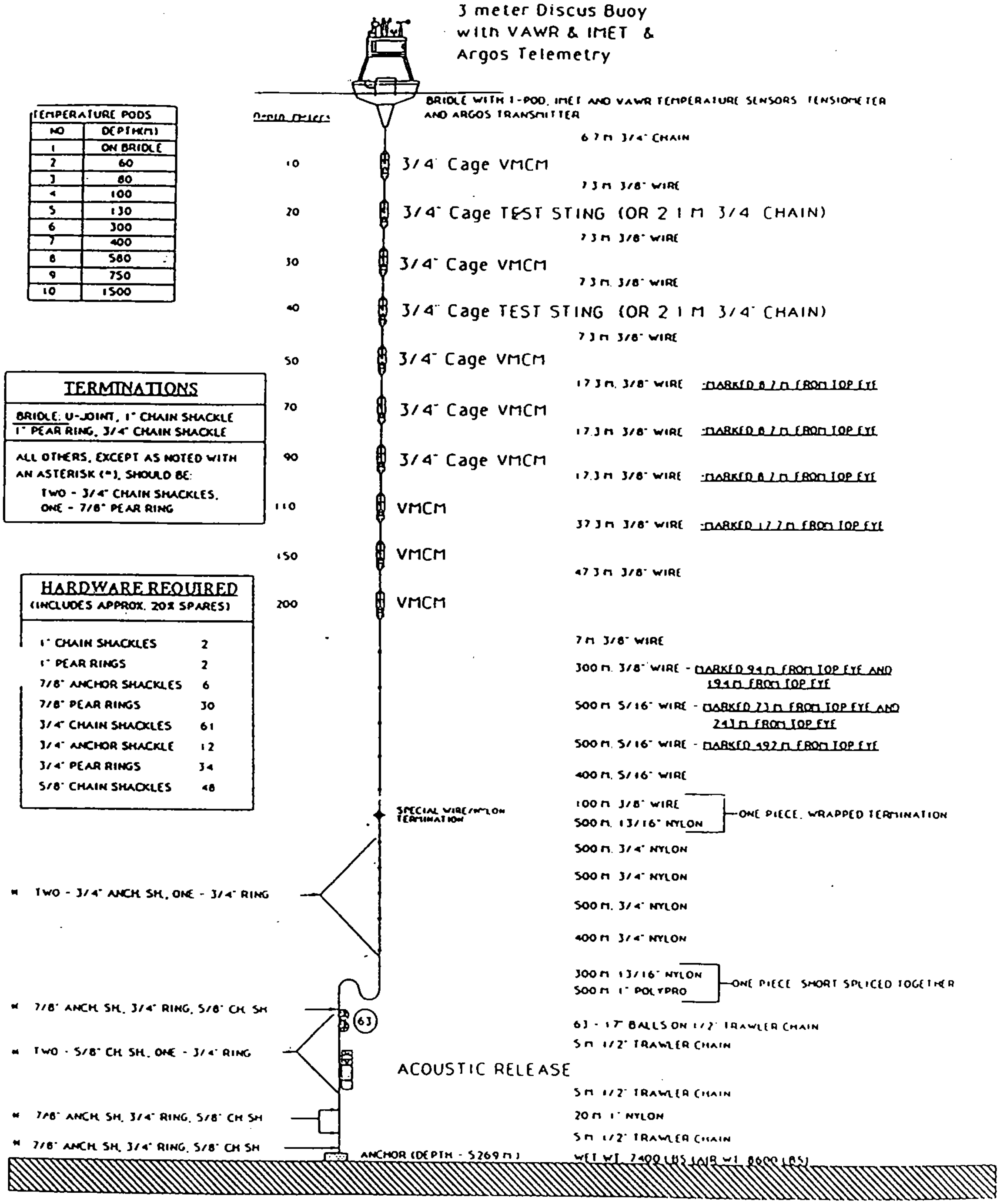
Northeast Mooring

The Knorr arrived at the Northeast buoy at 1050 UTC on Monday, 14 June 1993 at position 33°01.46'N, 21°59.74'W. Figure 5 is a schematic of the Northeast Subduction 3 mooring (WHOI mooring number 952) as deployed in October 1992. As the ship passed by the buoy, it appeared in good condition. The ship then moved to a position .25 miles downwind of the surface buoy and remained there for four hours while meteorological observations were recorded every 5 minutes. With the meteorological observations completed, several attempts were made to talk to the acoustic release. After sending a number of enable commands, a faint response was finally heard. The ship deassigned all engines to try to make things as acoustically quiet as possible. Unable to range on the release, a decision was made to send a release command. An appropriate response to the release command was detected and slant ranges were checked for a short period in order to ascertain that the mooring was coming to the surface. The ship then moved into position for recovery. The discus buoy was alongside and hooked into at 1615 UTC.

While the buoy was alongside, one of the pickup hooks became caught on the VAWR air temperature sensor cable at the base of the sensor. It was freed relatively soon with no visible damage to the wiring. The multiplate shield suffered a small dent. During a short delay in getting a pickup hook in the primary lifting bale, the buoy came in contact with the ship on several occassions. As the buoy was brought on board a tag line caught the R.M. Young wind speed and direction sensor and pulled it from its IMET module. The sensor landed on deck and was retrieved.

The buoy was recovered and secured to the deck. The recovery of the mooring commenced using the WHOI Lebus double barrel capstan winch. The entire mooring was on board by 2118 UTC, 14 June 1993.

Figure 5. Subduction 3 Northeast Mooring Schematic



TEMPERATURE PODS	
NO	DEPTH(m)
1	ON BRIDLE
2	60
3	80
4	100
5	130
6	300
7	400
8	580
9	750
10	1500

TERMINATIONS

BRIDLE: U-JOINT, 1" CHAIN SHACKLE
1" PEAR RING, 3/4" CHAIN SHACKLE

ALL OTHERS, EXCEPT AS NOTED WITH AN ASTERISK (*), SHOULD BE:
TWO - 3/4" CHAIN SHACKLES,
ONE - 7/8" PEAR RING

HARDWARE REQUIRED
(INCLUDES APPROX. 20% SPARES)

1" CHAIN SHACKLES	2
1" PEAR RINGS	2
7/8" ANCHOR SHACKLES	6
7/8" PEAR RINGS	30
3/4" CHAIN SHACKLES	61
3/4" ANCHOR SHACKLE	12
3/4" PEAR RINGS	34
5/8" CHAIN SHACKLES	48

SUBDUCTION NORTHEAST - THIRD SETTING

C. TUPPER 22 JUN 92

Mooring number 952 had six WHOI Brancker temperature recorders. All six intruments collected data for the full deployment. There were also four SIO Brancker temperature recorders on the Northeast mooring. All of the SIO instruments recorded data for the full deployment as well.

Eight WHOI VMCMs were also recovered from this mooring. The upper instrument (10-meters depth) had a number of goose barnacles both on the pressure case and propellers. The instruments at 30 and 50 meters depth had commercial fishing gear entangling the upper and lower rotors of both instruments. The rotors of these instruments were unable to spin on recovery. The remaining deeper instruments appeared in good mechanical condition as they came on board. Propeller bearings spun freely and all propeller blades were intact. There was minimal growth on the instruments below 10 meters. The buoy hull was also clean upon recovery. Some sections of the hull no longer had any antifouling paint presumably because it had worn off during the eight-month deployment. Even in these bare spots there was no growth. The buoy bridle legs were covered with goose barnacles as was the cabling to the bridle-mounted instruments.

Hourly XBTs were resumed at 2200 UTC on 14 June 1993, while the ship was enroute to the Central mooring site.

Central Mooring

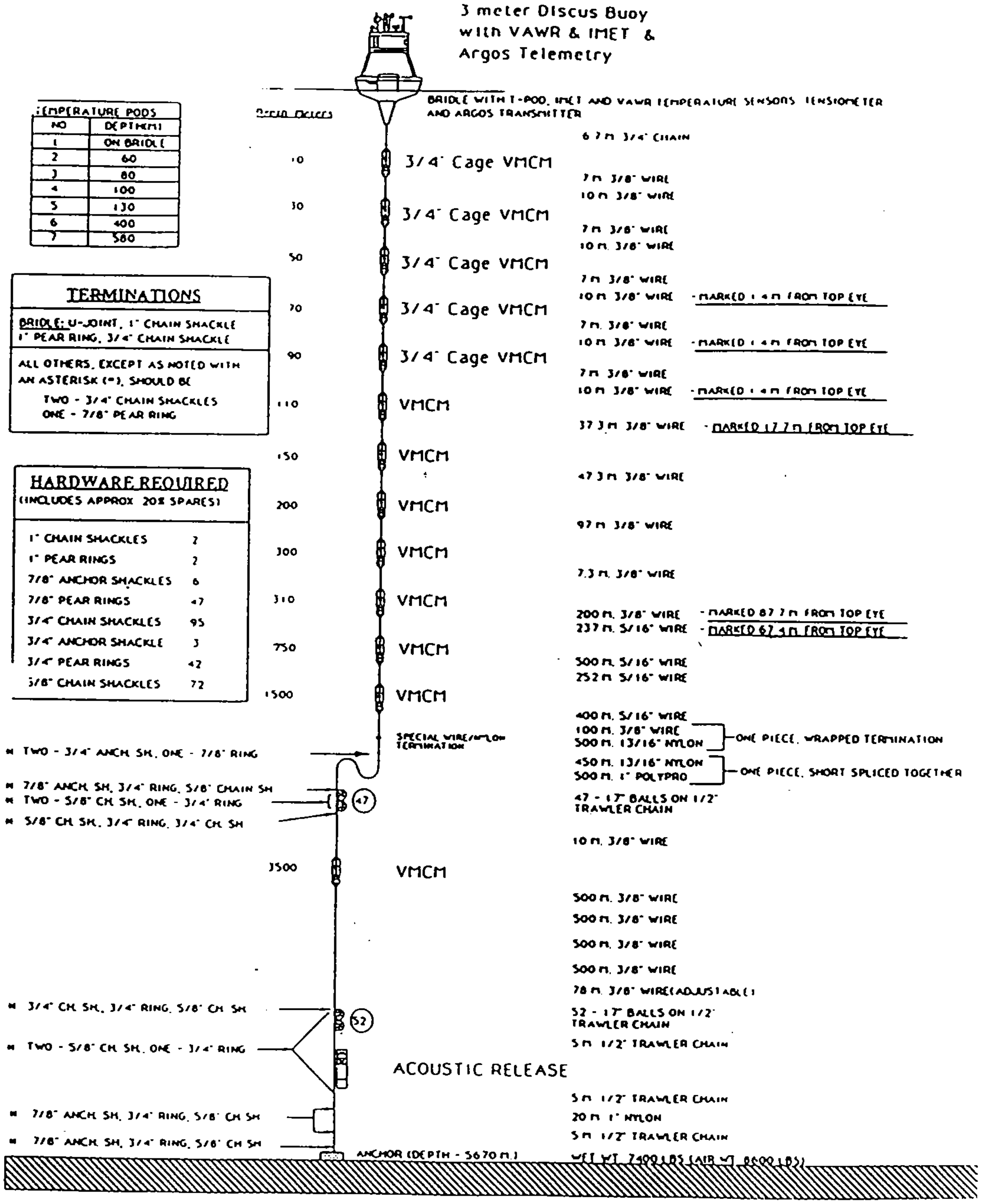
The ship arrived at the Central mooring buoy at 1600 UTC on 16 June 1993, at which time meteorological observations were made every five minutes for four hours. The buoy was located at position 25°31.60'N, 28°56.88'W. Figure 6 shows the Central mooring as deployed in October 1992. The acoustic release was fired at 2009 UTC, and the ship moved to recover the buoy. The recovery of the buoy proceeded very smoothly and without incident. Some chafe in the nylon portion of the wire-to-nylon shot was noted immediately below where the urethane coating ended. The urethane may need to be tappered slightly more than is presently done. Recovery of the acoustic release occurred at 0226 UTC, 17 June 1993.

Six glass balls recovered from the lower cluster had imploded; four occurred in the same string. It was impossible to determine whether the other two were adjacent to those four due to the way the cluster came on deck. One of the four imploded balls was in a super-ribbed hardhat.

The upper VMCM at 10-meters depth (VM032) had a number of goose barnacles on the pressure case and propeller blades but the propellers were spinning freely when recovered. All the instruments appeared in good condition. There were no broken blades and the bearings were in good condition. All instruments pulled about the same amount of tape except VM009 which appeared to pull considerably less than the others.

The Brancker temperature loggers recovered from the Central mooring recorded data for the full deployment. The VAWR pulled tape and appeared to have good data during the initial tape reading and data transfer. The IMET system optical disk was pulled and will be read in Woods Hole.

Figure 6. Subduction 3 Central Mooring Schematic



SUBDUCTION CENTRAL - THIRD SETTING

G. TUPPER 22 JUN 92

Several minutes after the bottom of the Central mooring was recovered (0240 UTC) the ship lost all power and became dark and dead in the water. Minutes later the power slowly came back on line and normal operation resumed. The bridge advised that, due to the power failure, the gyro information should be considered suspicious for a few hours while the gyros came back up to speed. The ship got underway for the Southeast mooring at 0301 UTC . Hourly meteorological observations began at 0330 UTC and XBTs started at 0400 UTC.

Southeast Mooring

The Knorr arrived at the Southeast buoy at 0130 UTC on Saturday, 19 June 1993. Figure 7 is a schematic of the Southeast mooring as deployed in October 1992. After a brief inspection of the surface buoy, the ship was positioned .25 miles downwind of the buoy so that meteorological observations could be made every 5 minutes for 4 hours. At the end of the meteorological observations the mooring's acoustic release was fired at 0525 UTC. Recovery of the buoy was accomplished without any damage to the buoy or meteorological instrumentation. The subsurface instrumentation was recovered without any problems, and the glass balls and release were on board by 0840 UTC.

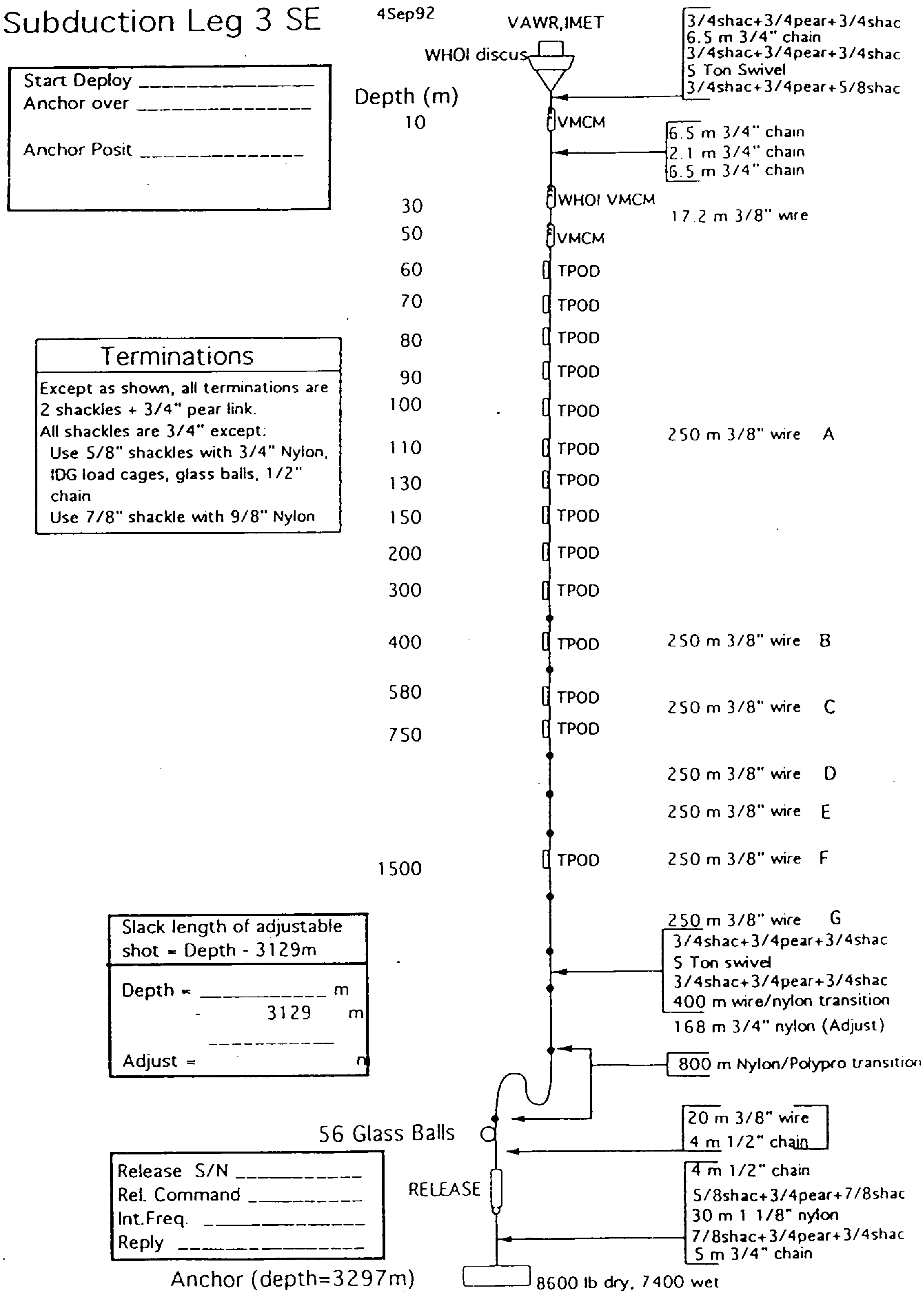
The surface buoy that was recovered from the Southeast mooring had a considerable quantity of gooseneck barnacles on the underside of the hull. The deck of the buoy was covered by a dark brown growth that looked like a kind of algae. The tower top with meteorological instrumentation was covered by a light brown, very fine clay-like material. Sensors were covered with the same material. Solar radiation sensors and solar panels had a very fine coating that presumably would impair the passage of radiation. The trailing edges of the sensors had a greater accumulation of brown sediment than did their leading edges. The whole tower top took on a light brown color rather than the usual white. The Subduction 2 Southeast buoy had the same appearance upon recovery in October 1992.

The subsurface Argos transmitter was found hanging from the bridle on recovery. The hose clamps used to secure the transmitter to an upper bracket were missing and the transmitter appeared to have worked its way down the bridle, such that the lower bracket had moved off its neoprene spacer and became very loose on the bridle leg. Extreme wear was evident in the plastic antenna housing of the transmitter, as well as on the case itself.

One WHOI VMCM was recovered from the Southeast mooring. On recovery the upper propeller shaft appeared bent. The propeller hub rubbed against the sting hub preventing it from spinning freely. Upon close examination the delrin propeller hub showed evidence of abrasion, as if a piece of wire or line had been bearing against it. When the instrument was disassembled in order to remove the tape, the upper part of the sting also appeared bent; the lower rotor was in good condition. None of the propellers had any broken propeller blades.

Two SIO VMCMs were also recovered from the Southeast mooring. The propeller bearings on these instruments exhibited slightly more radial and axial endplay than when deployed. Both instruments pulled tape and appeared to work for the entire deployment. On one instrument (SIO number 20 at 50 meters depth) the temperature record was approximately one month long. The cause was found to be a temperature circuit board that was dislodged from the backplane of the instrument. The other SIO VMCM (number 6) had blue-green line around the lower rotor but was freely spinning upon recovery.

Figure 7. Subduction 3 Southeast Mooring Schematic



Subduction Leg 3 SE

4Sep92

Start Deploy ________________
Anchor over ________________

Anchor Posit ______________

Terminations

Except as shown, all terminations are 2 shackles + 3/4" pear link.
All shackles are 3/4" except:
Use 5/8" shackles with 3/4" Nylon, IDG load cages, glass balls, 1/2" chain
Use 7/8" shackle with 9/8" Nylon

Slack length of adjustable shot = Depth - 3129m

Depth = __________ m
- 3129 m
____
Adjust = m

Release S/N ___________
Rel. Command __________
Int.Freq. _____________
Reply ________________

Anchor (depth=3297m)

The VAWR on the Southeast mooring appeared to collect data for the entire deployment. The IMET system was working on recovery, and its optical disk was removed for reading back at Woods Hole.

Four WHOI owned and eleven SIO owned Brancker temperature recorders were recovered from this mooring. All four WHOI instruments recorded data for the entire deployment; nine of the eleven SIO instruments worked for the full deployment. Brancker serial number 2418 failed to start at the begining of the deployment and collected no data. Instrument number 2422 appeared to leak, and its data could not be recovered.

Hourly XBTs were resumed at 0900 UTC as the ship got underway for the Southwest mooring site. Hourly meteorological observations were also continued on the half hour.

