

Woods Hole Oceanographic Institution

Coryl

WHOI-99-15

Technical Report

December 1999



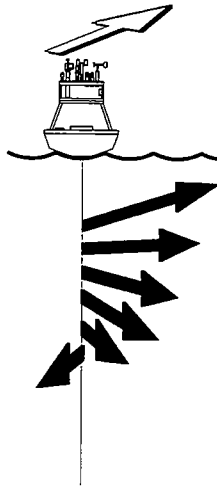
Coastal Mixing and Optics Experiment Moored Array Data Report

by

Nancy Galbraith
Albert Plueddemann
Steven Lentz
Steven Anderson
Mark Baumgartner
James Edson



December 1999



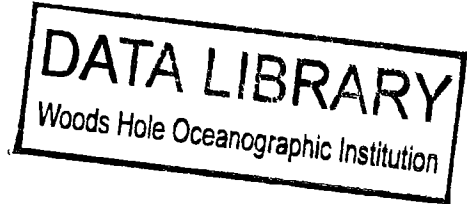
Upper Ocean Processes Group
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543
UOP Technical Report 99-03

WHOI-99-15
UOP 99-03

**Coastal Mixing and Optics Experiment
Moored Array Data Report**

by

Nancy Galbraith
Albert Plueddemann
Steven Lentz
Steven Anderson,
Mark Baumgartner
James Edson



Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

December 1999

Technical Report

Funding was provided by the Office of Naval Research under Contract No. N00014-95-1-0339.

Reproduction in whole or in part is permitted for any purpose of the United States Government. This report should be cited as Woods Hole Oceanog. Inst. Tech. Rept., WHOI-99-15.

Approved for public release; distribution unlimited.

Approved for Distribution:

Terrence M. Joyce, Chair

Department of Physical Oceanography



Abstract

To investigate vertical mixing processes influencing the evolution of the stratification over continental shelves a moored array was deployed on the New England shelf from August 1996 to June 1997 as part of the Office of Naval Research's Coastal Mixing and Optics program. The array consisted of four mid-shelf sites instrumented to measure oceanic (currents, temperature, salinity, pressure, and surface gravity wave spectra) and meteorological (winds, surface heat flux, precipitation) variables. This report presents a description of the moored array, a summary of the data processing, and statistics and time-series plots summarizing the data. A report on the mooring recovery cruise and a summary of shipboard CTD surveys taken during the mooring deployment are also included.

Table of Contents

Page No.

Abstract	ii
Table of Contents	iii
List of Figures	iv
List of Tables	vi
1. Introduction	1
2. The Moored Array and Instrumentation	4
3. Data Processing Summary	27
3.1 Wind Direction	27
3.2 Wind Speed	29
3.3 Air Temperature	30
3.4 Barometric Pressure	31
3.5 Incoming Longwave Radiation	32
3.6 Relative Humidity	32
3.7 Sea Surface Temperature	33
3.8 Precipitation	33
3.9 Incoming Shortwave Radiation.....	34
3.10 Water Temperature.....	35
3.11 Current Meter Velocity	39
3.12 Conductivity and Salinity.....	43
3.13 Pressure	52
3.14 Surface Waves.....	52
3.15 ADCP Velocity	59
4. Data Presentation	62
4.1 Surface Forcing	63
4.2 Water Temperature.....	81
4.3 Salinity	99
4.4 Bottom Pressure	112
4.5 Water Velocity	118
5. Mooring Recovery Cruise Report	141
6. CTD Sections	146
Acknowledgments	146
Bibliography	156