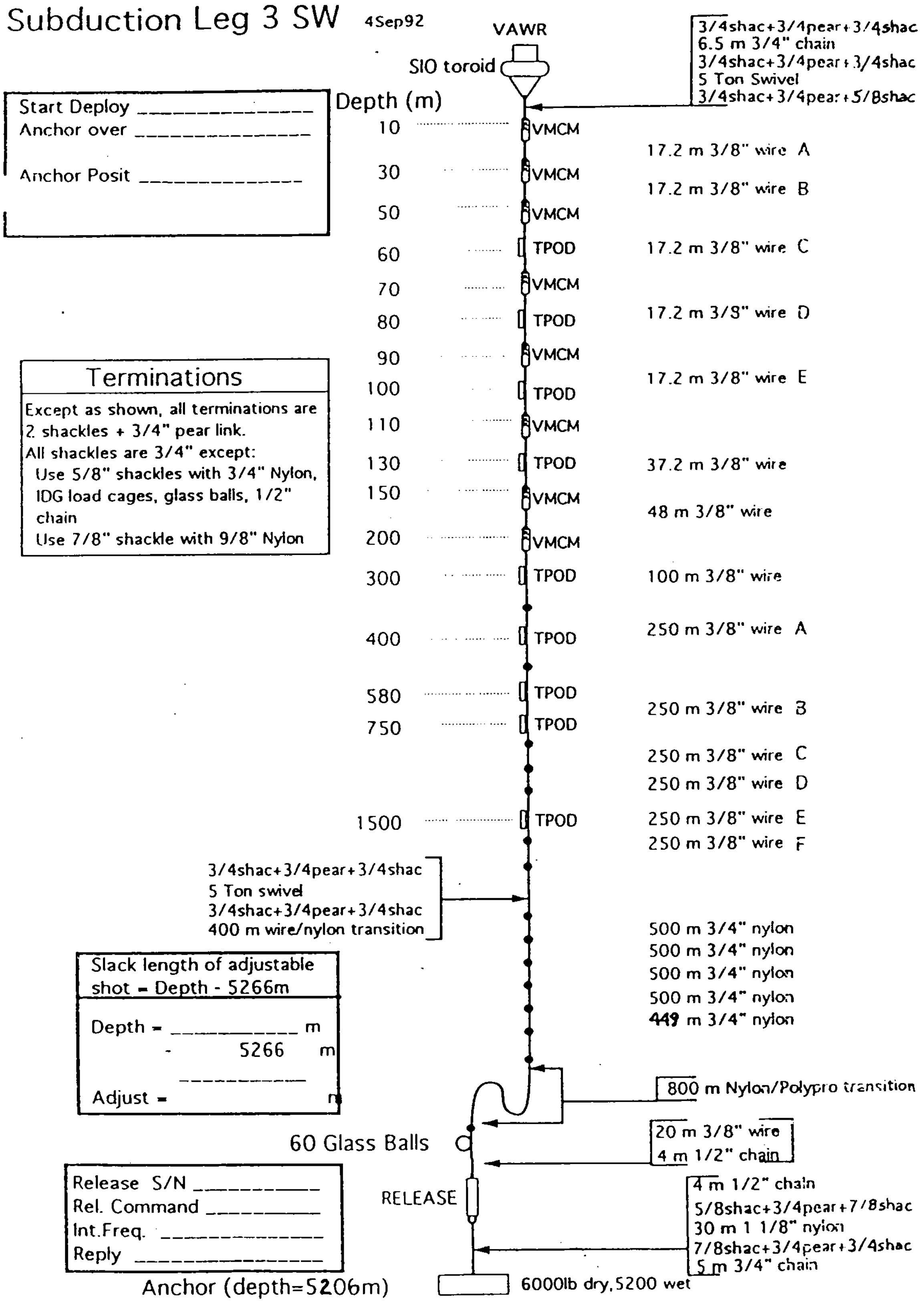
Southwest Moorings

The bottoms of two moorings (WHOI mooring numbers 924 and 954) were at the Southwest site. Mooring 924 was deployed in February 1992 and could not be recovered in October 1992 during Darwin cruise 73. Mooring 954 was deployed from the Darwin in October and had recently failed in May 1993. The ship arrived at the site of mooring 924 at 1157 UTC, on 21 June 1993. A release command was the first signal sent in hopes that, if battery power were low, it would have enough to activate the release mechanism. The release responded to the command sent but did not confirm release. This was the same response obtained in October 1992. Fortunately the release was still operational, and it was obvious from its response that a dragging operation would be required in order to attempt recovery. The dragging operation would require resurveying the anchor and setting a navigation network. Rather than use daylight hours to prepare for the dragging, a decision was made to attempt recovery of mooring 954 in the daylight and prepare for dragging at night.

Before attempting recovery of mooring 954 (shown schematically in figure 8), it was necessary to resurvey the anchor in the event that it had moved. The GPS receiver used for this purpose was capable of correcting errors intentionally introduced in the signal in order to degrade its accuracy. The error corrected GPS information will henceforth be referred to as undithered GPS. The anchor position determined during the KN138 survey was nearly identical to the original anchor position, indicating that it had not moved. The ship was positioned .25 miles downwind of the anchor position and the release was fired at 1506 UTC, 21 June 1993. Confirmation of release was received. Slant ranges to the release were monitored every minute. Steadily decreasing ranges indicated the mooring was rising to the surface. Due to the ship's drift away from the site, it was necessary to reposition the ship to the original position from which the release was fired. At 1610 UTC the balls were spotted on the surface two ship lengths away. The balls were recovered at 1630 UTC, and the remainder of the mooring was on board by 1927 UTC. Most of the instrumentation was recovered in one large wuzzle. The uppermost component recovered was the bottom of the SIO VMCM cage at 10-meters depth. The triangular-shaped cage end with bottom bale was still attached to the mooring. Three cage rods failed right at the bend where they become parallel, and the fourth pulled away where it was welded to the bale.

The WHOI instrumentation on this mooring consisted of four Brancker temperature loggers. Two of the four WHOI loggers (serial numbers 2539 and 2541) were crushed due to the pressure. Their pressure cases were not rated for full ocean depth. The other two had no leaks and recorded data up to the time the mooring failed. As the instruments

Figure 8. Subduction 3 Southwest Mooring Schematic



fell to the bottom, the temperature went out of the instrument's measurable temperature range. All five SIO temperature recorders collected data up to the time the mooring failed. Seven SIO VMCMs were recovered. With the exception of one VMCM which had a tight propeller, all the others appeared in satisfactory mechanical condition. All instruments, except the 10 meter VMCM, were recovered.

With mooring 954 on board the ship transitted back to the site of mooring 924. Figure 9 is a mooring schematic for the Subduction 2 Southwest mooring (mooring number 924). The release on mooring 924 was resurveyed using the undithered GPS. The survey placed the anchor at 17°59.93'N, 34°00.64' W, which was nearly identical to the positioned determined during Darwin cruise number 73 in October 1992.

The deployment of the dragging gear began at approximately 0700 UTC on 22 June 1993. Details of the dragging operation can be found in Appendix 3. The ship was positioned 1 kilometer downwind of the anchor and the dragging equipment was deployed.

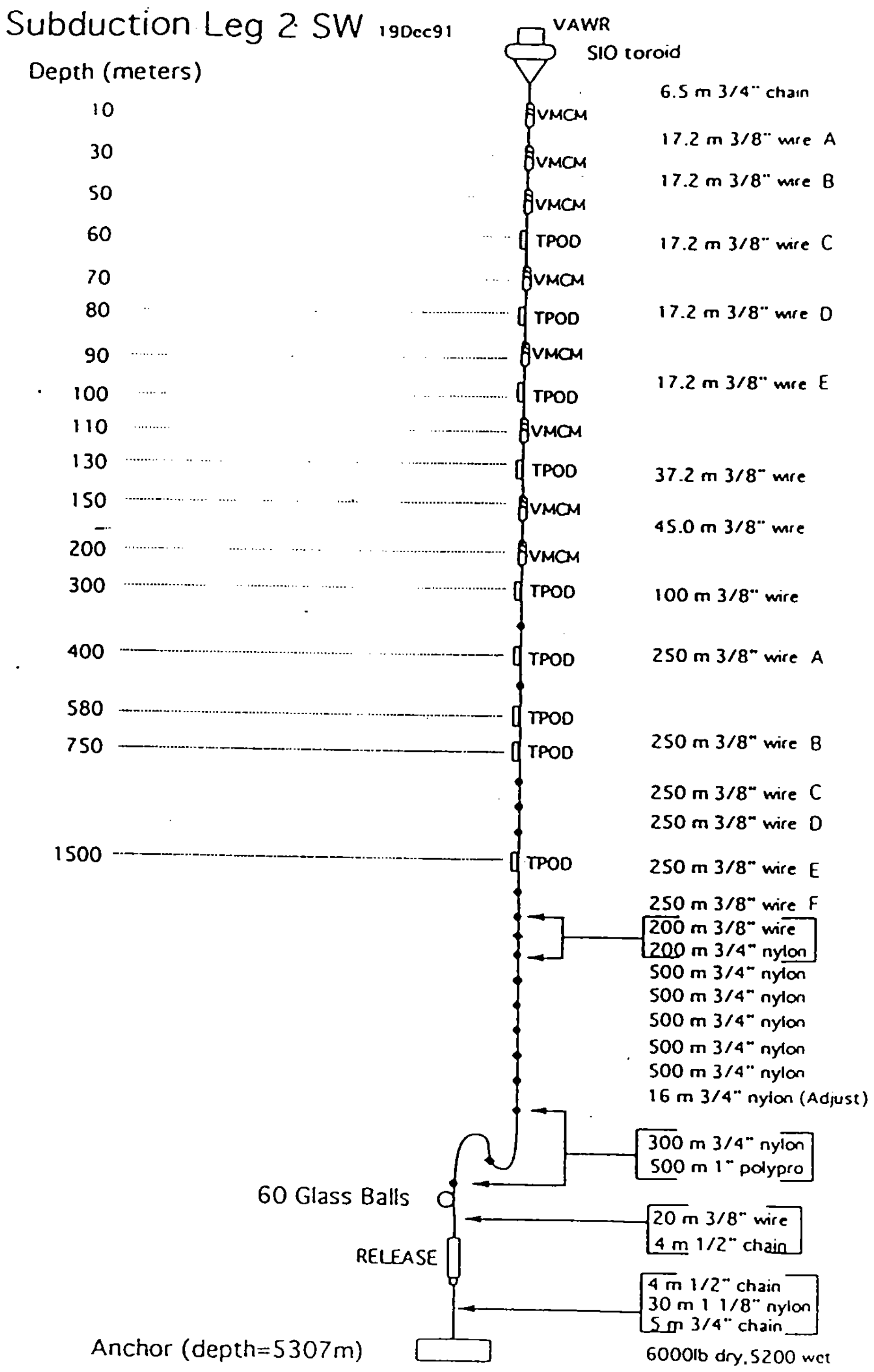
With the dragging gear very near the bottom, the ship was eased forward at .2 knots so that it would be laid out along the bottom rather than piled up in one place. The trawl wire was paid out at 5 meters per minute. The trawl payout rate was increased to 10 meters/minute since it was not obvious that the hooks were on the bottom yet, and it was necessary to get all the dragging gear on the bottom before passing the mooring anchor position. With the pinger 675 meters off the bottom, the ship's speed was increased to .3 knots. At 1710 UTC the ship passed directly over the mooring's anchor position. By the time the dragging gear approached the anchor site the pinger was a nominal 100 meters off the bottom. The pinger was flown at that height for the remainder of the dragging operation. When approximately half of the dragging grapnels were past the anchor position, the trawl winch started to haul in at 25 meters/minute. The rehaul speed was increased to 50 meters/minute soon thereafter.

Winch tension readings reached 11,000 pounds during rehaul and gradually dropped back to between 6000 to 7000 pounds where they remained. With the trawl wire completely recovered the only gear remaining in the water was the dragging gear which weighed about 2000 pounds. A slant range to the release indicated that it was 2736 meters away. With a water depth of 5300 meters the slant range indicated that the release was off the bottom. Since the mooring wire weighed between 1500 and 2000 pounds the additional tension was attributed to the anchor. Presumably the anchor had been dragged up with the mooring. The anchor weighed 6000 pounds, the mooring wire was 1500 pounds, and the dragging gear was 2000 pounds giving a downward force of 9500 pounds less the 3000 pounds buoyancy provided by 60 glass balls gave a net downward force of 6500 pounds.

To make sure that the mooring was completely free of the bottom the ship steamed away from the anchor at 1.5 to 2.0 knots. Tensions never changed significantly during the tow. With the ship eventually 5 km away from the original anchor position we were confident that the anchor was, in fact, hanging off the trawl wire.

High tension recoveries such as this can be very tricky and potentially dangerous operations. Since it was late and everyone was tired a decision was made to wait until morning before attempting recovery. Rest and daylight were considered important factors which would greatly increase the chances of a safe and successful recovery.

Figure 9. Subduction 2 Southwest Mooring Schematic



The following morning the slant range to the release remained at 2747 meters. After ranging on the acoustic release a release command was sent. To our surprise, confirmation of release was received and the tension dropped to 4000 pounds. Fortunately the anchor dropped away and the recovery tensions dropped to something more manageable. The ship immediately put some way on so as to move the ship out of the way of the rising glass balls. The glass balls surfaced about a mile aft of the ship.

The dragging gear was recovered and with it parts of the nylon and wire rope from the mooring. During the recovery the glass balls and release were cut free and retrieved after the mooring was on board. Most of the instrumentation came on board in several large wuzzles. All of the instrumentation was recovered. The 10 meter instrument had lost its cage when the mooring parted and its sting had become severely bent, but the instrument was still operational when its data tape was removed. The other VMCMs and temperature recorders appeared in good mechanical condition.

With the mooring on board the glass balls were located and recovered along with the acoustic release. Nothing was obviously wrong with the release, and it is unknown why it failed to release the mooring when on the bottom. Four glass balls were found imploded upon recovery. The remainder of the mooring still attached to the glass balls was completely recovered by 1840 UTC, 23 June 1993.

The Subduction 2 Southwest mooring recovered during KN138 had five SIO Brancker temperature loggers, 4 WHOI temperature loggers and eight SIO VMCMs. The WHOI temperature loggers and two of the five SIO instruments (serial numbers 3285 and 3310) collected data up to the time the mooring failed. SIO temperature logger number 3713 leaked and collected data until 23 February 1992. Instrument number 2430 stopped collecting data on 28 April 1992. It had a bad ROM installed which would not correctly sample cold temperatures. Temperature logger number 2429 also had a bad ROM and did not collect any data after it was deployed. The eight SIO VMCMs all ran out of tape prior to recovery.

The ship then got underway to recover the drifting Subduction 3 Southwest toroid buoy. At 0330 UTC, on 25 June 1993, the toroid was spotted. The ship was positioned .25 mile downwind of the buoy and meteorological observations were taken every 5 minutes for 4 hours. Following the intense meteorological observations, the ship moved in for recovery. Due to extreme difficulty in getting a hook into the lifting bale the buoy came in contact with the ship on several occasions. Once hooked up the buoy was recovered without difficulty. The 10 meter VMCM was also recovered with the bottom part of its cage missing and several cage welds broken.

Before getting underway for Bermuda the toroid buoy was dismantled. While removing the tower top the 3-cup anemometer on the VAWR was broken. The bridle was removed and the buoy secured with the discus buoys. The ship got underway for Bermuda at 1027 UTC. Hourly XBTs were ended at 1400 UTC, and the last meteorological observations were made at 1700 UTC, 25 June 1993.

The ship arrived in St.Georges, Bermuda, on Wednesday, 30 June 1993, at 1330 UTC.

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We also wish to thank Jim Ledwell (WHOI) and Neil Oakey (BIO) for their willingness to track down the drifting Northwest buoy while participating in a cruise on the Canadian research vessel Hudson. The efforts of Brian Guest who was "our man on the scene" during the Hudson recovery are greatly appreciated. The bottom part of the Northwest mooring was successfully recovered by Jim Luyten and Jerry Dean during an Oceanus cruise. Jim Luyten's willingness to use his shiptime to attempt the Northwest recovery saved our Knorr cruise a considerable amount of time which in turn was used for dragging for the failed Subduction 2 Southwest mooring.

Special thanks go to "Norm" for all his help throughout the entire Subduction field program. It made no difference whether we were at work in a foreign port or at sea, he was always willing to put his carpentry skills to work. We also wish to thank Bob Weller, Nancy Brink, and Penny Foster for their help in preparing this report.

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Appendix 1 Cruise personnel

Richard Trask	WHOI Chief Scientist
William Ostrom	WHOI
Neil McPhee	WHOI
Nancy Galbraith	WHOI
Dave Hosom	WHOI
Paul Robbins	WHOI
Lloyd Regier	SIO
Glenn Pezzolli	SIO
Jim Dufour	SIO
John Lilly	SIO
Anna Flak	Agriculture University of Poland
Stanley Rosenblad	WHOI Marine Technician

Appendix 2 Surface mooring recovery operations

W.Ostrom (WHOI)

The surface mooring operations on KN138, Leg XV were commenced from the starboard side using primarily the following equipment: the trawl crane, 5000 lb. portable capstan, three, 1000 lb. line pull air tuggers and the UOP Lebus capstan winch. The relative placement of this equipment on the Knorr's main deck is shown in figure A2-1.

The deck personnel during the discus and glass ball recovery operations totaled 11 people. The Lebus winch system required three personnel stationed each: at the spooler, capstan and barrel slewing stations for the entire duration of the recoveries. The Lebus control operator controlled the haul-in and payout of the mooring. The slewing operator's responsibility was to oversee that the mooring's six wire wraps were clear of each other on the winch's twin barrels and to supervise the operation of changing reels and coils on the spooler. The spooling operator controlled the Lebus spooler in the winding of wire and nylon onto wooden reels. The seven remaining personnel were three line/air tugger operators, mooring recorder/observer, crane operator, Bosun and deck supervisor.

The following description of the mooring recovery operation is generic for all the intact surface mooring recoveries. First the mooring was acoustically released. Once confirmation was obtained that the mooring had released, the R/V Knorr maneuvered so that the surface mooring passed alone the starboard side amidships. The trawl crane was positioned crowned up approximately 40 ft. with the whip just forward of the open starboard rail section.

Two personnel equipped with WHOI-owned 13 ft. long pickup poles with Renfro hooks and 40 foot tag lines attached, secured their hooks onto the passing discus' tower top and stopped off their line to the ship's rail. It was found that two lines were needed to orient the buoy hull so as to make the buoy lifting bail accessible to be hooked for the main lift onto the ship using the trawl crane. The hook up points for the two tag lines were on the upper bails of the two tower legs which did not have the wind vane (see figure A2-2). The discus was then hooked up using a 4-ton Crosby snap hook on a 12-foot long, 6000 lb. capacity Lift All combination sling attached to a WHOI pickup pole. The free end of the sling was then passed over the trawl crane's whip hook and tension was taken up lifting the discus so that its hull was parallel to the ship's rail. The forward air tugger line was attached to an accessible bail on the discus tower. The inboard air tugger was hooked at that time to an inboard buoy deck bail. The two tuggers took up the slack and maintained tension on the discus. With the two tuggers under tension, they paid out slowly as the trawl crane lifted the discus up to a height to allow the aft tugger's line to be hooked to the apex of the discus bridle. With the three tugger lines drawn up to keep the discus hull under check, the discus was raised, so that 2 to 3 ft. of 3/4" chain shackled to the discus bridle cleared above the ship's deck edge. A 3/4" chain grab attached to a 1 1/4" nylon, Samson bull rope was hooked onto the 3/4" mooring chain approximately 1 ft. below the shackle junction attaching the discus to the mooring. The bull rope was tended back to the 5000 lb. line pull portable capstan and tension was taken up. The discus cleared the ship's deck by approximately 1 to 2 ft. and was swung inboard and lowered down onto the deck. The bull rope was simultaneously hauled in to slacken the upper shackle, ring, and shackle joint at the bridle apex. Wooden wedges were slid between the discus hull and deck to prevent the buoy from rolling. The loose shackle connection at the apex of the bridle was then disconnected from the discus. Due to the limited work space the discus was shifted forward out of the mooring recovery area and secured.

Figure A2-1. KN138 Leg XV Deck Layout

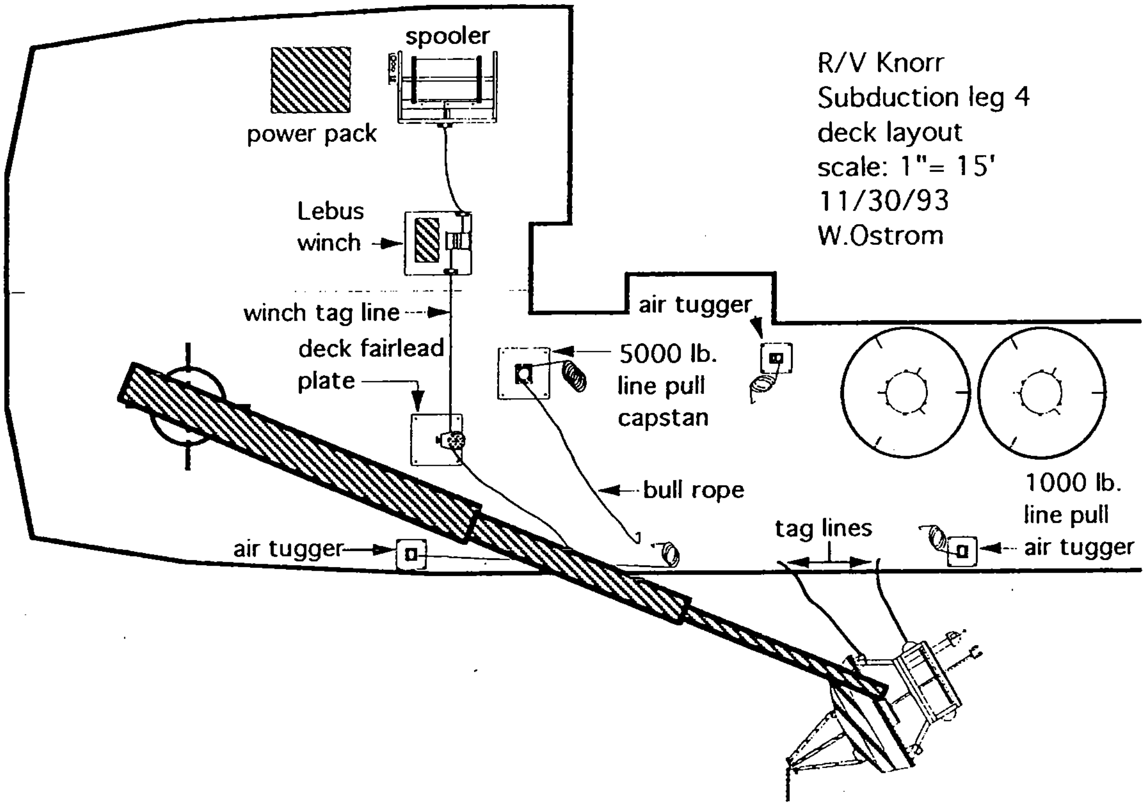
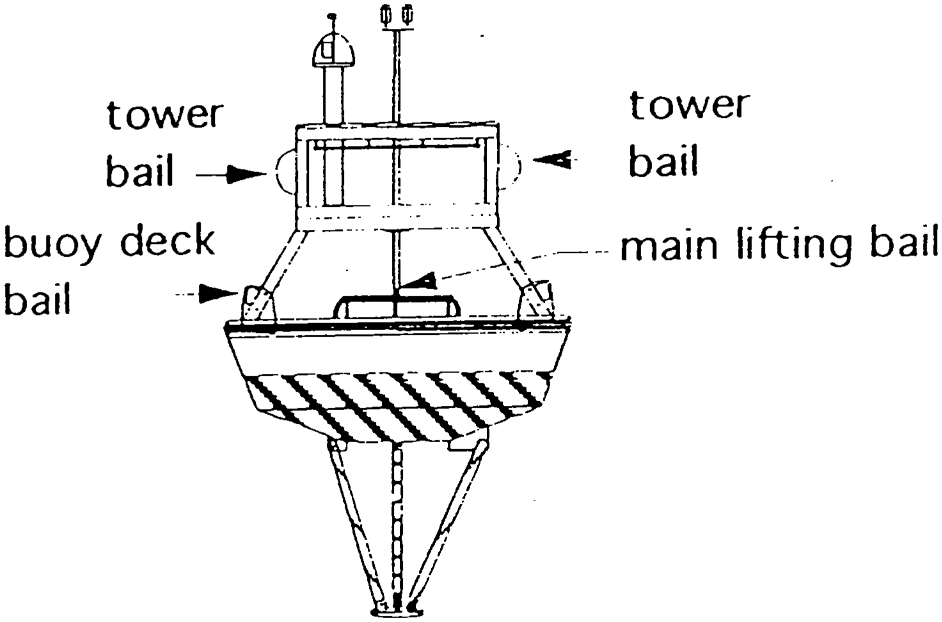


Figure A2-2. Discus buoy bail terminology



The trawl crane was then swung over the stopped-off 3/4" chain and the crane whip was lowered and hooked into the chain. The crane whip was then raised taking up the mooring tension from the bull rope. The bull rope was then removed.

Approximately 30 ft. of the mooring string was raised out of the water out board of the ship's rail. The mooring was then swung inboard and stopped off at deck level using the bull rope to the capstan. The crane's whip was then lowered to the deck and removed. The recovered instrumentation and wire slack on deck was removed from the recovery area. The crane was then repositioned over the hanging mooring and reattached. The crane whip was raised, taking the mooring tension from the bull rope. The bull rope was removed, and this procedure was continued until the individual wire shot lengths exceeded 15 meters.

The Lebus winch tag line, which was previously reeved around the traction drums (six times) and lead through the deck and crane Gifford blocks prior to the start of the mooring recovery, was shackle into the stopped off, hanging mooring string. The Lebus winch took up the line tension, and the stopped-off bull rope was paid out and removed. We found that it was necessary, due to the large size of the shackles and pear rings, to wrap the terminations with kevlar chaffing gear before the hardware passed around the traction drums. Once the mooring termination passed completely through the Lebus traction winch, the mooring wire was held manually to maintain minimal line tension on the traction drums while the termination was unshackled, cut, and the loose wire end attached to the Lebus wire coiler.

The remainder of the mooring was recovered in the standard WHOI Buoy Group technique (Heinmiller 1976).

Appendix 3 Dragging for the Subduction 2 Southwest mooring

Lloyd Regier (SIO)

The Southwest mooring in Subduction 2 was deployed on 5 February 1992. It parted on 4 June 1992 and began drifting to the west. The surface toroid was recovered by the R/V Malcolm Baldridge and returned to Miami, Florida. The recovered mooring ended with the completely shattered load cage of the SIO VMCM at a depth of 10 meters; there was nothing of the VMCM left in the load cage. Almost all of the welds were broken and in several places the 0.5 inch diameter titanium rods had been sheared in two. The force which had torn the cage asunder must have been tremendous because all of the load cages had been tested to a tension of 10,000 pounds with no damage.

In October 1992, the RRS Darwin returned to the site and attempted to release the anchor so that the lower portion of the mooring might be recovered. The acoustic release appeared to function correctly in all ways but would not release the anchor. After many doubtless, frustrating tries, an attempt was made to drag for the mooring line. The drag tackle consisted of several 500 pound depressor weights separated by 400 meters of old trawl wire with a grapnel at each end. An acoustic pinger 520 meters above the dragging section was used to determine the distance above the sea floor. Starting 3 kilometers from the anchor position, line was let out until the hooks touched the bottom and the ship steamed slowly towards the anchor, letting out line at the speed of the ship over the earth. The slowest speed the ship could maintain was 1 knot. The ship went 2 kilometers past the anchor and then did a loop around the anchor. At the start of the turn, 7200 meters of line had been paid out. When 9200 meters had been put into the water, the winch began to haul in. The final result of this effort was empty hooks.

A post-mortem on the trawling data suggests that, in spite of the great amount of wire used and the great distance traveled, the hooks never got within 2 kilometers of the anchor. The giant loop of line, which was intended to snag on the section of the mooring just above the acoustic release, which would be held vertical by the 3000 pounds of buoyancy of 60 glass balls, in all likelihood never got close enough to the bottom to hit its target, which was at most 100 meters high. Without some way to navigate the end of the dragging line, it is difficult to know what is going on at the end of a 6 kilometer line.

We came to Subduction 4 armed with equipment which, hopefully, would erase some of the uncertainties. We planned to put an acoustic network on the bottom, with which we could navigate the ship, and a transponder on the dragging line. Jeff Sherman made a tension meter which acoustically transmitted the line tension. It was placed at the top end of the drag line so we could "weigh" our catch without having to pull the drag hooks all the way to the surface, thereby decreasing the turn-around time for starting another drag. Jim Dufour designed and made drag hooks, which had no sharp cutting edges, and which were designed so if anything should be snagged it would slide through the hook until the shackles between components jammed in the throat of the hook. We did not want to cut any part of the mooring because the mooring configuration was such that if the "soft" sections of the mooring were cut, it was not likely that the instruments, which were all in the wire rope section of the mooring, would be recovered. As it turns out, of all these preparations only the hooks played a role in the success of our dragging.

At 2125Z, on 21 June 1993, we began a survey to determine the position of the anchor. We obtained the ship's position from an undithered P-code GPS receiver while measuring the acoustic slant range to the anchor:

Latitude	Longitude	Slant range (meters)
8 00.86 N	34 00.62 W	1733
17 15.90 N	34 01.69 W	1789
17 58.92 N	34 00.01 W	2164

The anchor position, assuming a release depth of 5311 meters and a sound speed of 1514 m/s, is :

Latitude = 17 59.93 N
Longitude = 34 00.64 W

This differs by .01 minute (20 meters) from the position determined on the Darwin in Leg 3. The triangle of confusion on the position is about 50 meters across.

We then deployed two acoustic transponders about 1 kilometer from the anchor along a line through the anchor and approximately perpendicular to the wind direction. We planned to tow upwind to ease ship handling. We did a 5-point survey of the transponder net and a depth survey to determine the bottom depth at both transponders and at the anchor. The positions of the transponders were obtained to an accuracy of about 20 meters (size of the triangle of confusion of three best ranges):

Transponder	Latitude	Longitude	Depth(m)
A	18 00.41 N	34 00.96 W	5178
B	17 59.57 N	34 00.46 W	5312

The surveying ended at 0316Z, on 22 June, having taken five hours to deploy the network and to survey it and the anchor positions.

The R/V Knorr had the P-code GPS receiver tied directly to the ship's controls, which allowed it to very precisely hold a station or to move with very tight control over speed and direction. As the ship was held 1 kilometer downwind from the anchor position, the dragging gear was lowered over the side. The assembly started at 0700Z on 22 June. The dragging gear, starting from the top, was:

Ship's 9/16 inch trawl wire
EG&G release(transponder)
Tension meter
400m 1/2 inch old trawl wire
500 pound depressor weight
1m 1/2 inch chain
Hook
5 ton swivel
3 80m shots of 3/8 inch wire rope
5 ton swivel
Hook
2 80m shots of 3/8 inch wire rope
2 ton swivel
1m 1/2 inch chain
2 Hooks
2 80m shots of 3/8 inch wire rope

5 ton swivel
1m 1/2 inch chain
2 Hooks
1 80m shot of 3/8 inch wire rope
2 ton swivel
1m 1/2 inch chain
2 Hooks
300 pound depressor weight.

The portion of this gear below the tension meter weighed 2000 pounds. At 0900Z this gear had been assembled over the side. It was then lowered to 4000 meters where tests were conducted on the acoustic navigation. In these tests we were unable to reliably interrogate the bottom transducers or the transponder on the tow wire. The shipboard transducer was hanging off the crane about 10 meters from the hull and at a depth of 20 meters. We tried several different positions, but no improvement was noted. We had no such problems during the survey of the previous night. We ascribe the difference to the increased noise of the ship while dynamically positioning and to the increased flow noise past the ship's transducer. Nor could we see either the signal from the tension meter, which transmitted at 11 kHz, or the on-wire transponder, transmitting at 10.5 kHz, on the ship's 12 kHz echo sounder. The bandwidth of the echo sounder was too narrow and there was no way to change it. Since knowledge of the elevation of the end of the drag gear is essential, we pulled in all of the gear to put a Benthos 12 kHz pinger on the wire. We removed the tension meter since its usable range was to only 4000 pounds and the weight below it was 2000 pounds with nothing on the hooks. Its transmission frequency of 11 kHz was also the same as that of the release on the anchor. We paid out 4000 meters of wire and conducted the same tests. We could easily determine the depth of the pinger from the echo sounder trace. We were still unable to acoustically range on the bottom or the on-wire transducers with any regularity. The pinger was approximately 1130 meters above the very bottom of our dragging gear. The uncertainty was due to inaccurate knowledge of the length of the 1/2-inch trawl wire between the pinger and the depressor weight. At 1443Z we started our first dragging attempt, sans acoustic navigation. We started moving toward the anchor at 0.2 knot (about 6 meters/minute) with the tail 130 meters off the bottom. As we were playing with the fabrication of the dragging gear, the ship had drifted northward so it was directly west of the anchor site. Thus our course to the anchor was directly east. We paid out wire at 5 meters/minute to keep the gear stretched out on the bottom. Since we saw no increase in pinger height or wire tenstion to indicate that the hooks were starting to drag, we increased the payout to 10 meters/minute while keeping the ship speed at 6 meters/minute . By 1626Z with the pinger 600 meters off the bottom, we were pretty sure the tail was dragging on the bottom so we increased ship speed to 0.3 knot or 10 meters/minute. At 1715Z the ship passed over the anchor with 5268 meters of line out and the pinger 122 meters off the bottom. We paid out wire as needed to keep the pinger between 70 and 150 meters off the bottom.

At 1912Z we measured the slant range from the ship to the on- wire transponder to be 5309 meters, and the pinger altitude determined the transponder to be 75 meters off the bottom. Assuming a bottom depth of 5311 meters and assuming the wire to be straight we computed the transponder to trail the ship by 890 meters. Since the wire had a catenary, the transponder must have trailed the ship by less. At this time the GPS position indicated the ship was 969 meters past the anchor so the head of the drag gear was at least 100 meters past the anchor.

We continued dragging at 0.3 knots, manipulating the wire to fly the pinger around 100 meters off the bottom, until 2030Z when the ship was 1656 m past the anchor. We then started pulling in the wire at 25 meters/minute. The tension measured at the trawl winch was about 8-10 kilopounds at this point. When half the trawl wire had been retrieved, the line tension was the same. We stopped pulling in wire to see if the tension was due to drag; it remained the same. We took a slant range on the anchor and got 4911-4928 meters which was 400 meters less than the bottom depth. We resumed retrieving the wire. At 2300Z we had reeled in all of the ship's trawl wire. The tension was 6000 pounds. We concluded that we had about 4000 pounds of something on the hooks since we had only 2000 pounds of dragging gear in the water. This agrees within 500 pounds of our estimate of what the mooring would weigh:

+6000 pound anchor
-3000 pound buoyancy in glass balls
+1500 pounds in mooring wire rope

4500 pounds

Over the night we moved 4-5 miles from the original mooring site while measuring the slant range to the anchor release. It remained at about 2700 meters, and the tension remained at 6000 pounds. At 0847Z on 23 June, Glenn Pezzoli made another attempt to release the anchor. This time the release confirmed that it had dropped the anchor, and the slant range began to decrease. When the glass balls surfaced about an hour later, we started to pull in the hooks. The third hook in line had snagged the mooring line at the bronze thimble at the end of a nylon shot. After fiddling with the moderate wuzzle on the hook, we pulled the line onto the Lebus winch. We noticed the nylon around this thimble had been chafed by the hook. Will Ostrom tied a safety line across this junction and 30 seconds later as the junction was pulled through a block, the nylon parted; but the safety line held so we have a happy ending. At 1840Z on 23 June the last of the mooring had been recovered. All of the instruments were recovered, including the VMCM which had been at 10 meters. Its sting was bent into a question mark by a mass of wire rope and a few of its blades were broken, but it was still working when it was opened in the laboratory.

The dragging operation had taken:

2 hours to assemble drag gear over the side
2 hours to lower to bottom
6 hours to drag 2.6 km
2.5 hours to haul in wire
10 hours to recover mooring

22.5 hours total

To what can we ascribe our success? It would be rather arrogant for one who is prepared to blame his failures on "bad luck" to attribute his successes to "good planning". Clearly there was a good deal of chance involved in the dragging operations. Our odds were greatly enhanced by the ability of the Knorr to precisely move at very low speeds. The ability to know the height of the head of the drag gear was also important. The drag hooks worked exactly as planned. The good weather was greatly appreciated.

Appendix 4 Data tape reading summary

Moored Instrument Data Tapes

Tapes from VMCMs and VAWRs were read using the Seadata model 12 reader and program Seadata, internally called v1.01 of PC-Carp. Tapes in all U.O.P. instruments, except VMCM 9, appeared to have complete records.

Statistics for the tapes are listed below. Errors listed are parity, long and tape, as reported by Seadata when tapes were read at sea.

Central Mooring

VAWR		Records	Parity	Long	Tape	Tape removed
121		25611	1	2	1	6/17 13:50

VMCM	Depth	Records	Parity	Long	Tape	Tape removed
32	10m	51769	5	0	0	6/18 10:43
18	30m	51818	6	1	0	6/18 10:37
24	50m	51830	175	2	1	6/18 9:57
30	70m	51818	2	2	1	6/18 9:10
28	90m	51820	5	6	2	6/18 8:57
39	110m	50886	2	2	1	6/18 9:47
9	150m	602	5	5	1	6/18 10:25
34	200m	47753	2	5	3	6/18 9:39
35	300m	47747	19	23	2	6/18 8:11
27	310m	47733	15	1	1	6/18 8:25
36	750m	47768	346	346	1	6/18 9:22
11	1500m	47722	36	4	2	6/18 8:42
45	3500m	47696	3	1	0	6/18 10:50

Northeast Mooring

VAWR		Records	Parity	Long	Tape	Tape removed
721		25729	19	5	0	6/15 13:36

VMCM	Depth	Records	Parity	Long	Tape	Tape removed
38	10m	50073	1337	876	860	6/15 19:15
21	30m	51240	5	1	0	6/15 19:23
12	50m	51289	2	1	0	6/15 17:53*
33	70m	51298	2	3	2	6/15 19:05
37	90m	51214	7	11	0	6/15 18:56
41	110m	51314	3	3	2	6/15 18:42
15	150m	51146	3	0	0	6/15 18:30
16	200m	47903	93	27	20	6/15 18:15

*fouled props

Southeast Mooring

VAWR		Records	Parity	Long	Tape	Tape removed
704		26071	19	13	0	6/19 10:30

VMCM	Depth	Records	Parity	Long	Tape	Tape removed
22	30m	52079	148	157	0	6/20 8:44

Southwest Mooring

VAWR		Records	Parity	Long	Tape	Tape removed
720		26699	942	392	1	6/25 9:45

Appendix 5 IMET systems recovered during KN138 Leg XV

Neil McPhee (WHOI)

This cruise was the final recovery of the surface buoys containing IMET and VAWR meteorological systems. The Northwest buoy, having broken free, had been recovered by the Canadian research vessel HUDSON. Of the remaining four, three had IMET systems installed: Northeast, Central, and Southeast. The Southwest buoy was fitted only with a VAWR.

Argos telemetry received at WHOI since deployment and prior to the cruise indicated most modules were functioning well with good correlation between IMET and VAWR. The discrepencies were as follows:

Northeast:	Some bad points in longwave and erratic tension.
Central:	Possible problem with precipitation as indicated by plots from year day 132 to 136.
Southeast:	VWD does not appear to be tracking wind direction.

During the four-hour intense meteorological observation period, Argos telemetry was received and recorded for both the IMET and VAWR. Analysis of this data for the IMET confirmed these discrepencies, with the exception of the precipitation on the Central buoy.

Prior to recovery all modules on the tower tops were intact with no apparent damage. During recovery the wind vane and stem top were knocked off the Northeast IMET and the wind vane dislodged from the Southwest VAWR. As noted from previous recoveries, the SE tower was coated with dust. Noticeable amounts were on all radiation domes.

Post-recovery check out revealed all three LOPACS functioning well, the acquisition programs were running, all modules responding, and the battery voltages between 12.4 and 12.8. A check of the files written to optical disk showed complete files for at least the last month for each system. The optical disks were removed, but since no readers were available, complete data analysis will be done at a later date.

Physically all three buoy wells were dry and clean. Some of the top pads on the alignment rails of the well insert on the NE had completely broken or cracked welds. All the IMET, VAWR and solar panel junction boxes were, dry and clean. There was no indication of chaffing or worn cables anywhere, nor signs of fish bite on the bridle cables.

The VAWR data loggers and Argos transmitters were shut down and the data tapes removed. Voltage readings were also taken as per instrument Current Meter Operation Information (CMOI) forms.

Appendix 6 VMCM recovery notes

Mooring 952, Subduction 3 Northeast

VMCM 038
both props spinning
goose barnacles on both upper and lower rotors
no blades broken

VMCM 021
both props entangled in commercial fishing gear
both upper and lower rotors not spinning
antifouling looks good
after removing fishing line the upper and lower propeller bearings feel good
no broken blades
no goose barnacles evident

VMCM 012
both props entangled in commercial fishing gear
both upper and lower rotors not spinning
after removing fishing line the upper and lower bearings feel good

VMCM 033
both rotors spinning
antifouling paint looks ok
bearings of both upper and lower props feel fine
antifouling paint on the blade near the hub is, in most cases gone, possibly due to blade flexing and then antifouling paint chipping away
no goose barnacles

VMCM 037
both hubs spinning
slightly more play in upper rotor
antifouling looks good
no broken blades
antifouling paint on blade near hub not as worn away as on shallower instruments

VMCM 041
both hubs spinning
antifouling looks good
missing paint near hub of propeller blade evident
propeller bearing in good condition

VM 015
both rotors spinning
slight play in both rotors
antifouling paint looks good

VM 016
both rotors spinning
antifouling looks good

Mooring 953 Subduction 3 Southeast Mooring

SIO VMCM 06 at 10 meters
rotors: blue green fishing line on bottom hub but both rotors free
bearings loose (worn) but look good
rewind on reader went beserk breaking tape after first read; bad read
corrosion on hub endcaps and sting topcap flange underside,
due to electrolysis with copper antifouling despite anodize. Must paint.