List of Figures

	Page No.
1.1. Site Map	2
1.2. Mooring Schematics.....	3
2.1-2.2 Central site plans	5-6
2.3 Inshore site plan	7
2.4 Offshore site plan	8
2.5 Alongshore site plan.....	9
2.6-2.9 Mooring Diagrams, Central Site Moorings.....	16-19
2.10-2.11 Mooring Diagrams, Inshore Site Moorings.....	20-21
2.12-2.13 Mooring Diagrams, Offshore Site Moorings	22-23
2.14-2.15 Mooring Diagrams, Alongshore Site Moorings.....	24-25
2.16 Mooring Diagram, Guard Buoy	26
4.1.1 Surface Forcing Data Return, Central Site.....	64
4.1.2-4.1.3 Meteorology time series, Central Site	67-68
4.1.4-4.1.5 Air-Sea Flux time series, Central Site.....	69-70
4.1.6-4.1.7 Surface Waves time series, Central Site.....	71-72
4.1.8-4.1.9 Meteorology time series, Inshore Site.....	73-74
4.1.10-4.1.11 Meteorology time series, Offshore Site.....	75-76
4.1.12-4.1.13 Meteorology time series, Alongshore Site	77-78
4.1.14 Autospectra of meteorological parameters at Central Site.....	79
4.1.15 Autospectra of air-sea flux parameters at Central Site.....	80
4.2.1-4.1.4 Water Temperature Data Return	82-85
4.2.5-4.2.8 Temperature time series, Central Site	88-91
4.2.9-4.2.10 Temperature time series, Inshore Site	92-93
4.2.11-4.2.12 Temperature time series, Offshore Site.....	94-95
4.2.13-4.2.14 Temperature time series, Alongshore Site	96-97
4.2.15 Autospectra of temperatures at Central Site.....	98
4.3.1-4.3.2 Salinity Data Return	100-101
4.3.3-4.3.4 Salinity time series, Central Site	103-104
4.3.5-4.3.6 Salinity time series, Inshore Site	105-106
4.3.7-4.3.8 Salinity time series, Offshore Site.....	107-108
4.3.9-4.3.10 Salinity time series, Alongshore Site	109-110
4.3.11 Autospectra of salinity at Central Site.....	111
4.4.1 Bottom Pressure Data Return	113
4.4.2-4.4.3 Bottom Pressure time series	115-116
4.4.4 Autospectra of Bottom Pressure.....	117
4.5.1-4.5.2 Water Velocity Data Return.....	119-120
4.5.3-4.5.6 Water Velocity time series, Central Site	125-128
4.5.7-4.5.9 Water Velocity time series, Inshore Site.....	129-131
4.5.10-4.5.12 Water Velocity time series, Offshore Site.....	132-134
4.5.13-4.5.14 Water Velocity time series, Alongshore Site	135-136

4.5.15 Progressive vectors from selected current meters at Central Site 137
4.5.16-4.5.18 Autospectra of Water Velocities 138-140

6.1 CTD Locations 147
6.2-6.4 Cross-shelf CTD Sections, deployment cruise..... 148-150
6.5 Cross-shelf CTD Section, Ledwell cruise 151
6.6. Cross-shelf CTD Section, Pickart cruise 152
6.7-6.9 Cross-shelf CTD Sections, recovery cruise 153-155

List of Tables

	Page No.
2.1. Mooring Deployments and Recoveries	10
2.2-2.6 Instrumentation Summaries.....	11-15
3.1.1 Offsets between wind direction measurements	27
3.1.2 Wind direction sources by date	28
3.1.3 VOS, RUC, and AWR comparison.....	29
3.2.1 Wind direction data sources	30
3.3.1 Air Temperature comparison	30
3.14.1 Seatex Data Dates.....	53
3.14.2 Recorded Wave Parameters	54-55
3.14.3 Wave Data Gaps.....	56
3.14.4 Seatex compass correction evaluation.....	57
3.14.5 Comparison of Seatex and NDBC buoy data.....	59
3.14.6 Non-directional wave parameter sources	59
4.1.1 Surface Forcing Statistics.....	65
4.1.2. Surface Wave Statistics	66
4.2.1. Temperature Statistics	86-87
4.3.1. Salinity Statistics	102
4.4.1. Pressure Statistics	114
4.5.1-4.5.2 VMCM Water Velocity Statistics	121-122
4.5.3-4.5.4 ADCP Water Velocity Statistics	123-124

1. Introduction

A moored array was deployed on the New England shelf from August 1996 to June 1997 as part of the Office of Naval Research's Coastal Mixing and Optics program. The primary objective of this component of the program is to identify and understand the dominant vertical mixing processes influencing the evolution of stratification on continental shelves. The moored array consisted of four sites located in the middle of the New England continental shelf, about 100 km south of Cape Cod, Massachusetts (Figure 1.1).

This site was chosen for several reasons. There is a large seasonal variation in both stratification and atmospheric forcing (Beardsley and Boicourt, 1981). In summer, winds are weak, surface heating is strong, and the water column is strongly stratified. In winter, winds are strong, there is often strong cooling at the surface, and the water column is typically unstratified. The shelf at this site is wide, the isobaths at mid shelf are fairly straight, and the bottom is relatively flat and featureless. These factors should simplify interpretation of the observations, by reducing the likelihood of complications associated with complex bathymetry.

Previous studies in this region provided a basis for planning and a broader temporal context to the observations from this study. The mid shelf location was chosen as roughly halfway between the the complex bathymetry onshore and the shelfbreak front offshore. The shelfbreak front is a narrow region of sharp temperature and salinity contrasts separating the fresher, cooler shelf water from the warmer, saltier slope water.

The moored array was deployed from August 1996 to June 1997 to capture the breakdown of the stratification in fall and the redevelopment of the stratification in spring. The moored array consisted of a heavily instrumented Central site on the 70-m isobath and three more lightly instrumented surrounding sites (Figures 1.1 and 1.2). The Inshore site is about 11 km onshore of the Central site in 64 m of water, the Offshore site is about 12.5 km offshore of the Central site in 86 m of water, and the Alongshore site is 14.5 km along-isobath toward the east from the Central site. The separations between sites were chosen so the array would be coherent but the sites would be far enough apart to resolve subtidal temperature and salinity gradients based on historical data.