VM022
upper rotor drags
lower rotor spinning
goose barnacles on both propellers
no broken blades
bearings of lower rotor feel good
top rotor propeller shaft appears bent
top of sting appears bent

SIO VMCM 20 at 50 meters
Rotors: barnacles both fans; both free, bearings ok
Sting: noted missing paint and anodize at site of titanium crossbrace, (btw rotors) due to loose fitting delrin insulator? or strumming? or?.
Electronics: Temperature quit after 762 hrs due to board being displaced backed out despite card edge lock.
Card edge lock installed properly however was tied tightly at center position since the screw has long since broken of there.

Mooring 954 Subduction 3 Southwest Mooring

SIO VMCM02 at 10 meters

Recovered still attached to SW3 drifting toroid despite broken cage. Holding in cage by one pressure case to cage bolt. Other pulled through titanium. Sting insulators in place. Earlier had recovered only very bottom (clevis and tang support portion) of titanium cage with titanium tang pin still safety wired in place. Pressure case tang broken, hole pulled out. Old design.
Rotors: worn but spin freely, lots of side and end play.
Severed Delrin purge port vacuum plug of same design in Brancker TPods. Still holding vacuum.

SIO VMCM 22 at 30 meters
Rotors: Top Rotor very stiff. Back prop up hard against hub endcap.
Encoder prop clear. NO play in shaft.
Delrin tang insulator blown out, bent titanium pin.

SIO VMCM 07 at 50 meters
Rotors: both good.
Delrin purge port plug severed.

SIO VMCM 23 at 70 meters
CCS VMCM: 4 min averages of 1 min scans recorded to flash card. 15 scans/hr.
Rotors: both very good.

SIO VMCM 13 at 90 meters
Rotors: both good

SIO VMCM 04 at 110 meters
Rotors: both very good. Reusable.

SIO VMCM 24 at 150 meters
Rotors: both very good. Reusable

SIO VMCM 19 at 200 meters
Rotors: both rotors very good. Reusable

Mooring 955 Subduction 3 Central Mooring

VM032
Props spinning on recovery
Propeller bearings feel good
No broken blades
Antifouling paint missing from root of blade near hub
Gooseneck barnacles on props and pressure case
Slime on cage rods and sting

VM018
Both rotors spinning on recovery
Bearings in good condition
No broken blades

VM045
Upper and lower rotors spinning in wind
No broken blades
Bearings in good condition
No goose barnacles

VM024
Upper and lower rotors spinning freely
Bearings feel good on both upper and lower rotor
Antifouling paint not gone near root of propeller
No broken blades
No gooseneck barnacles

VM009
Upper and lower rotors spinning
Antifouling paint looks good
Bearings feel in good condition
No broken blades
Antifouling paint missing from root of blade near hub of both upper and lower rotors

VM036
Upper and lower rotors spinning freely
Bearings in good condition
No broken blades
Antifouling paint looks ok

VM030
Upper and lower rotor spinning
Antifouling paint looks good
No broken blades
Bearings feel good

VM034
Upper and lower rotors spinning
Bearings feel good
Antifouling paint intack
No broken prop blades

VM028
Upper and lower rotor spinning
Antifouling paint intack
No broken blades
Bearings feel good
Antifouling paint missing from root of blade near hub

VM039
Upper and lower rotor spinning
Antifouling paint looks good
Bearing in good condition
No broken blades

VM035
Upper and lower rotors spinning
No broken blades
Bearings in good condition
Antifouling paint missing from root of propeller blades

VM027
Bearings in good condition
No broken blades
Antifouling paint missing from root of propeller blades

VM011
Upper and lower rotors spinning freely
No broken blades
Bearings feel good
Antifouling paint looks good

Mooring 924 Subduction 2 Southwest Mooring

SIO VMCM 01 at 10 meters
Rotors: worn but good
Sting: bent 180 degrees and twisted.
    Now measures current around corners!
    Vacuum still holding, but minimal.
PCB: card edge lock bowed. PCB's backed out.
Hub end caps: (bare anodize) used badly corroded;
    zinc well chewed.

SIO VMCM 16 at 30 meters
Rotors: lots of play, worn but free spinning.
Hub end caps: badly corroded, aluminium oxide deposits.
PCB's: edge lock bowed, memodyne, control cards 1/8" backed out.

SIO VMCM 08 at 50 meters
Rotors: top has play but both good, spinning freely.
Hub end caps: badly corroded
PCB: seated but card edge lock bowed.

SIO VMCM 15 at 70 meters
Rotors: bottom has play, top very good. Both spinning freely.
Zincs: good
PCB's: edge lock bowed, control card almost out.

SIO VMCM 14 at 90 meters
Rotors: very good.
Hub end caps: corrosion, aluminium oxide deposits.
PCBs: ok.

SIO VMCM 12 at 110 meters
Rotors: excellent. reusable.
Zincs: good, reusable, chaulky.
PCBs: seated but card edge lock bowed.
Damaged top of purge port while drilling out severed delrin plug.
    Drill bit broke.

SIO VMCM 11 at 150 meters
Rotors: excellent, reusuable.
Zincs: good, reusable but chaulky.
PCBs: memodyne,control,bus,reg1, all backed out.

SIO VMCM 18 at 200 meters
Rotors: excellent; reusuable.
Zincs like new.
Hub end caps: slightly corroded.
PCB's backed out 1/8".

Appendix 7 Scripps instrumentation condition and cruise notes

Glenn Pezzoli (SIO)

The condition of the SIO VMCMs both internal and external tells of violence and shock not encountered in previous Instrument Development Group (IDG) mooring work spanning two decades. Load cages were recovered snapped in pieces, printed circuit boards displaced in spite of their locks, leaving us wondering about the source of this violence and ideas for re-design. Electronic chassis were bent, left broken and twisted on their mounts. Failures occured in sub systems that had been considered tried and true. Despite these failures the only VMCM data lost was one temperature record at the 50 meter position on Subduction 3 Southwest mooring.

Last September after recovering a partial broken load cage from under the SW2 drifting mooring, we pull tested the remaining ten VMCM cages on hand to 8,000 pounds static load, with no failures. The cage housing VMCM 02 at the 10 meter postition under the Subduction 3 Southwest buoy was one of these tested cages, but it broke apart just like the cage at this position on the Subduction 2 Southwest mooring. Using tensile strengths of titanium at 200,000 psi and that of 316 stainless steel at 82,000 psi we calculate an ultimate breaking strength of ~40,000 pounds for the 1/2" cage rod of our load cages versus ~36,226 pounds for the 3/4" 316 stainless steel rod of the WHOI cages. Some of the broken welds did not have the best penetration. If one weld breaks then the whole cage can be expected to unravel. Many of the breaks occurred in the rod near the welds.

While recovering these moorings many ships were seen in the area particularly at the Southeast site where two fuel tankers were seen passing nearby within minutes steaming to the east. There was evidence of extensive fishing activity at the Southeast site with blue 1/8" line around the bottom hub of the 10m VMCM on the Subduction 3 Southeast mooring as we had seen also on Subduction 2 Southwest mooring broken cage recovered with orange monofilament netting enveloping the broken load cage. During the recovery of that Subduction 2 Southwest drifting buoy the Malcomb Baldridge had to chase off a long liner fishing on the toroid. Were these toroids hit by passing tankers or fouled during fishing where the VMCM load cages were bent over the transom of some trawler only to part? It is a definite possiblity.

Whatever the source of this violence - ship traffic, fishing, cyclic loading, mooring design - it is clear that these failures are unacceptable. Although it is impossible to design against every calamity it seems to be time to build new cages out of larger-diameter material to carry at least the upper VMCMs on these types of surface moorings, if these instruments are still to be used. Also the belly band clamping of WHOI's and the Center for Coastal Studies' (CCS) cages should be incorporated to hold the pressure case since it better isolates the instrument from shock exerted on the cage. Our present design more directly transfers shock to the electronics since the pcase is bolted directly into the cage and pinned at the bottom. It looks as though a re-examination of the ADCP load cage design might be in order as well.

Despite the failure of these cages the only IDG VMCM data lost were that of temperature in SW3 50-meter position. However, several instruments' printed circuit cards were backed out and in danger of losing electrical connection. We dodged a big bullet here. This might explain the incomplete records from Subduction 2. This was the cause of the loss of the temperature channel in SW 50 meter VMCM 20. The card edge lock will be reworked, using tempered 4000 steel and locking both sides of the cards to eliminate this problem.

Between Legs 1 and 2 of Subduction we built 13 new stings, incorporating a cone one inch in diameter at its base tapering to 1/2" diameter within four inches from the topcap to form the bottom of the sting. This was to eliminate the breaking of stings, which had been a problem in the past. This design proved to be very effective. Coupled with the addition of purge ports, which allowed a vacuum to be pulled on the instrument seating the o-ring and effectively holding the instrument together in the event of the pressure case bolts failing, this design resulted in data and instrument loss due to certain sting breach of the old design under these conditions.

VMCM 01 at the 10 meter position on SW2 returned with its sting doubled, bent 180 degrees and wrapped slightly around its pcase. It did not leak despite two of its four pressure case bolts were missing, sheared off when the load cage let go. It did not have a hermetic seal so a sting break would have flooded the entire instrument. We now use hermetics and have a system to draw a vacuum on the sting to seat those o-rings and still make the instrument more immune to hot deck temperatures prior to launch causing o-rings in transition during deployment which was felt to be the cause of some small sting leaks and previous data loss.

The CCS VMCMs on the SW3 mooring at 70 and 150 meters were equipped with 1 meg of flash card memory and wrote 4-minute averages. The time series from the two CCS VMCMs has yet to be processed, but a cursory examination indicates that they both took data; they were still working on recovery. CCS VMCM 24 showed signs of trauma as its electronic's chassis was broken from the top end cap. The 1/4" thick aluminium ring that bolts to the topcap was bent in two places between the four screws. As far as we know, the CCS has never had this problem with any of its coastal moorings. This warrents further investigation.

At least three of the new stings fitted with purge ports returned with broken delrin purge plugs. The purge port seems to be drilled deeper than specified (or the plug is too short) and as a result the point of the plug does not bottom out. The unsupported plug is then put in tension by the external seawater pressure (up to 10000psi) exerted directly across the plug at the first o-ring seal. This tension breaks the delrin plug from its top, driving it down until it bottoms out. At this point the remainder of the plug is supported as it was designed and the second o-ring seals. Give thanks! Several Brancker Tpods had this problem as well.

The ZSPAR cuprous oxide ablative antifouling paint that SIO used seems to perform as well as the WHOI AMERON tributyl tin. As long as the anodized aluminium has a good epoxy primer and polyurethane paint --we use proline 4000 and proline 4500 series paints-- we see no attack upon the aluminium whatsoever. We did run into problems with our bare anodize, however, when it was covered with cuprous oxide or even in close proximity to it.

There were the same sorts of startup problems with the XBT system that we always seem to have. Last leg it was a bad splice in the cable right out of the launcher that gave it a bad ground; this time a bath test with several bucket thermometers dispatched an apparent disagreement with the bucket SST's and the first XBT temperatures.

There was difficulty communicating with the WHOI 263 release at NE3 because the transducer cable that was supplied was too short to allow a descent depth for the transducer. Although the box was tuned and we adjusted the receive threshold down to a ridiculous 1.2 volts (default is 2.5volts) where the noise grew too large, the box would not recognize the release reply; and thus we could not range on it. We could, however, faintly hear the replies through the headphones and decided to go ahead and send the release command. The confirmation of release reply came through faintly on the headphones, but we could not monitor its ascent. This situation was remedied at the Central mooring site by moving the deck box to the rail, giving enough transducer cable to clear the ship's noise.

We also had transducer woes during dragging. We successfully navigated in our transponder net using our EG&G deck box adapted with multi-channel receive with the deck transducer held at 10m off the port side. This was done while under way ~.5 knots. We also communicated to the SW2 release in this configuration. However, when we started our dragging run the first time with the transducer held by crane off the starboard rail five meters and down 20 meters we could not communicate with the transponder net nor the tensiometer or pinger on the wire. Neither could we talk to the SW2 release, at the same ships speed. Consensus was that there was either ship's noise causing interference in that area or there was more turbulence around the transducer preventing communications. We should have brought the towed fish. Also, some sort of decoupling of the transducer from surface motion (e.g. bungie cord) might have helped. We could not find the bottom either. At any rate we brought the dragging rig back to the surface and installed WHOI's benthos pinger and removed the tensiometer. We did not try to talk to the transponder net ever again.

Later with the transducer hand-held at 10 meters from the port rail, we were able to range on the SW2 release just after we unknowingly hooked into the mooring. Later we ranged on it and discovered that we had the whole shebang suspended off the bottom including the bloody anchor. After dragging it around the ocean like this for awhile, and having a night to sleep on it, the release decided to let go - just as we were preparing to attempt recovery with some very scary tensions.

The release showed no sign of external mechanical fouling. It must either be an internal mechanical jam or marginal adjustment ie. a bent shaft on the rotary solenoid or it could be an intermittant electrical problem which the vibration of a night of towing could have remedied. It will be torn apart and investigated.

During the recovery of the SW2 and SW3 broken moorings where there were many wuzzels in the wire and many bites coming in at once, chain slings made by Mr. Mac McCreedy at Pacific Rigging, San Diego, were very useful. These chain slings are ~ 5ft of Crosby System 8 chain fastened in a loop using 9/32" (7.0mm) CM Hammerlok coupling links, code no.664228, tested at Pacific Rigging with static load against PMI cable grips. The PMI galvanized sand- coated grips (for 3/8" bare wire) started slipping on the 3 x 19 3/8" to 7/16" jacketed wire at 10,000 pounds static load. The Chain slings held firm on the bitter end of this wire rope.

Hammerlock made by:
Columbus Mckinnon Corporation
Chain Division
140 John James Audubon Parkway
Amherst, New York 14228-1197
ultimate break strength 14,000 lbs.
working load limits 3500lbs with 4:1 design factor

The dragging hooks worked exactly as designed, slipping along the nylon or wire until reaching a termination. We needed swivels for each of the hooks and luckily found enough among SIO gear, WHOI's and the ship's.

The new PMEL-style thimbles for nylon terminations looked very good but perhaps the cheeks could be a little higher to prevent the nylon from flattening so much under load and biting into the jacket; this did not seem to be much of a problem, however.

In view of the successful turnaround with the WHOI Brancker temperature pods, we will probably conformally coat ours as well and should probably consider the gimballed bolt.

Appendix 8 XBT data

Hourly XBT profiles were taken during transits between moorings using a launcher mounted on the port side of the stern. Approximately 206 casts were taken, not including test casts fired while checking out the system. Probes were Sparton T-7 XBTs with a rated depth of 760 meters. Figure A-8-1 is a plot of the XBT locations.

Recording was done using the Sippican MK-12 Data Acquisition System, version 1.3, running on a dedicated shipboard PC. Profiles were processed using Sippican's Post Trace Analysis program, version 1.2a. Processed files were ported to the Sun Sparc 1, for plotting using Matlab.

Each processed XBT profile header contains GPS position and XBT cast number, entered manually by the watch. The launch date and time are automatically entered by the MK12 acquisition software.

File names on original acquisition files were assigned by the MK12 program. These file names were of the form T-7$nn, where nn was the sequential cast number assigned by the program. Cast numbers in original file names were, thus, limited to two-characters, which was inadequate for our data set of 206 casts. File names were changed as the files were copied to the processing PC, and processed file names should reflect cast number as recorded in the science log.

XBT Sections taken were:

1) Transit to NE mooring	XBT 3 - 23
2) NE to C moorings	XBT 24 - 68
3) C to SE moorings	XBT 69 - 114
4) SE to SW moorings	XBT 115 - 168
5) SW to drifter	XBT 170 - 202
6) Transit from drifter	XBT 203 - 206

Two contoured temperature sections obtained using XBT numbers 1 through 114 and 115 through 206 are shown in figures A8-2 and A8-3 respectively. Contours are labelled in degrees Celcius. Vertical dotted lines indicate changes in ship heading at the mooring recovery sites. Ticks across the top of the plot indicate the location of each XBT station used for generating the contours. Figure A8-4 (a through j) shows individual XBT profiles. Table A8-1 contains the positions and time of the XBTs.

Figure A8-1. XBT Locations

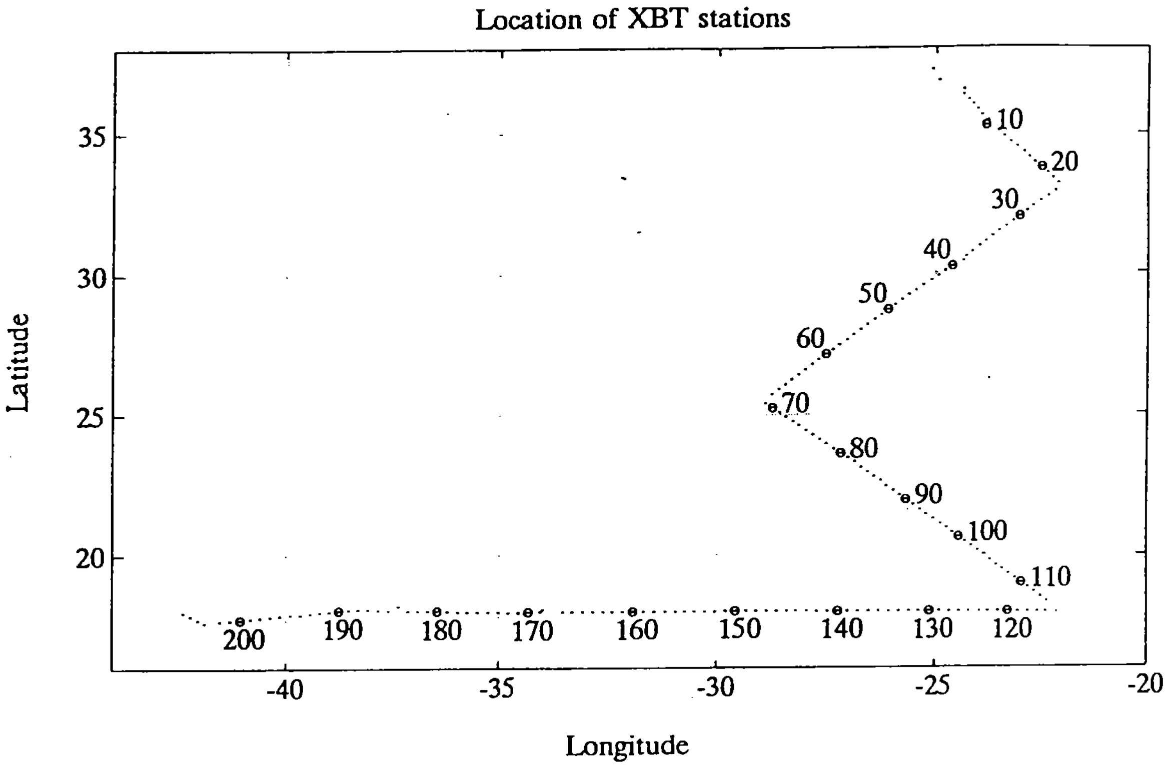


Figure A8-2. Contoured temperature section using XBT stations 1 through 114. Successive profiles are offset by 1°C.