Temperature, conductivity, and current sensors spanning the water column were deployed on surface/subsurface mooring pairs at each site. The Central site discus buoy also supported a redundant suite of meteorological sensors to estimate wind stress, surface heat flux, and freshwater flux. This included sensors to measure wind speed and direction, air temperature, near-surface water temperature, relative humidity, incoming short and longwave radiation, atmospheric pressure, and precipitation. A sonic anemometer and motion package were also mounted on the buoy to make direct covariance estimates of stress (Martin, 1998). A Seatex Wavescan wave buoy was deployed at the Central site to measure surface gravity wave spectra. An upward-looking fanbeam acoustic Doppler current profiler (ADCP) was deployed to monitor the presence of Langmuir circulation. Bottom pressure gauges were deployed on the anchors of the three surrounding sites to estimate pressure gradients. Wind, air temperature, relative humidity, and atmospheric pressure sensors were also deployed on the surface buoys at each of the surrounding sites.

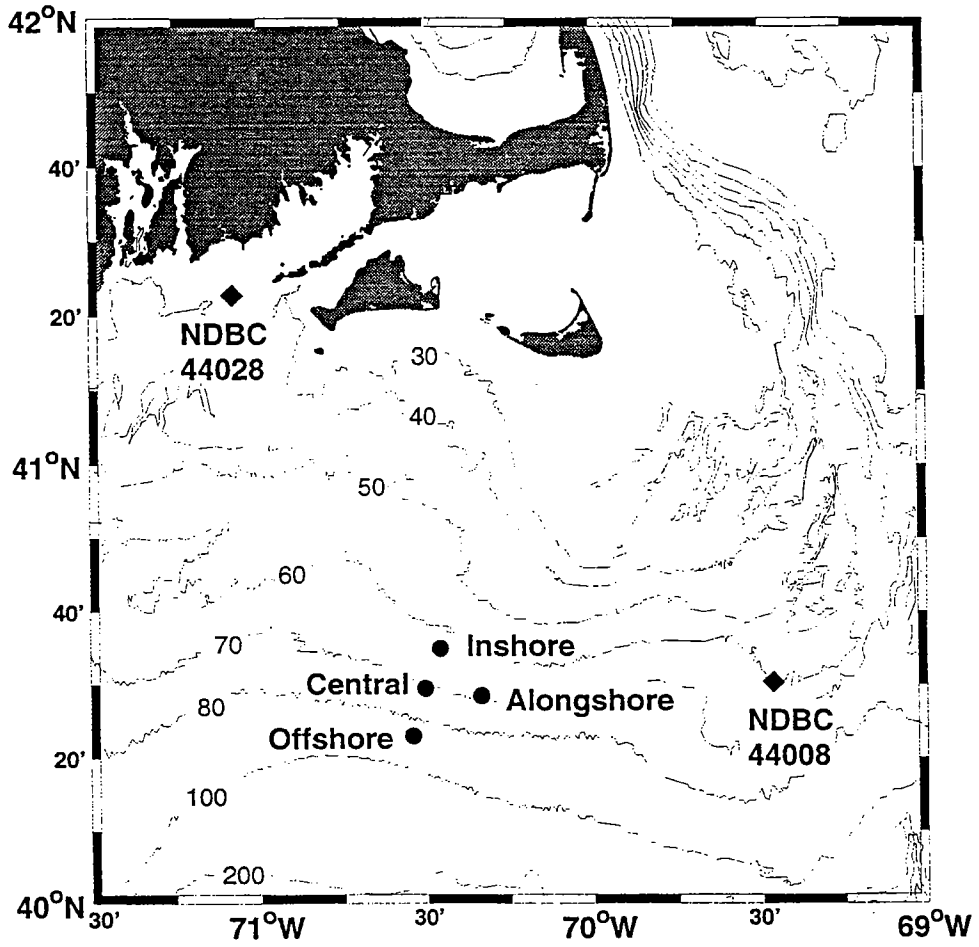


Figure 1.1. Site Map

Coastal Mixing and Optics Moored Array

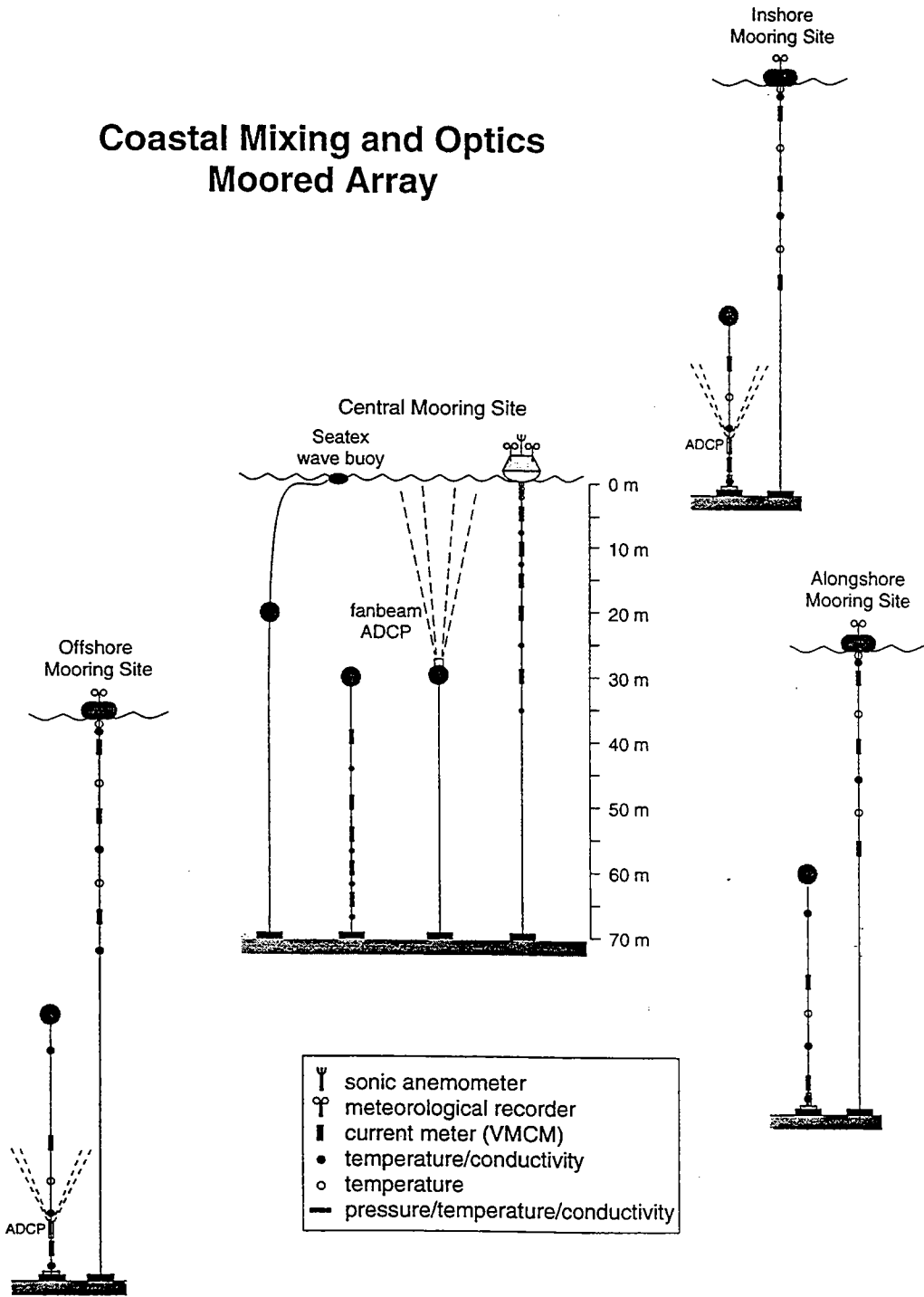


Figure 1.2. Mooring Schematics

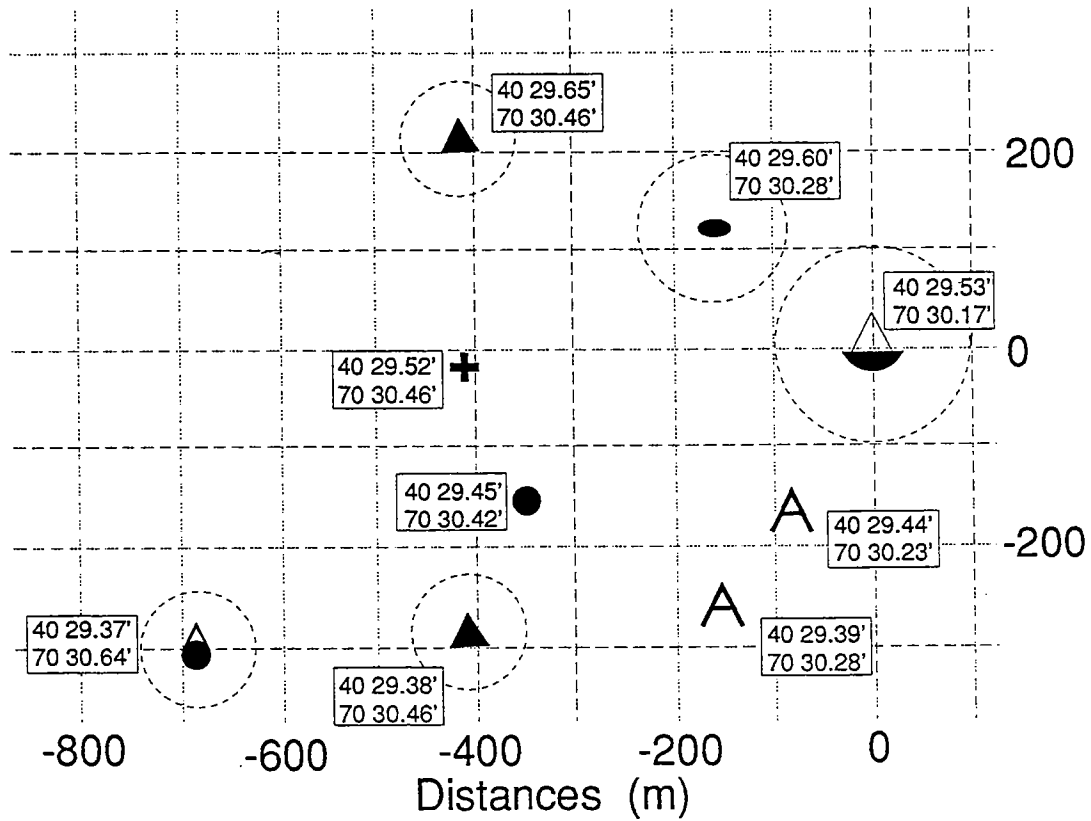
2. The Moored Array and Instrumentation