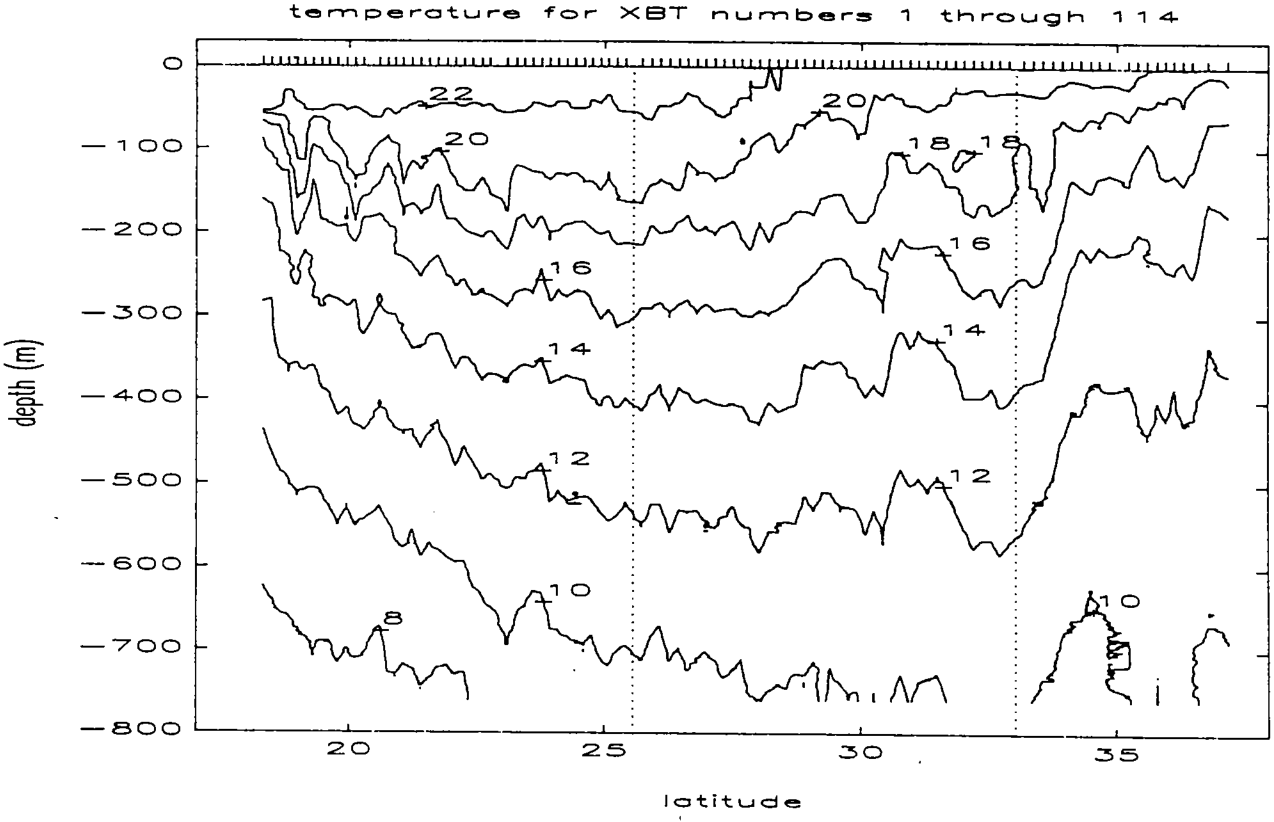


Figure A8-3 Contoured temperature section using XBT stations 115 through 206. Successive profiles are offset by 1°C.

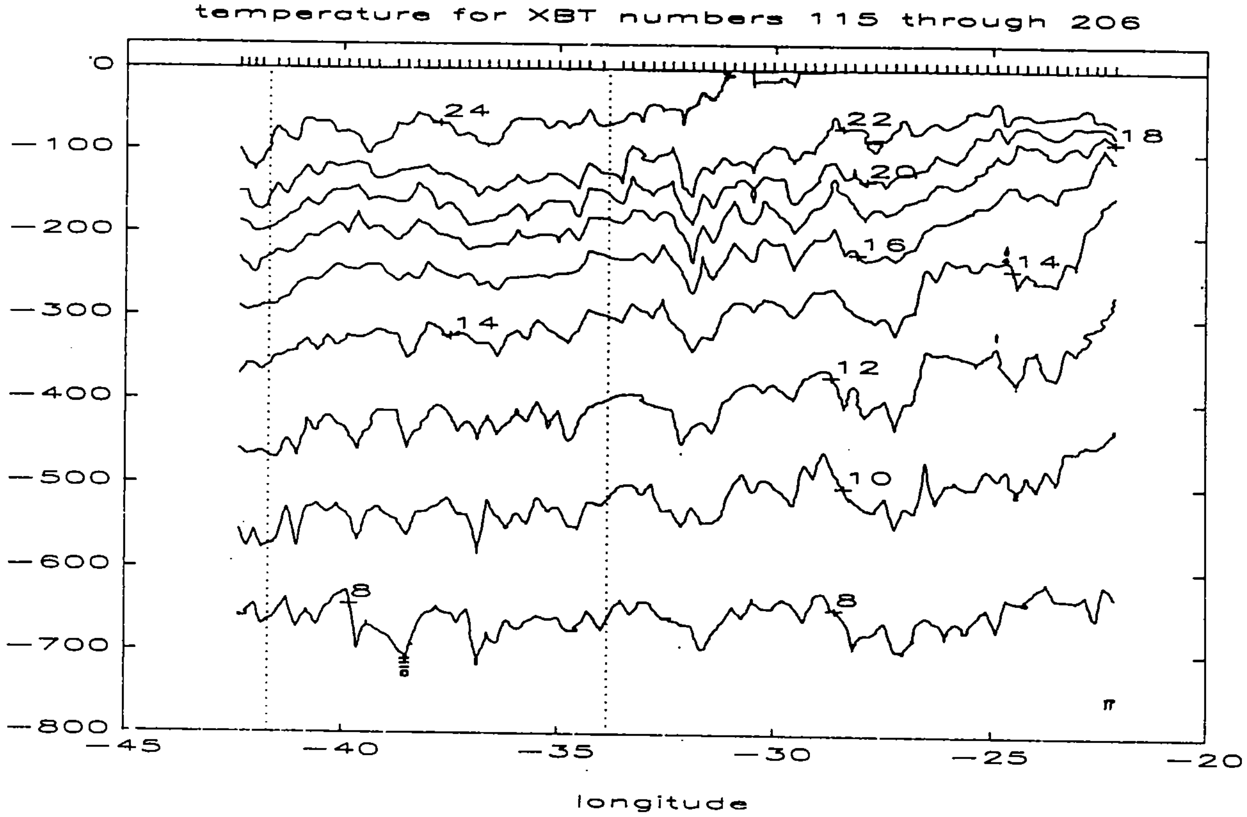


Figure A8-4a Overplot of XBT Profiles 3 to 10, 12 to 14 and 17-24. Successive profiles are offset by 1°C.

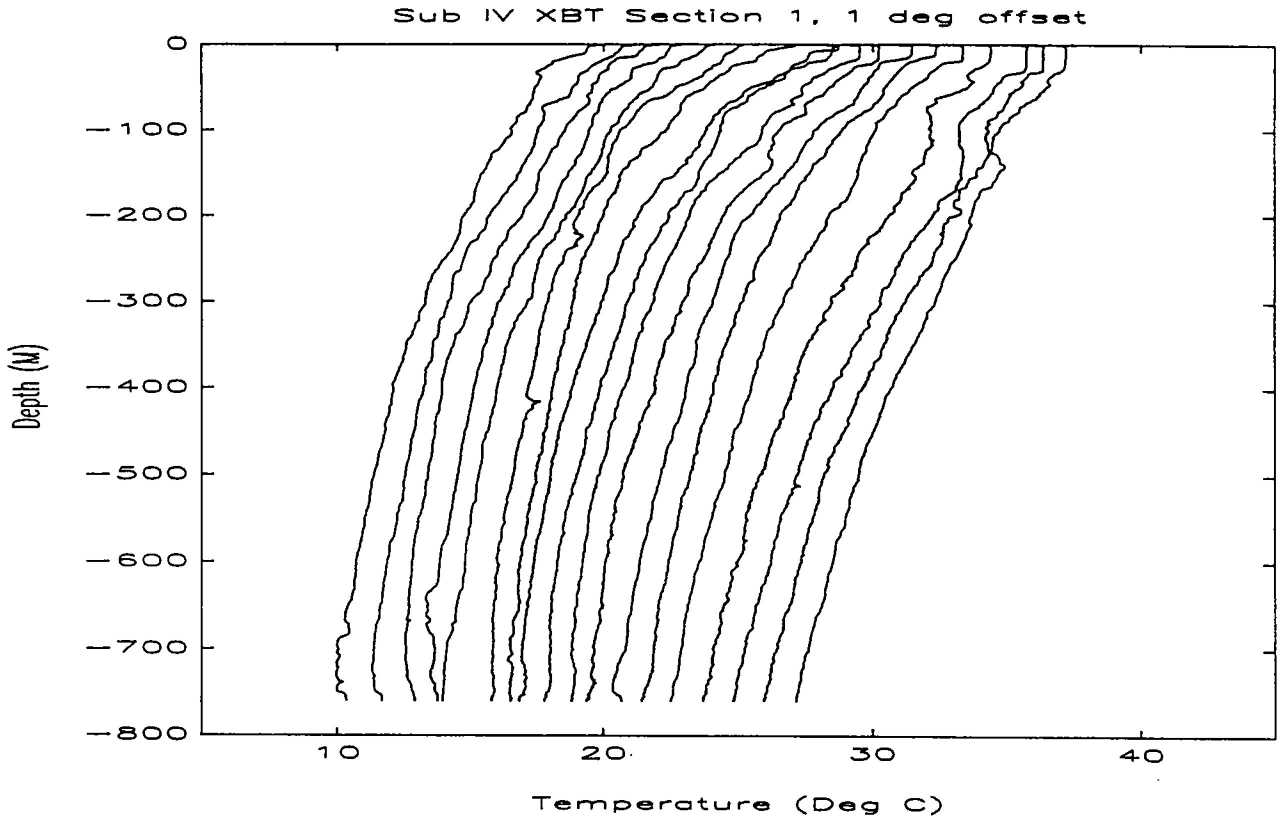


Figure A8-4b Overplot of XBT Profiles 25 to 45.
Successive profiles are offset by 1°C.

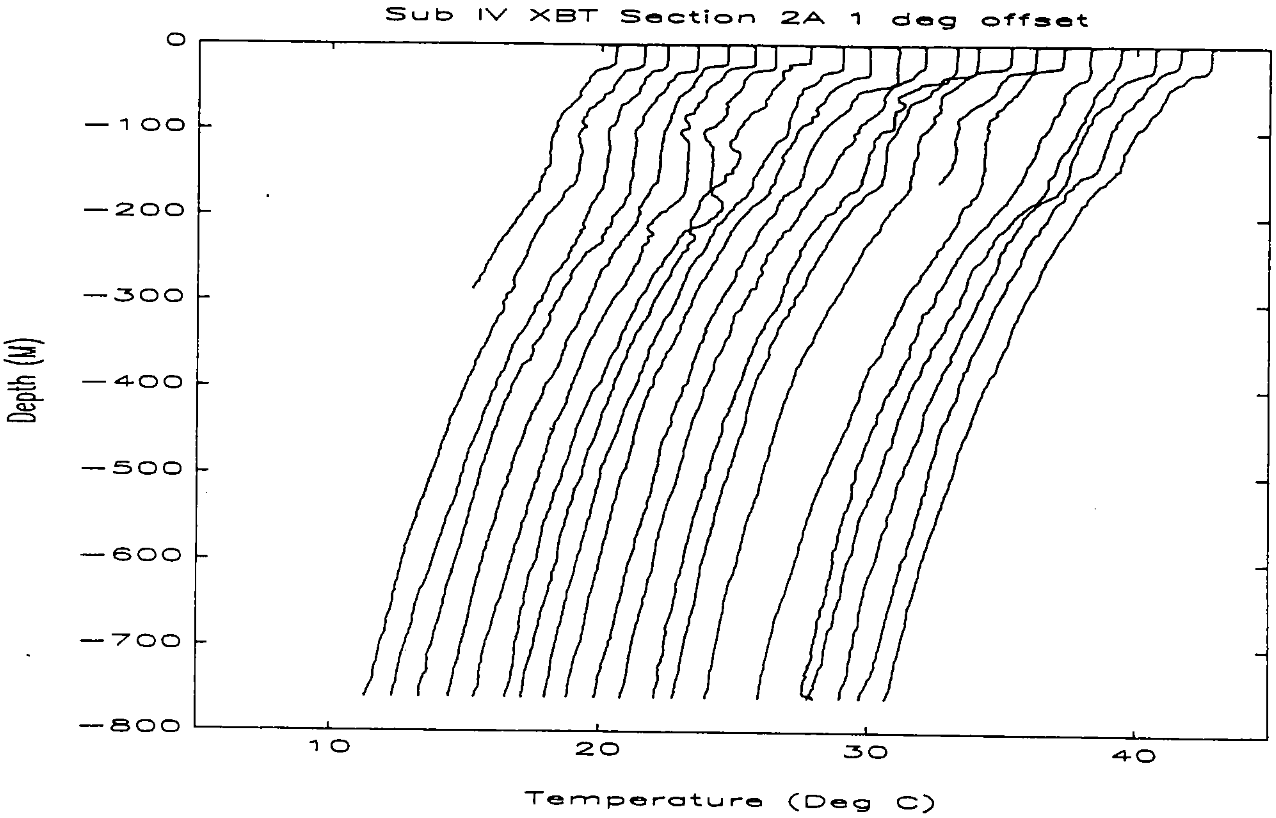


Figure A8-4c Overplot of XBT Profiles 46, 47, 49, 50, 52 to 57, and 59 to 68.
Successive profiles are offset by 1°C.

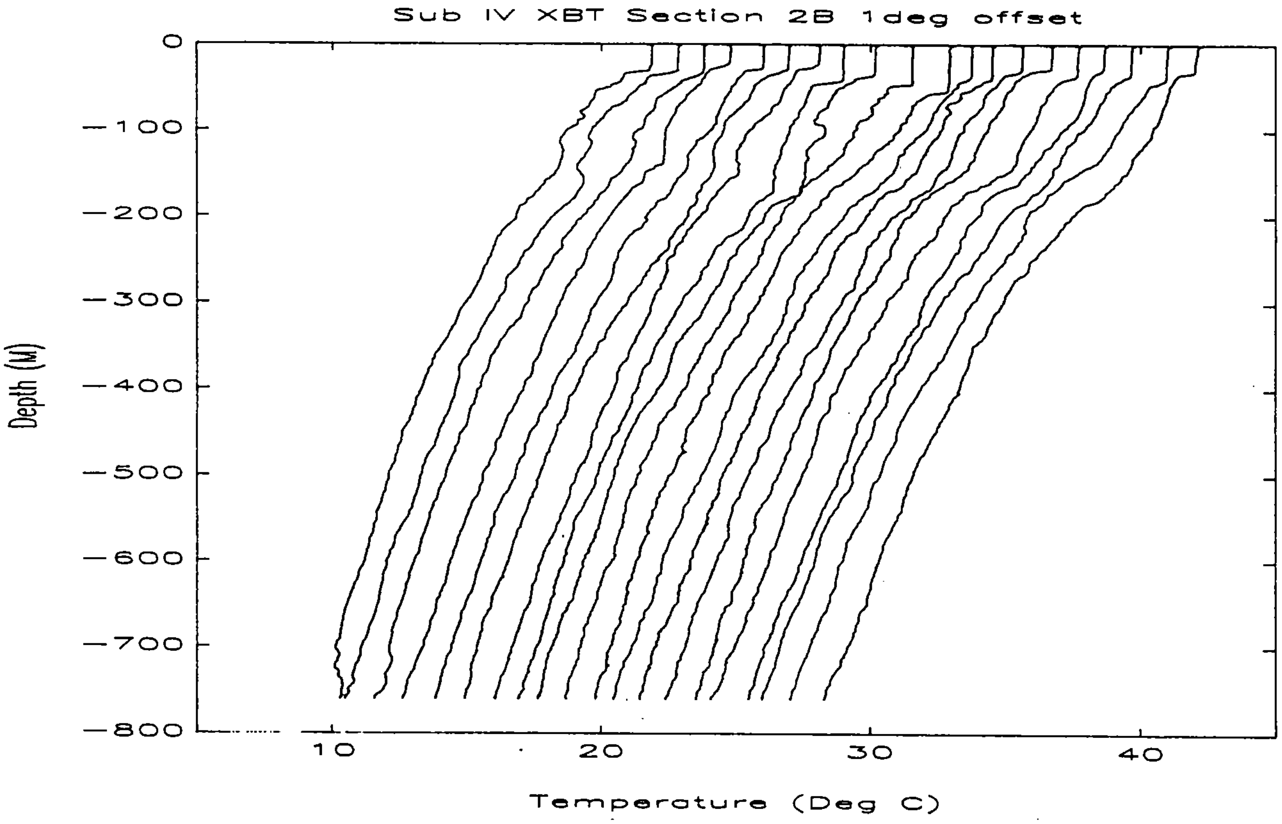


Figure A8-4d Overplot of XBT Profiles 69 to 89. Successive profiles are offset by 1°C.

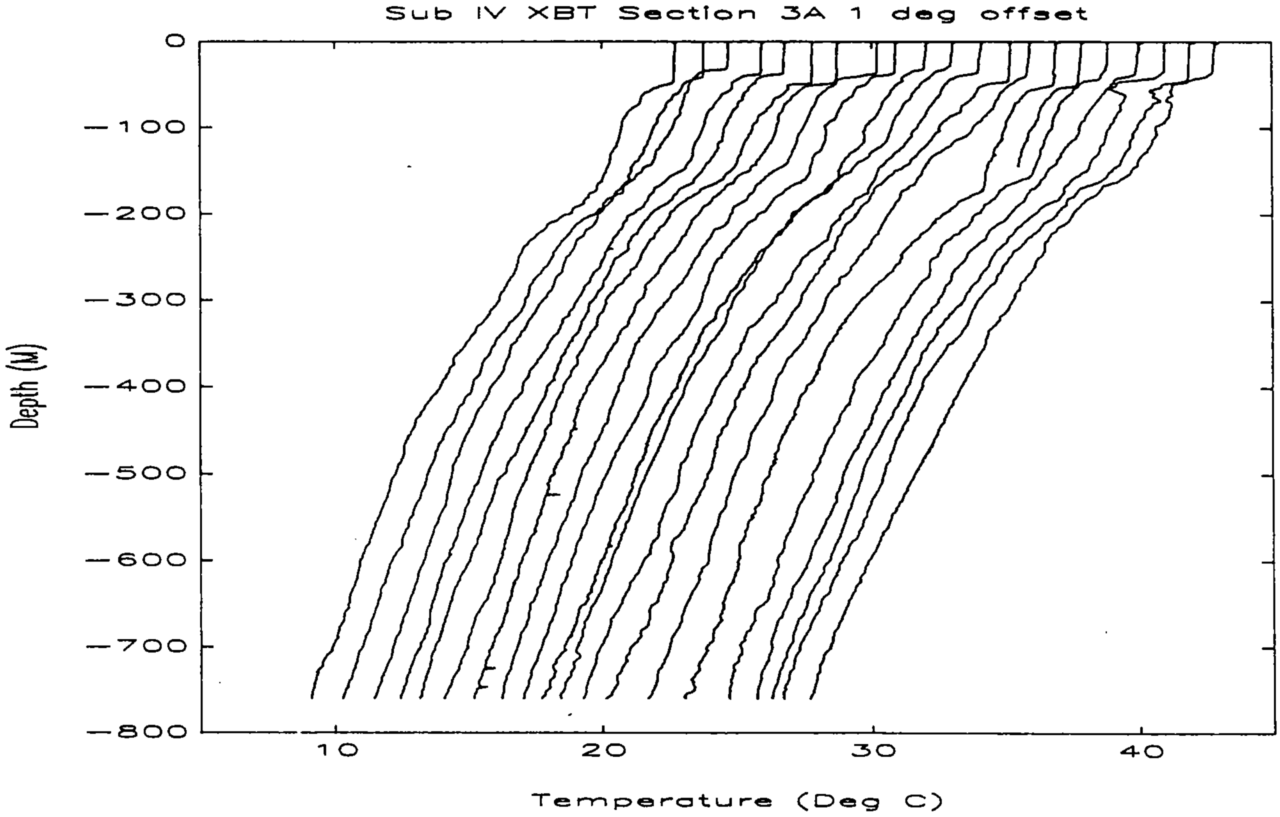


Figure A8-4e Overplot of XBT Profiles 91 to 94, 97 to 100, 102 to 107, and 109 to 114.
Successive profiles are offset by 1°C.

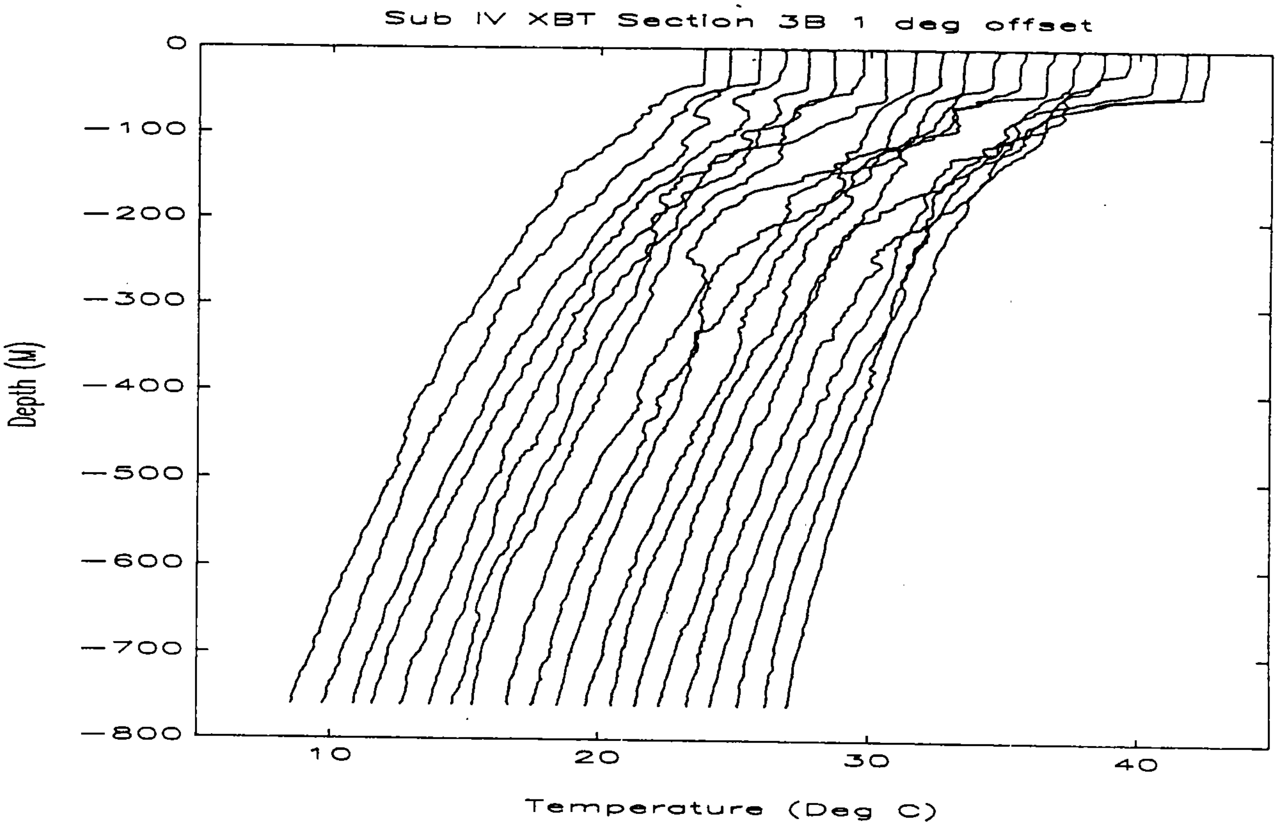


Figure A8-4f Overplot of XBT Profiles 115 to 121, 123 to 128, and 130 to 136. Successive profiles are offset by 1°C.

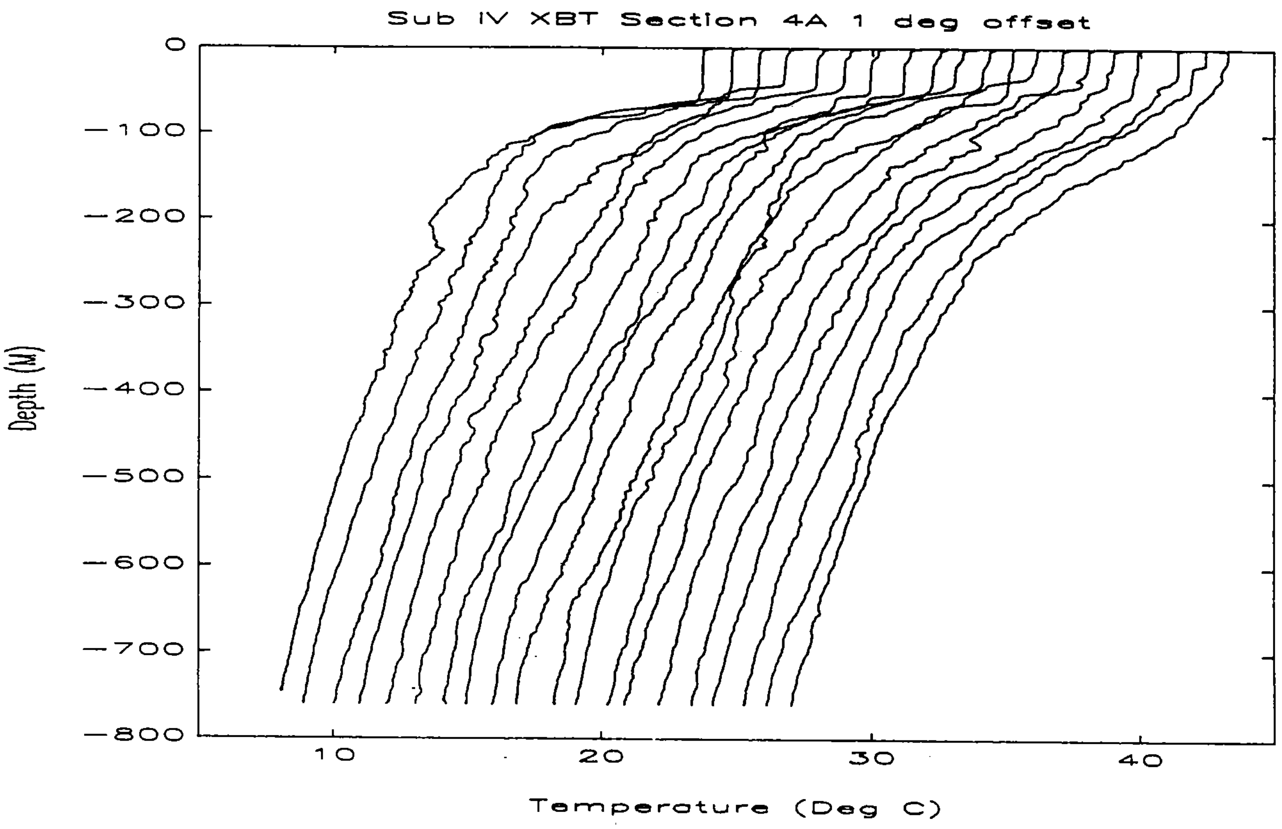


Figure A8-4g Overplot of XBT Profiles 137 to 156. Successive profiles are offset by 1°C.

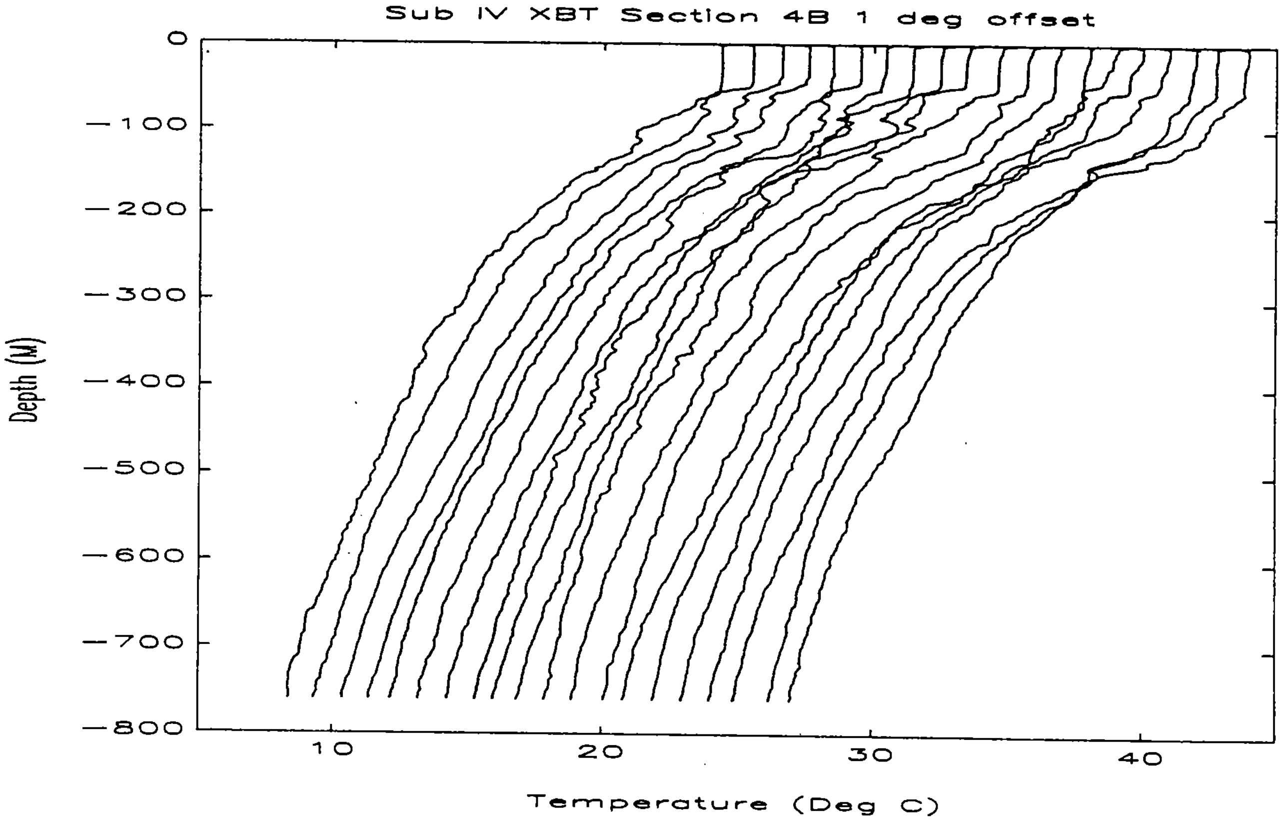


Figure A8-4h Overplot of XBT Profiles 157 to 167. Successive profiles are offset by 1°C.

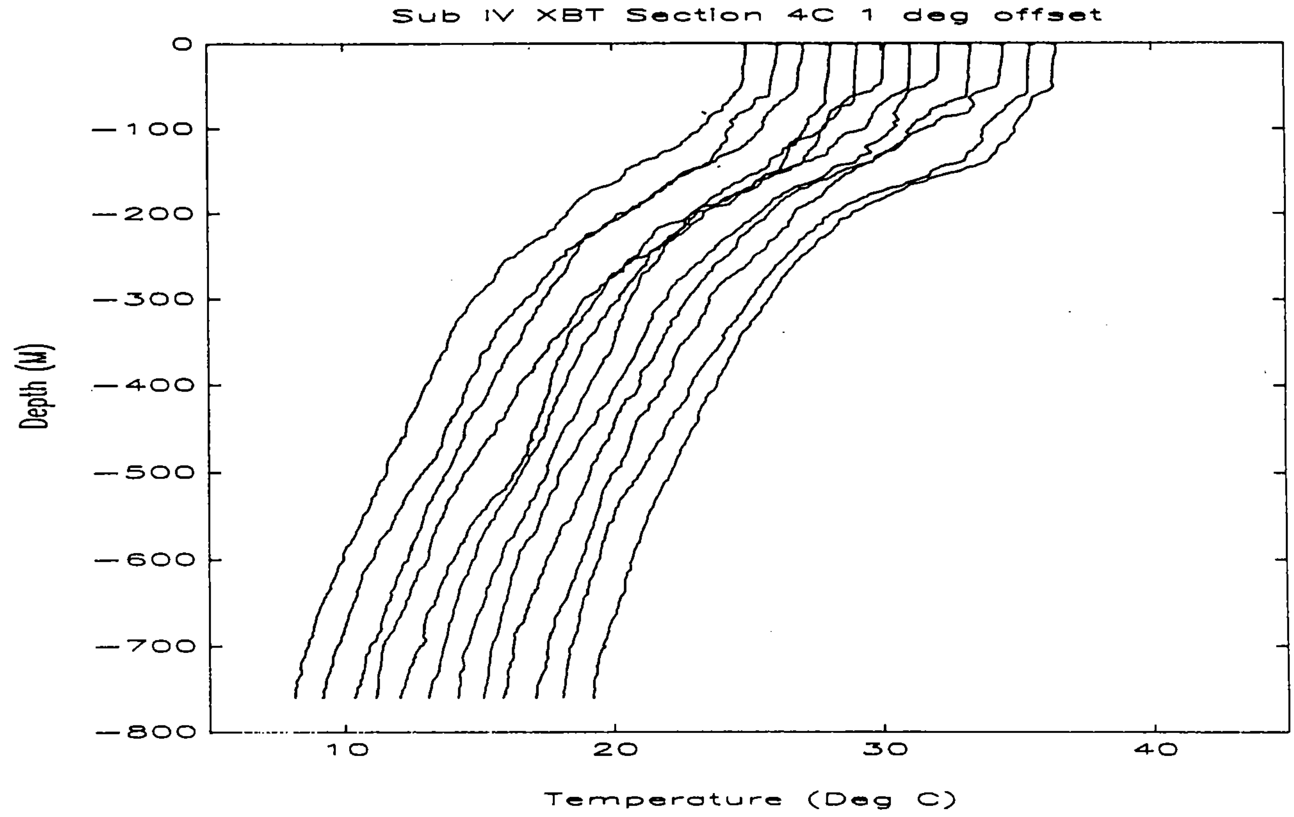


Figure A8-4i Profiles 167b, 169, 169b, and 170 to 184. Successive profiles are offset by 1°C.

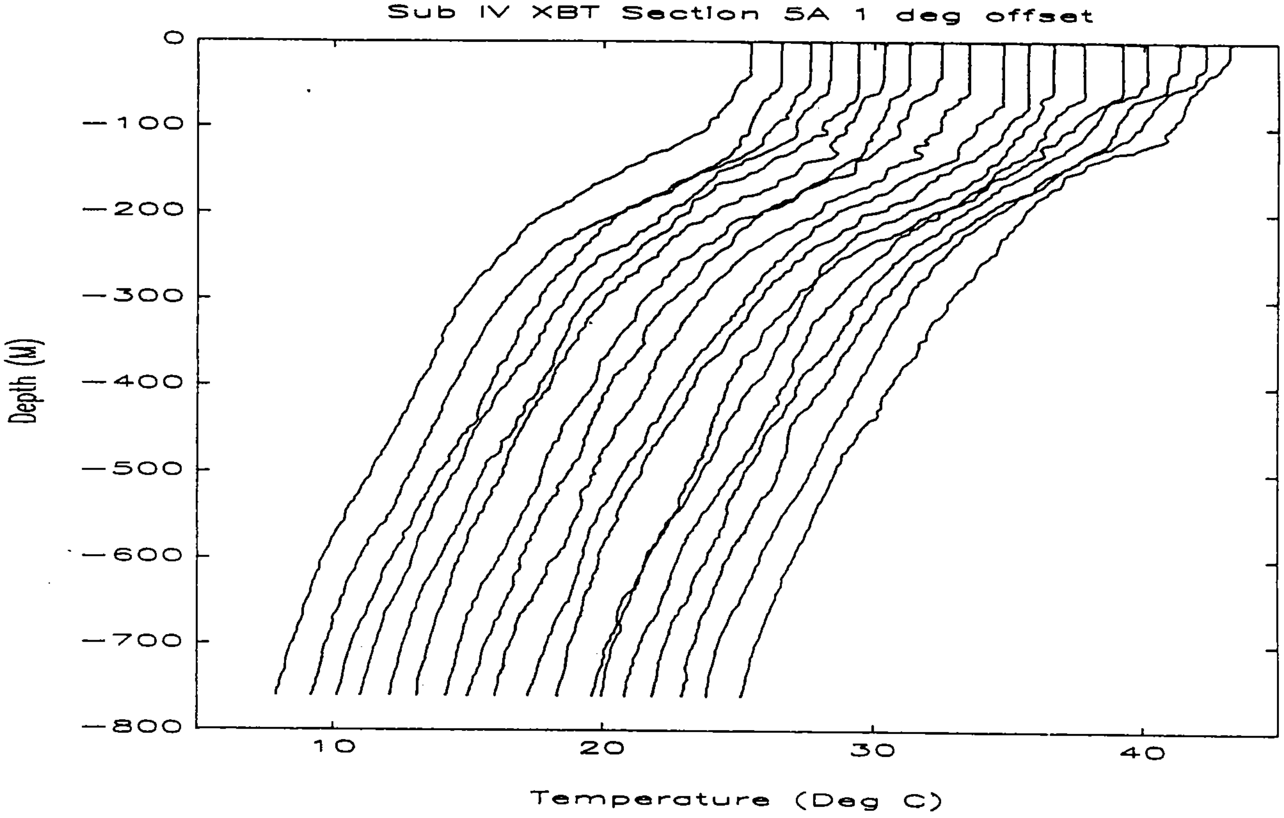


Figure A8-4j Overplot of XBT Profiles 185 to 187 and 190 to 203. Successive profiles are offset by 1°C.

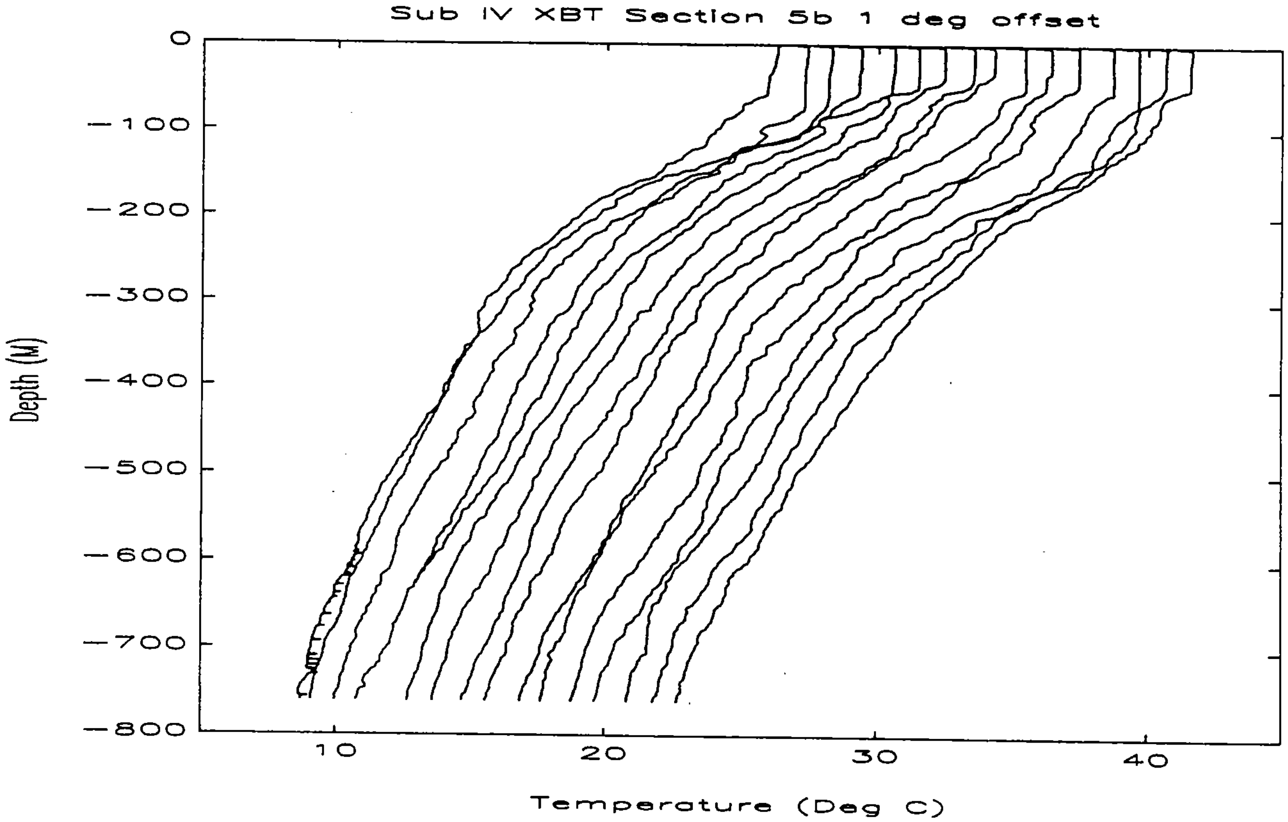


Table A8-1 XBT Positions

Subduction 4 XBT Profiles

xbt	date	time	latitude	longitude	sst
1	06-13-1993	12:03:20	37 12.93	25 05.98	19.63
2	06-13-1993	13:00:25	36 49.55	22 56.08	19.85
3	06-13-1993	16 04 10	36 30.76	24 20.98	19.73
4	06-13-1993	17 01 05	36 19.91	24 21.35	20.02
5	06-13-1993	18 00 24	36 08.52	24 13.44	19.83
6	06-13-1993	18 58 16	35 58.53	24 07.15	19.76
7	06-13-1993	20 01 50	35 48.31	24 01.19	19.94
8	06-13-1993	21 00 17	35 36.75	23 54.41	20.15
9	06-13-1993	22 01 09	35 25.18	23 46.63	21.11
10	06-13-1993	23 00 17	35 14.18	23 48.54	21.55
11	06-13-1993	23 58 17	35 03.03	23 30.42	21.16
12	06-14-1993	01 00 41	34 51.61	23 22.09	20.76
13	06-14-1993	02 06 41	34 39.95	23 13.03	20.49
14	06-14-1993	03 00 59	34 29.35	23 04.35	20.22
15	06-14-1993	03 58 29	34 18.60	22 55.98	20.37
16	06-14-1993	04 03 43	34 17.65	22 55.25	20.36
17	06-14-1993	04 08 31	34 17.65	22 54.58	20.45
18	06-14-1993	05 00 17	34 06.98	22 47.48	20.46
19	06-14-1993	05 57 57	33 55.91	22 39.14	20.28
20	06-14-1993	07 00 03	33 44.26	22 29.93	20.33
21	06-14-1993	08 00 53	33 32.95	22 21.20	20.77
22	06-14-1993	09 00 20	33 21.65	22 13.04	20.29
23	06-14-1993	09 59 25	33 10.26	22 05.39	20.09
24	06-14-1993	22 01 42	32 53.95	22 09.38	20.70
25	06-14-1993	22 08 12	32 53.95	22 09.38	20.64
26	06-14-1993	23 00 49	32 42.59	22 19.82	20.44
27	06-15-1993	00 00 56	32 32.28	22 30.32	20.55
28	06-15-1993	01 04 40	32 21.85	22 41.01	20.60
29	06-15-1993	02 02 03	32 11.67	22 50.74	20.64
30	06-15-1993	03 00 23	32 00.70	23 00.65	20.31
31	06-15-1993	04 00 33	31 50.04	23 10.41	20.78
32	06-15-1993	04 57 52	31 39.63	23 19.63	20.95
33	06-15-1993	05 57 46	31 29.06	23 29.31	20.77
34	06-15-1993	06 58 47	31 18.33	23 39.08	20.92
35	06-15-1993	07 59 31	31 07.40	23 48.82	21.02
36	06-15-1993	08 59 00	30 57.03	23 57.89	21.29
37	06-15-1993	10 02 06	30 46.20	24 7.68	21.08
38	06-15-1993	11 00 27	30 36.06	24 16.83	21.31
39	06-15-1993	11 58 21	30 26.39	24 20.21	21.29
40	06-15-1993	13 00 55	30 15.71	24 36.37	21.38
41	06-15-1993	14 04 52	30 05.18	24 46.74	21.37
42	06-15-1993	15 00 34	29 55.56	24 56.09	21.58
43	06-15-1993	15 57 36	29 45.44	25 06.36	21.79
44	06-15-1993	16 59 16	29 35.02	25 17.01	21.88
45	06-15-1993	17 58 39	29 24.63	25 27.23	21.92
46	06-15-1993	18 58 30	29 14.33	25 37.05	21.92
47	06-15-1993	20 00 28	29 3.74	25 47.18	21.94
48	06-15-1993	20 59 49	28 53.40	25 56.91	26.23
49	06-15-1993	21 02 18	28 53.40	25 56.91	21.93
50	06-15-1993	22 00 47	28 43.21	26 06.76	21.86
51	06-15-1993	22 59 35	28 32.67	26 16.31	21.91
52	06-16-1993	00 00 47	28 22.22	26 25.38	22.04
53	06-16-1993	01 01 59	28 11.02	26 35.17	22.08
54	06-16-1993	02 01 19	28 00.47	26 44.59	22.19
55	06-16-1993	03 01 28	27 49.79	26 54.25	22.11
56	06-16-1993	03 59 14	27 39.59	27 03.66	22.34
57	06-16-1993	04 58 31	27 29.20	27 13.24	22.52
58	06-16-1993	05 59 03	27 18.57	27 22.71	22.66