To avoid losses due to the heavy shipping and fishing activity in this region, subsurface moorings and tripods were surrounded by the surface instrumented mooring and two additional guard buoys within a few hundred meters or less (Figures 2.1–2.5.). This strategy was effective as no moorings were lost to shipping or fishing. At the Central site, bottom tripods and physical/bio-optical moorings were also deployed by other investigators. Both the tripods and the bio-optical moorings were recovered and redeployed every 3 months to clean sensors and download data. Consequently the mooring and tripod locations at the Central site changed over the period of the study. The relative locations of the various moorings and bottom tripods at different times are shown in Figures 2.1–2.2.

The locations, deployment and recovery times for each element of the moored array are listed in Table 2.1. Most of the moorings were deployed July 30–August 3, 1996 and recovered June 10–16, 1997, with the following exceptions. A toroid was deployed at the Central site from July 31 to August 3 to compare the wind measurements from the discus and toroid buoys. It was then redeployed at the Alongshore site. The Fan Beam mooring was restricted to a six-month deployment because of both memory and power limitations. It was deployed September 27, recovered April 9, and redeployed April 17. The acoustic release on the Inshore surface mooring inexplicably fired on September 18. The mooring was recovered and reset on September 26. The acoustic release on the Alongshore surface mooring slipped in its bracket and released on October 9. It was recovered October 16 and redeployed November 2, 1996. The Seatex mooring failed twice. The first failure occurred September 1 during the passage of hurricane Edouard. The failure occurred at the connection between the mooring chain and the buoy. The buoy was recovered September 4 and redeployed September 26. The Seatex buoy failed again on January 24, this time due to parting of the buoyant surface tether. It was recovered February 6 and redeployed April 17. A guard buoy with a VOS wind sensor was deployed at the Central site April 8 to provide additional wind measurements because of the failure of the VAWR wind sensors.

The depths (or heights), serial numbers, and sample rates for each sensor at each site are listed in Tables 2.2–2.6. Detailed mooring diagrams indicating the mooring hardware and the locations of each of the sensors on the moorings are presented in Figures 2.6 through 2.16.

CMO central mooring site
 July 30 - September 27, 1996
 Discus buoy at 40° 29.53'N 70° 30.17'W
 water depth ~70 m



- ▲ surface discus buoy
- Oregon State University (OSU) surface mooring
- ⊕ OSU subsurface mooring w/surface spar
- ▲ guard buoy
- subsurface mooring
- Seatex Wavescan wave buoy
- A bottom tripods

Figure 2.1. Central Site Plan, through September 1996.

CMO central mooring site
 September 27, 1996 - July 12, 1997
 Discus buoy at 40° 29.53'N 70° 30.17'W
 water depth ~70 m