59	06-16-1993	06	02	40	27	18.57	27	22.71	23.11
60	06-16-1993	06	58	54	27	08.08	27	31.92	22.80
61	06-16-1993	07	59	45	26	57.40	27	41.26	22.49
62	06-16-1993	08	58	59	26	47.18	27	50.55	22.62
63	06-16-1993	09	58	26	26	36.74	27	59.71	22.79
64	06-16-1993	10	59	42	26	26.10	28	09.31	22.80
65	06-16-1993	12	00	28	26	15.46	28	18.64	22.75
66	06-16-1993	13	01	53	26	04.71	28	27.98	22.77
67	06-16-1993	14	00	22	25	54.28	28	36.93	23.12
68	06-16-1993	15	01	40	25	43.26	28	46.25	23.21
69	06-17-1993	04	01	40	25	24.03	28	54.35	22.78
70	06-17-1993	05	00	45	25	14.49	28	45.12	22.78
71	06-17-1993	06	02	00	25	04.94	28	35.68	22.68
72	06-17-1993	07	00	59	24	55.18	28	26.27	22.99
73	06-17-1993	08	00	29	24	45.75	28	16.98	22.80
74	06-17-1993	08	58	55	24	36.24	28	07.79	22.84
75	06-17-1993	10	00	25	24	26.16	27	58.54	22.82
76	06-17-1993	11	02	38	24	16.17	27	48.84	23.29
77	06-17-1993	11	59	57	24	06.54	27	39.59	22.99
78	06-17-1993	12	59	56	23	56.65	27	30.09	23.16
79	06-17-1993	13	59	35	23	46.84	27	20.56	23.10
80	06-17-1993	15	00	24	23	36.80	27	11.27	23.17
81	06-17-1993	16	01	34	23	26.71	27	01.73	23.26
82	06-17-1993	17	00	01	23	17.32	26	52.42	22.96
83	06-17-1993	18	00	01	23	06.87	26	43.22	23.05
84	06-17-1993	19	00	07	22	56.71	26	34.31	22.94
85	06-17-1993	19	58	37	22	46.99	26	25.83	22.89
86	06-17-1993	20	57	31	22	37.02	26	16.91	23.17
87	06-17-1993	21	58	35	22	26.89	26	07.77	23.02
88	06-17-1993	22	59	11	22	16.73	25	58.91	23.12
89	06-18-1993	00	01	31	22	06.27	25	49.76	23.02
90	06-18-1993	01	02	46	21	56.08	25	40.47	22.89
91	06-18-1993	02	02	24	21	45.97	25	30.85	22.92
92	06-18-1993	03	04	09	21	35.82	25	21.40	22.84
93	06-18-1993	03	58	56	21	25.96	25	12.30	22.90
94	06-18-1993	05	01	47	21	15.26	25	02.41	22.91
95	06-18-1993	06	00	37	21	05.79	24	53.38	22.77
96	06-18-1993	06	04	05	21	05.79	24	53.38	22.71
97	06-18-1993	06	07	55	21	04.53	24	52.19	22.82
98	06-18-1993	07	02	29	20	55.58	24	43.73	22.59
99	06-18-1993	07	58	24	20	46.57	24	35.19	22.78
100	06-18-1993	08	58	23	20	36.78	24	26.02	22.44
101	06-18-1993	09	58	19	20	27.15	24	16.99	22.59
102	06-18-1993	10	59	14	20	17.41	24	7.70	22.71
103	06-18-1993	12	01	39	20	07.65	23	58.26	22.70
104	06-18-1993	13	00	34	19	57.78	23	49.81	22.56
105	06-18-1993	14	04	09	19	46.99	23	40.82	22.93
106	06-18-1993	15	02	46	19	36.99	23	32.16	22.71
107	06-18-1993	16	01	17	19	27.18	23	23.53	22.89
108	06-18-1993	17	01	20	19	17.29	23	14.25	22.74
109	06-18-1993	18	00	32	19	07.67	23	05.13	22.65
110	06-18-1993	18	59	11	18	58.07	22	56.34	22.73
111	06-18-1993	19	58	45	18	48.35	22	47.42	22.60
112	06-18-1993	20	58	59	18	38.39	22	38.22	22.57
113	06-18-1993	21	59	03	18	28.33	22	29.18	22.78
114	06-18-1993	22	58	21	18	18.36	22	20.31	22.60
115	06-19-1993	09	01	24	17	55.83	22	6.13	22.84
116	06-19-1993	10	07	59	17	56.24	22	22.0	23.00
117	06-19-1993	10	59	03	17	56.57	22	33.86	23.16
118	06-19-1993	12	00	25	17	56.84	22	47.78	23.13

119	06-19-1993	12	59	37	17	56.87	23	01.26	23.33
120	06-19-1993	14	02	13	17	57.10	23	15.57	23.34
121	06-19-1993	14	59	10	17	57.34	23	29.16	23.42
122	06-19-1993	15	59	45	17	57.55	23	43.12	23.64
123	06-19-1993	16	04	56	17	57.55	23	43.12	23.64
124	06-19-1993	17	04	13	17	57.92	23	56.88	23.74
125	06-19-1993	17	59	50	17	57.92	24	11.12	23.83
126	06-19-1993	19	01	13	17	57.75	24	25.87	23.47
127	06-19-1993	20	00	11	17	57.83	24	39.67	23.23
128	06-19-1993	20	59	34	17	58.02	24	53.58	23.18
129	06-19-1993	21	59	59	17	58.22	25	7.71	23.25
130	06-19-1993	22	02	02	17	58.22	25	7.71	23.31
131	06-19-1993	22	59	36	17	58.42	25	22.10	23.20
132	06-19-1993	23	59	21	17	58.50	25	36.12	23.35
133	06-20-1993	01	01	16	17	58.59	25	50.68	23.03
134	06-20-1993	02	00	18	17	58.77	26	04.48	23.53
135	06-20-1993	03	02	13	17	58.18	26	18.67	23.44
136	06-20-1993	04	02	29	17	59.53	26	32.50	23.21
137	06-20-1993	05	01	53	17	59.83	26	47.25	23.52
138	06-20-1993	06	01	40	17	59.61	27	1.37	23.42
139	06-20-1993	06	59	22	17	59.54	27	14.69	23.56
140	06-20-1993	08	01	00	17	59.69	27	28.74	23.42
141	06-20-1993	08	59	58	17	59.86	27	42.86	23.48
142	06-20-1993	10	00	11	18	00.07	27	56.67	23.68
143	06-20-1993	11	03	28	18	00.21	28	11.22	23.81
144	06-20-1993	11	59	51	18	00.52	28	24.36	23.80
145	06-20-1993	13	03	29	18	00.35	28	38.69	23.78
146	06-20-1993	14	01	54	18	00.05	28	52.18	24.05
147	06-20-1993	15	00	57	18	00.03	29	06.12	24.09
148	06-20-1993	16	00	41	18	00.01	29	19.91	24.05
149	06-20-1993	16	59	28	18	00.24	29	34.20	24.09
150	06-20-1993	17	59	50	18	00.25	29	48.09	24.27
151	06-20-1993	18	59	43	17	59.96	30	2.47	23.96
152	06-20-1993	19	59	55	17	59.58	30	16.43	23.96
153	06-20-1993	20	59	14	17	59.39	30	30.36	23.92
154	06-20-1993	21	59	49	17	59.24	30	44.46	24.05
155	06-20-1993	22	59	00	17	59.36	30	57.95	23.89
156	06-20-1993	23	58	44	17	59.62	31	11.98	24.00
157	06-21-1993	01	00	15	17	59.91	31	26.04	24.09
158	06-21-1993	02	00	34	17	59.83	31	40.31	24.19
159	06-21-1993	03	01	31	17	59.76	31	54.42	24.01
160	06-21-1993	04	02	34	17	59.76	32	08.77	24.17
161	06-21-1993	04	58	40	17	59.77	32	22.25	23.97
162	06-21-1993	06	00	03	17	59.78	32	35.36	24.03
163	06-21-1993	06	58	25	17	59.72	32	49.06	24.17
164	06-21-1993	07	59	39	17	59.70	33	3.51	24.07
165	06-21-1993	08	59	26	17	59.54	33	18.75	24.39
166	06-21-1993	10	00	07	17	59.57	33	31.69	24.57
167a	6-21-1993	12	57	39	17	59.96	33	01.29	24.37
167b	6-21-1993	21	08	26	18	03.30	33	58.47	24.44
168	06-23-1993	19	05	00	17	58.20	35	05.10	
169a	6-23-1993	19	58	52	17	58.15	34	18.67	24.37
169b	6-23-1993	20	58	24	17	57.98	34	32.59	24.55
170	06-23-1993	21	59	35	17	57.77	34	46.50	24.40
171	06-23-1993	22	57	48	17	58.05	35	00.57	24.36
172	06-23-1993	23	58	15	17	58.39	35	14.70	24.35
173	06-24-1993	01	00	12	17	58.72	35	29.13	24.33
174	06-24-1993	02	00	24	17	59.12	35	43.35	24.28
175	06-24-1993	03	01	59	17	59.89	35	57.19	24.48
176	06-24-1993	04	01	48	18	00.26	36	11.14	24.47

177	06-24-1993	05	00	53	18	0.48	36	25.13	24.67
178	06-24-1993	05	59	39	18	0.61	36	38.96	24.69
179	06-24-1993	06	59	16	18	01.03	36	52.73	24.66
180	06-24-1993	07	57	38	18	01.69	37	06.42	24.62
181	06-24-1993	08	58	38	18	12.27	37	20.54	25.10
182	06-24-1993	09	58	46	18	02.91	37	34.32	24.86
183	06-24-1993	10	59	47	18	03.50	37	48.36	25.52
184	06-24-1993	11	59	57	18	04.04	38	02.10	25.17
185	06-24-1993	13	00	52	18	04.46	38	16.21	25.25
186	06-24-1993	13	57	52	18	03.65	38	30.15	25.32
187	06-24-1993	14	59	04	18	02.39	38	44.09	25.32
188	06-24-1993	15	59	52	18	00.35	38	57.96	25.32
189	06-24-1993	17	00	13	17	58.00	39	11.93	25.31
190	06-24-1993	17	58	23	17	56.15	39	25.60	25.07
191	06-24-1993	18	59	03	17	54.72	39	39.79	25.05
192	06-24-1993	19	57	54	17	53.34	39	53.52	25.39
193	06-24-1993	21	02	35	17	51.76	40	7.54	25.30
194	06-24-1993	21	58	59	17	49.72	40	21.74	25.15
195	06-24-1993	22	59	30	17	47.85	40	35.75	25.24
196	06-24-1993	23	58	27	17	45.82	40	49.37	24.95
197	06-25-1993	01	00	05	17	43.57	41	03.88	25.19
198	06-25-1993	01	59	14	17	41.88	41	17.73	24.89
199	06-25-1993	03	00	47	17	40.72	41	31.79	25.11
200	06-25-1993	11	03	10	17	37.34	41	52.39	25.55
201	06-25-1993	11	59	10	17	43.79	42	02.13	25.61
202	06-25-1993	12	58	55	17	51.06	42	12.58	25.66
203	06-25-1993	13	58	39	17	58.30	42	22.85	25.43

Appendix 9 Sample Minotaur log file

```
Sample Minotaur Log File from KN138 (Subduction 4)


R/V KNORR DATA LOG -   1 minute log file
06/29/93   00:01:35

01| CTIME   Computer time
02| GP20P_LL   Port GPS200 Lat/Lon
03| GP20P_TP   Port GPS200 time & position
04| GP20S_TP   Stbd GPS200 time & position
05| IMET   IMET meteorological measurements
06| JSECONDS   Julian seconds
07| OXYGEN   Sea Surface Oxygen (raw data)
08| SSCND   Surface Conductivity (S/m) FSI
09| SSTMP   Surface temperature (C) FSI
10| IMET_AIR   IMET air temperature (degrees C)
11| IMET_BPR   IMET barometric press (millibars)
12| IMET_HUM   IMET relative humidity (percent)
13| IMET_PRC   IMET precipitation (millimeters)
14| IMET_SEA   IMET sea surface temp (degrees C)
15| IMET_SWR   IMET SW radiation (watts/sq meter)
16| IMET_WND   IMET wind direction (degrees)
17| IMET_WNS   IMET wind speed (m/sec)

01| 00:01:35
02| 2802.420,N,05733.199,W
03| 000017,2802.420,N,05733.199,W,1
04| 000121,2802.560,N,05733.405,W,1
05| DT: 93/06/28
TM: 23:57:59
WNS:      3.6
WND:    205.8
BPR:   1021.9
HUM:     63.5
AIR:   24.752
SEA:   26.750
SWR:     -0.8
PRC:      0.0
FXT: 23:57:50
LAT:  28  2.15 N
LON:  57 32.72 W
HDG: 317.9 True
SPD: 9.60 kts
FXQ: 5 0 7

06| 12960604895
07|
08|
09|
10|   24.752
11|   1021.9
12|     63.5
13|      0.0
14|   26.750
15|     -0.8
16|    205.8
17|      3.6
```

Minotaur files were accessed through shell scripts such as getmet, which printed the most recent IMET data at the terminal. The text of scripts getmet and findlast follows.

Getmet:

```
   #! /bin/sh
   metfile=`findlast`
   echo "Reading data from $metfile"
   tail -55  $metfile | \
   {    awk '
                /DT/
                /TM/
                /WNS/
                /WND/
                /BPR/
                /HUM/
                /SEA/
                /AIR/
                /SWR/
                /PRC/
                /LAT/
                /LON/
                /SPD/
                /HDG/
        '
        }
```

Findlast:

```
# silently lists all the log files for imet in chronological order.
# selects the most recent and prints the ninth field, the filename.
 #! /bin/sh
 ls -lgatr /vol/mike/a/minotaur/asciilog/kn01min1.* | tail -1 | \
{       awk '
        /kn01/ { print $9}
        '
}
```

Appendix 10 Meteorological data comparison

Meteorological data (barometric pressure, relative humidity, air temperature, and short wave radiation) from three independent systems have been overplotted for a two week period during KN138 Leg XV. The data from the ship's IMET system were subsampled at 15-minute intervals and plotted as a solid line. Data from the Tattletale 7 data logger were also subsampled at 15-minutes and plotted as a dashed line. Data from the hand-held instruments were recorded hourly on the half hour and were plotted as a dashed-dotted line. The hand-held pressure was measured with an AIR barometric pressure sensor located in the main lab of the ship. The other hand-held observations were taken on the fore deck with a Vaisala relative humidity and air temperature sensor. Time series plots of barometric pressure, relative humidity, air temperature and short wave radiation appear in figures A10-1 through A10-4 respectively.

Figure A10-1. Overplots of barometric pressure data from the shipboard IMET system, the Tattletale 7 system and hand-held observations.

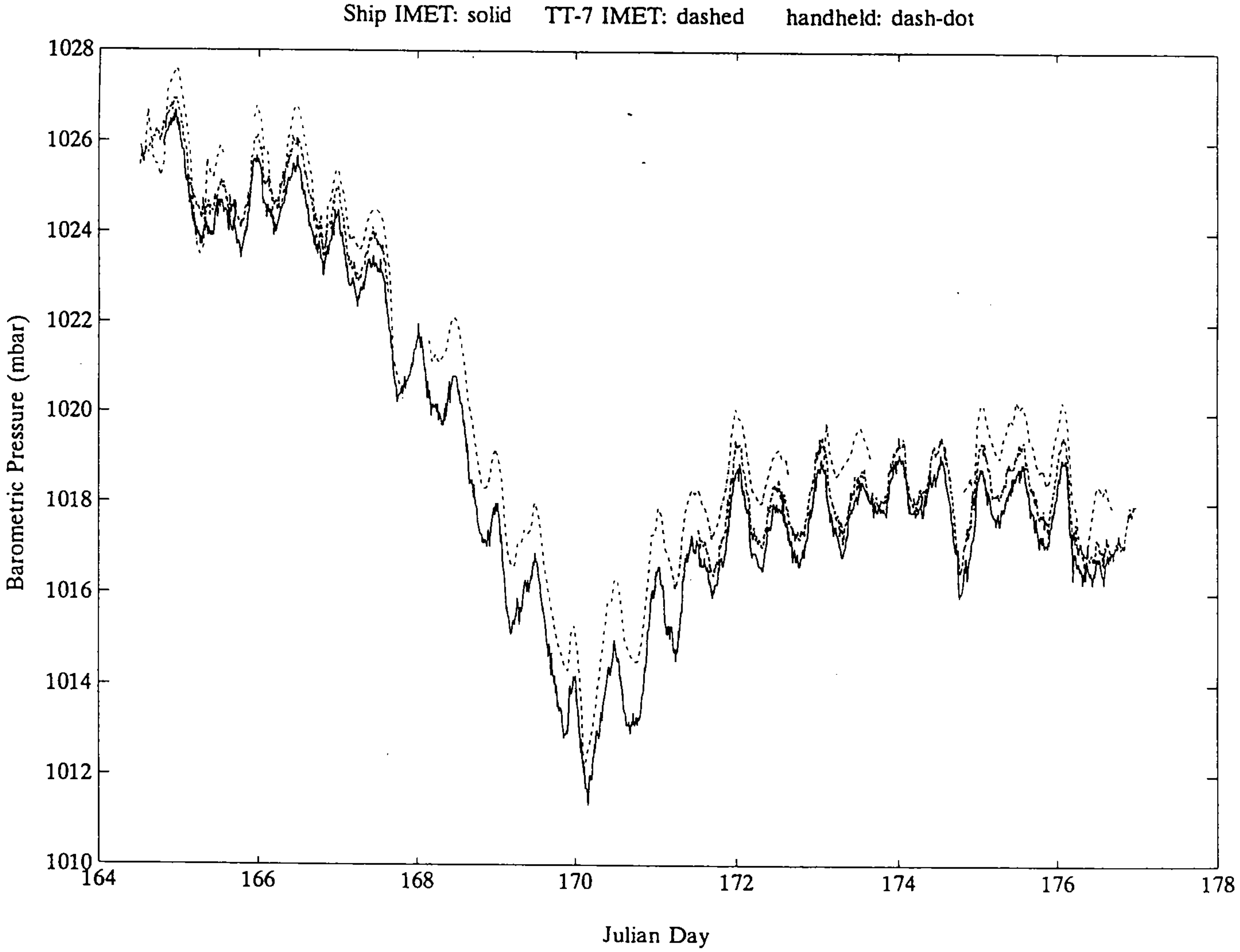


Figure A10-2. Overplots of relative humidity data from the shipboard IMET system, the Tattletale 7 system and hand-held observations.

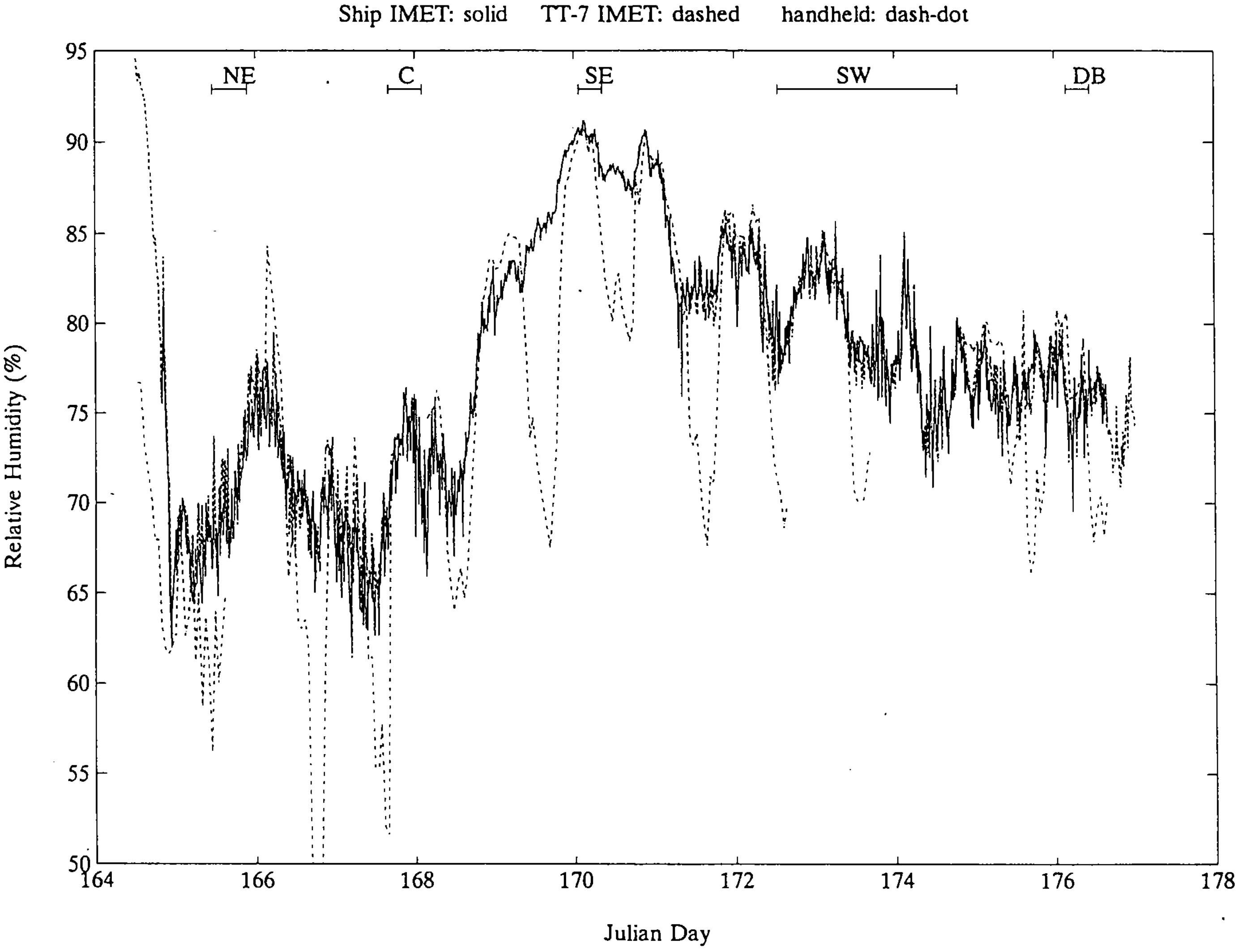


Figure A10-3. Overplots of air temperature data from the shipboard IMET system, the Tattletale 7 system and hand-held observations.

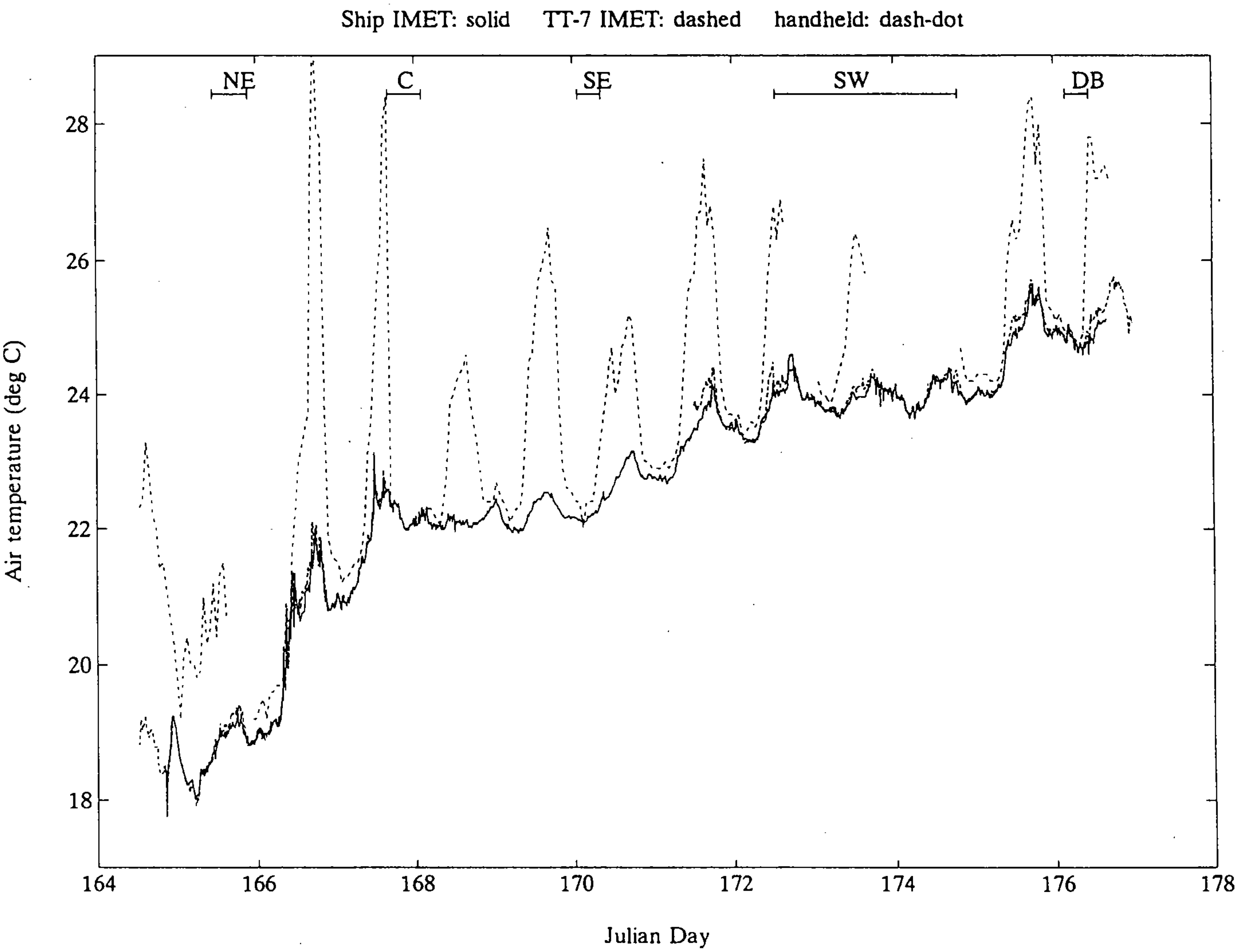
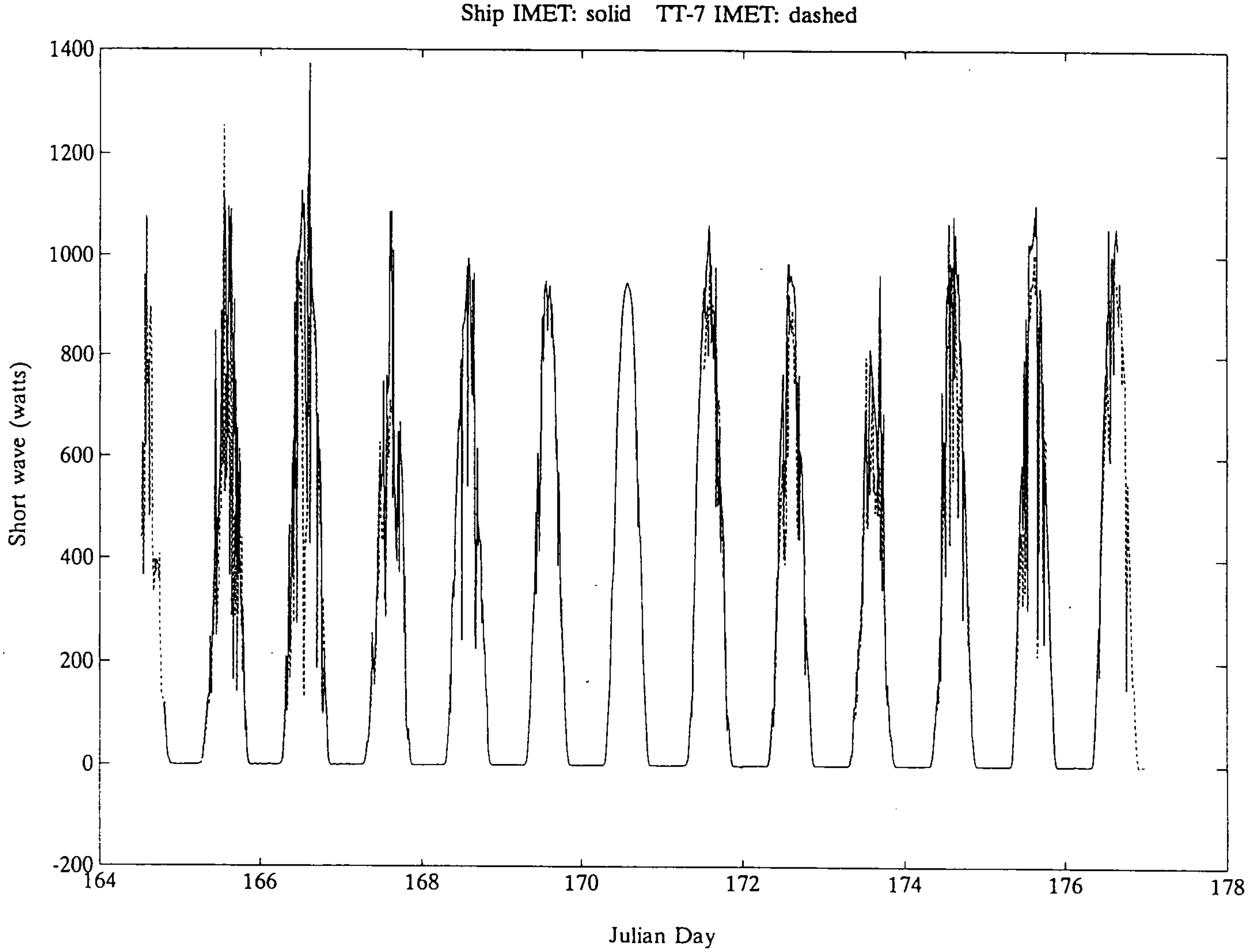


Figure A10-4. Overplots of short wave radiation data from the shipboard IMET system, and the Tattletale 7 system.



Appendix 11 Surface temperature data comparison

The surface temperatures obtained by the XBTs did not always agree with the bucket temperatures taken simultaneously nor did they always agree with IMET sea surface temperature (SST) data. Figure A11-1 is a comparison of the shipboard IMET SST, the XBT temperature at 4.53 meters (approximately the same depth as the IMET SST), and the bucket temperature. Figure A11-2 is a difference plot between IMET SST minus XBT temperature at 4.53 meters depth.

Since there was a noticeable difference between the bucket temperature and the very surface reading from the XBT we wanted to check the XBT system to make sure that it was operating correctly. To do this we wanted to measure the temperature of the same volume of water with both the XBT system and the bucket thermometer. A trash barrel was filled with seawater and stirred. An XBT was dropped into the barrel and at the same time bucket temperature readings were made. The bucket thermometer readings were within .1 to .2 degrees C of the XBT temperatures. This provided some confidence that the XBT system was functioning properly. It remains unclear why on occasion an actual XBT drop yields an SST considerably different from the surface temperature obtained with the bucket thermometer.

Figure A11-1 A comparison of the shipboard IMET SST, the XBT temperature at 4.53 meters and the bucket temperature.

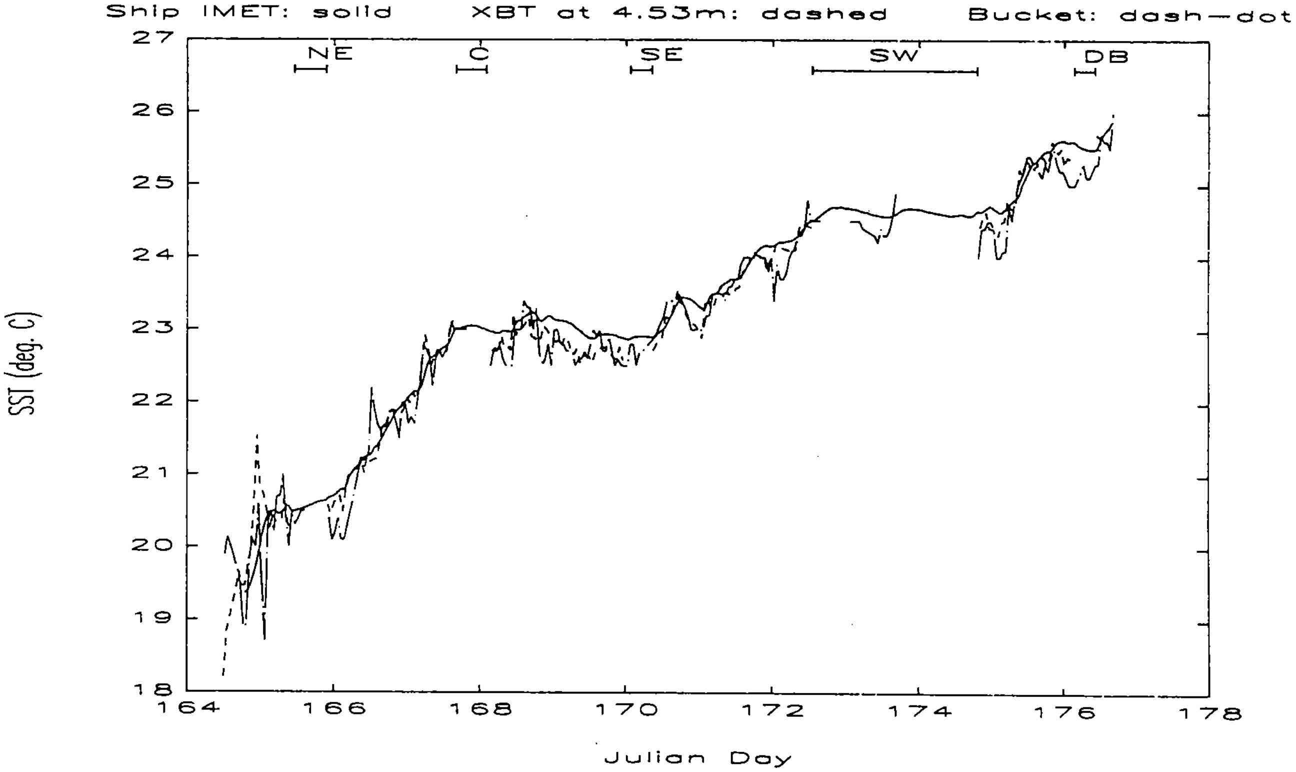
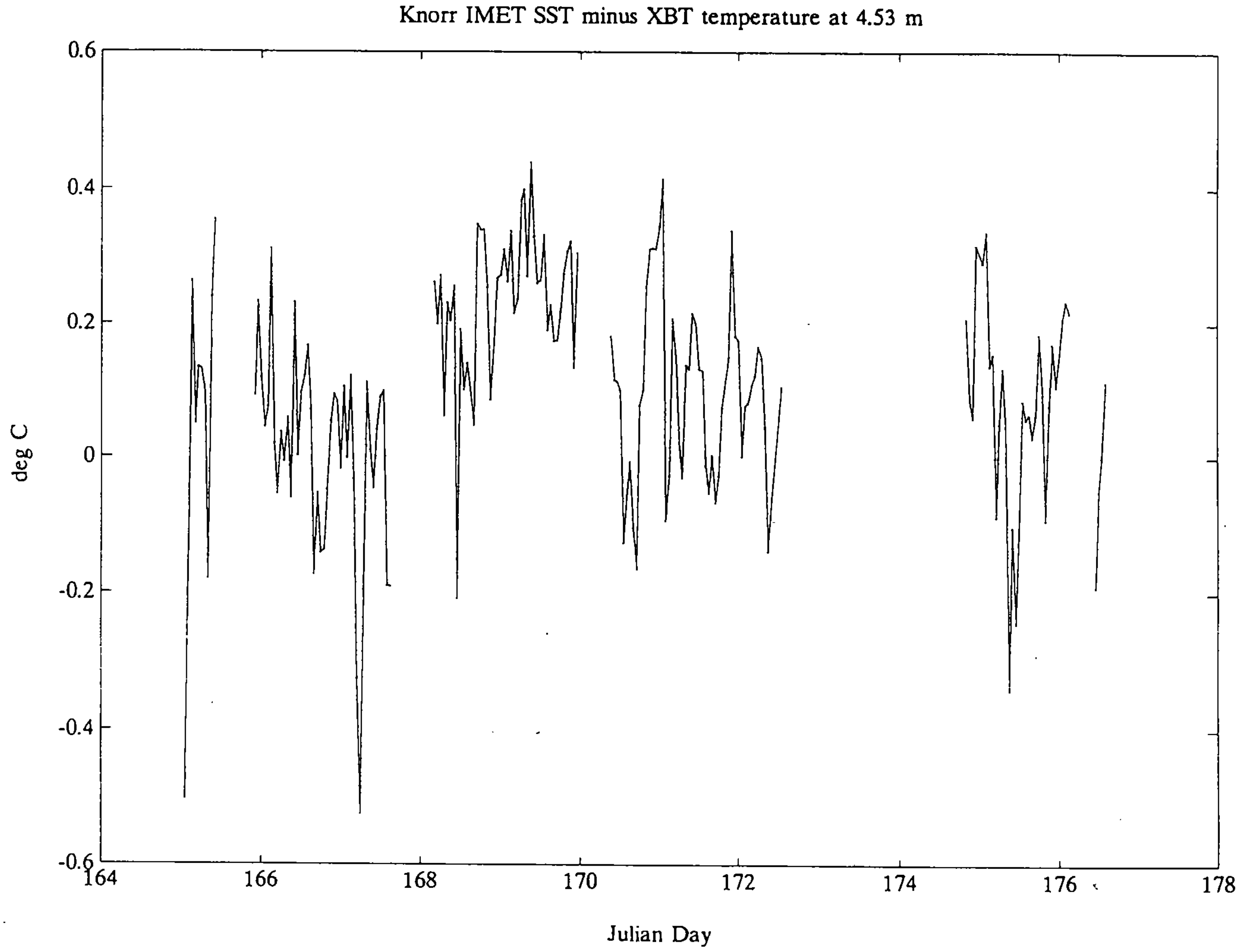


Figure A11-2 **A difference plot between IMET SST minus XBT temperature at 4.53 meters depth.**



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16. Abstract (Limit: 200 words)

Subduction is the mechanism by which water masses formed in the mixed layer and near the surface of the ocean find their way into the upper thermocline. The subduction process and its underlying mechanisms were studied through a combination of Eulerian and Langrangian measurements of velocity, measurements of tracer distributions and hydrographic properties and modeling.

An array of five surface moorings carrying meteorological and oceanographic instrumentation were deployed for a period of two years beginning in June 1991 as part of an Office of Naval Research (ONR) funded Subduction experiment. Three eight month deployments were planned. The moorings were deployed at 18°N 34°W, 18°N 22°W, 25.5°N 29°W, 33°N 22°W and 33°N 34°W.

A Vector Averaging Wind Recorder (VAWR) and an Improved Meteorological Recorder (IMET) collected wind speed and wind direction, sea surface temperature, air temperature, short wave radiation, barometric pressure and relative humidity. The IMET also measured precipitation. The moorings were heavily instrumented below the surface with Vector Measuring Current Meters (VMCM) and single point temperature recorders.

Expendable bathythermograph (XBT) data were collected and meteorological observations were made while transitting between mooring locations.

This report describes the work that took place during R/V Knorr cruise number 138 leg XV which was the fourth scheduled Subduction mooring cruise. During this cruise the moorings previously deployed for a third and final eight month period were recovered. This report includes a description of the moorings and instrumentation that were recovered, has information about the underway measurements (XBT and meteorological observations) that were made including plots of the data, and presents a chronology of the cruise events.

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