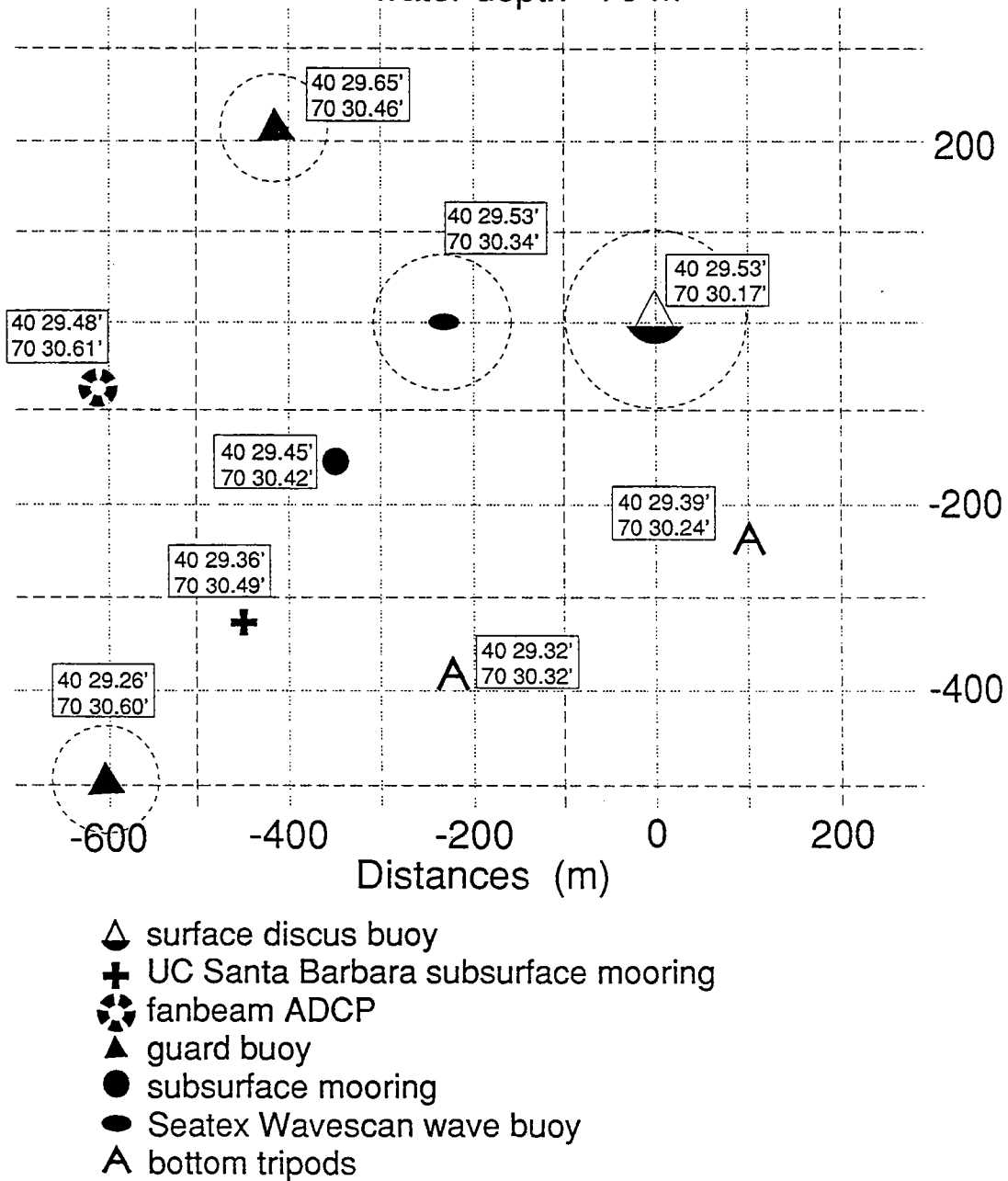
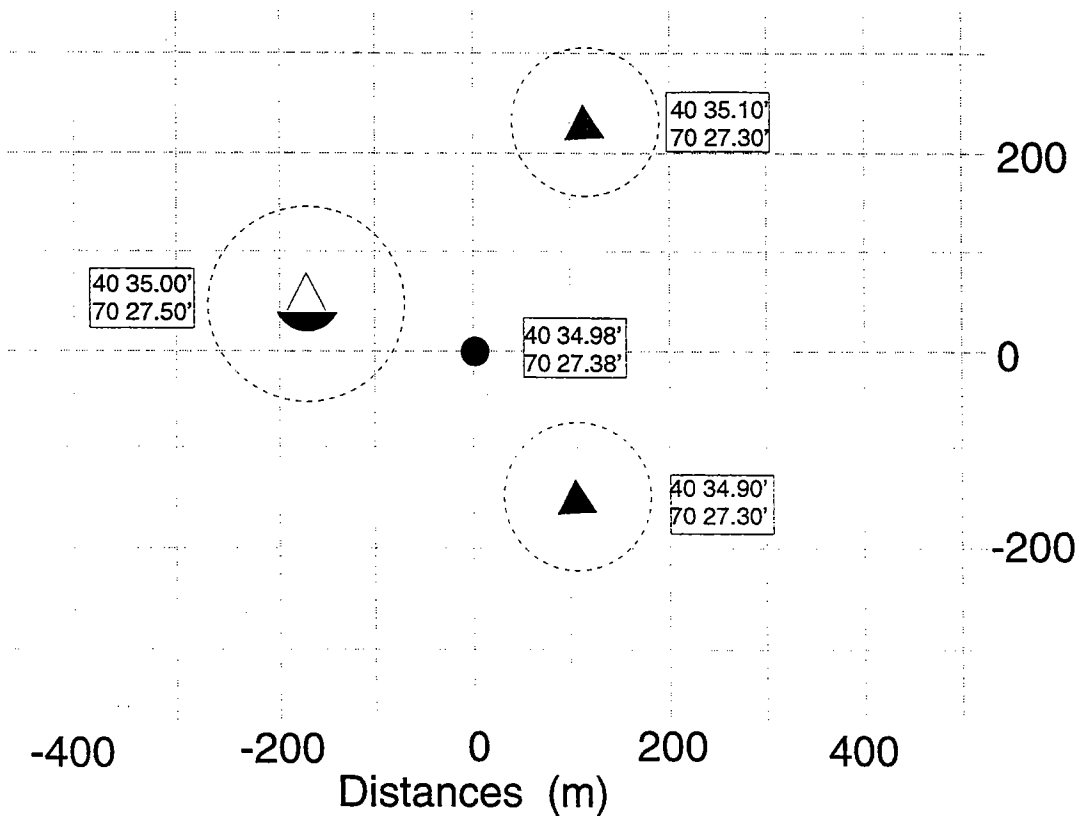


Figure 2.2. Central Site Plan through July 1997

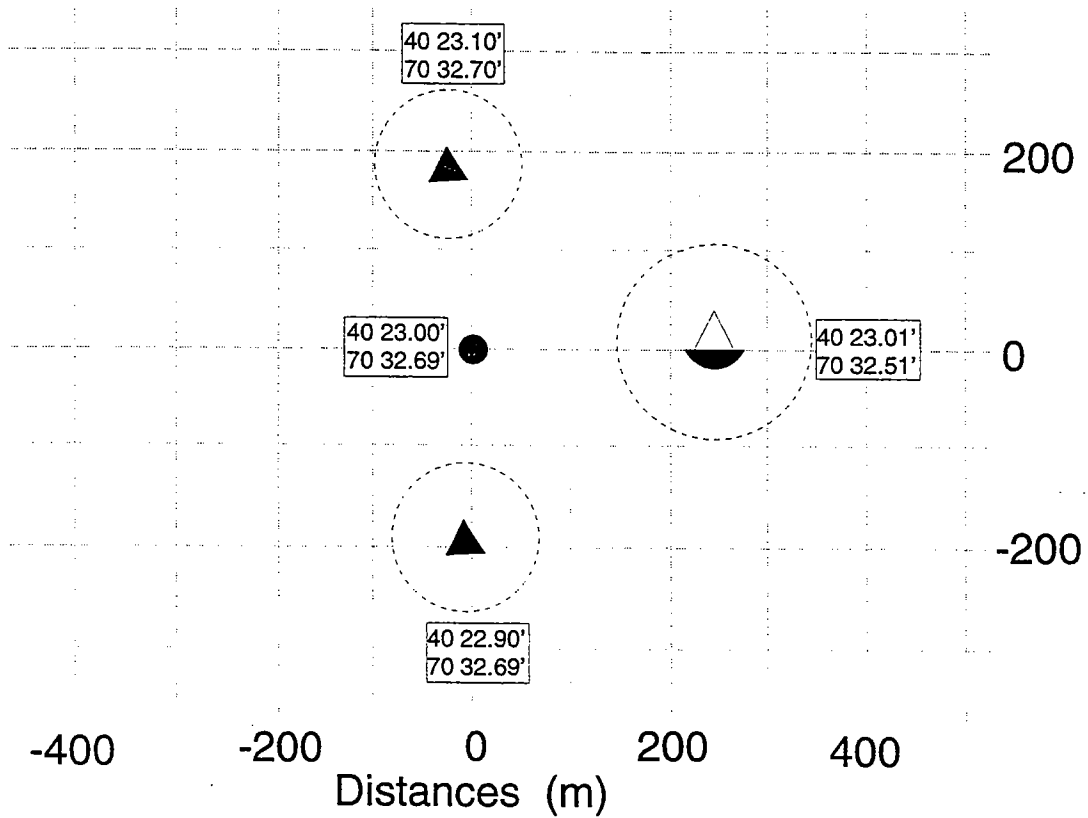
CMO inshore mooring site
water depth ~64 m



- △ surface toroid buoy
- ▲ guard buoy
- subsurface mooring

Figure 2.3. Inshore Site Plan

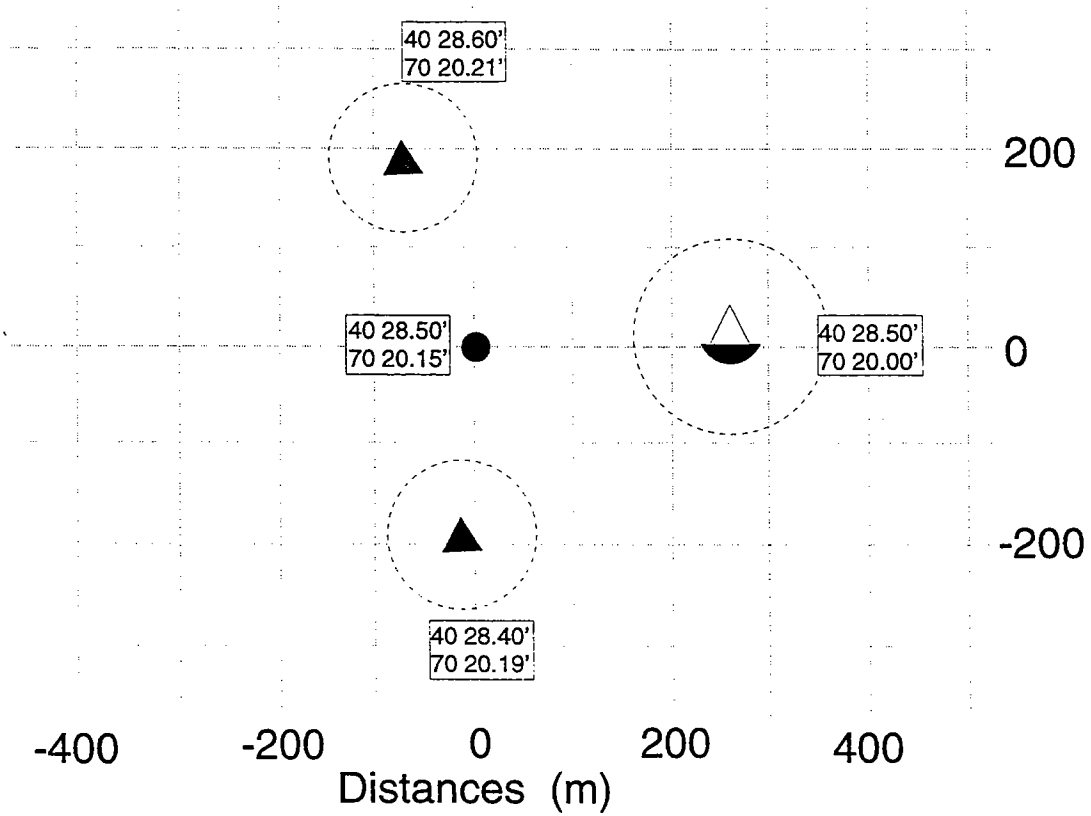
CMO offshore mooring site
water depth ~86 m



- △ surface toroid buoy
- ▲ guard buoy
- subsurface mooring

Figure 2.4. Offshore Site Plan

CMO alongshore mooring site
water depth ~70 m



- △ surface toroid buoy
- ▲ guard buoy
- subsurface mooring

Figure 2.5. Alongshore Site Plan

Central

Number	Buoy	Set	Recover	Depth	Lat	Long
1000	Discus	96-07-30 15:14	97-06-13 13:59	65.0	40 29.5	70 30.2
1001	Subsurface	96-07-30 18:32	97-06-12 19:17	70.0	40 29.5	70 30.4
1002	Seatex	96-07-30 21:28	96-09-04 21:00	Offstation 96-09-01 18:30		
1002	deployment 2	96-09-26 23:39	97-02-06 17:00	Offstation 97-01-24 21:35		
1002	deployment 3	97-04-17 04:31	97-06-12 21:26	71.0	40 29.6	70 30.3
1003	Toroid	96-07-31 00:16	96-08-03 12:18	70.0	40 29.4	70 30.2
1012	FanBeam	96-09-27 16:46	97-04-09 14:31	70.0	40 29.5	70 30.6
1012	deployment 2	97-04-17 12:52	97-06-12 18:24	70.0	40 29.5	70 30.6

Offshore

Number	Buoy	Set	Recover	Depth	Lat	Long
1004	Toroid	96-07-31 13:50	97-06-16 17:25	87.0	40 23.0	70 32.5
1005	Subsurface	96-07-31 18:38	97-06-16 12:15	86.0	40 23.0	70 32.7

Inshore

Number	Buoy	Set	Recover	Depth	Lat	Long
1006	Toroid	96-08-02 14:04	96-09-25 20:25	offstation 96-09-18 18:50		
1010	deployment 2	96-09-26 15:15	97-06-12 14:50	64.0	40 35.0	70 27.5
1007	Subsurface	96-08-02 18:25	97-06-12 10:32	63.0	40 35.0	70 27.4

Alongshore

Number	Buoy	Set	Recover	Depth	Lat	Long
1008	Toroid	96-08-03 15:51	96-10-16 09:15	offstation 96-10-09 06:00		
1008	deployment 2	96-11-02 20:37	97-06-10 15:24	70.0	40 28.5	70 20.0
1009	Subsurface	96-08-03 19:39	97-06-10 10:42	69.5	40 28.5	70 20.2

Table 2.1. Mooring Deployments and Recoveries

Central Discus			
depth (m)	type	sn	sample rate
-3.4	longwave radiation	28872 -704	15m
-3.4	longwave radiation	28380 -720	15m
-3.4	shortwave radiation	25418 -704	15m
-3.4	shortwave radiation	28315 -720	15m
-3.3	wind speed	704	15m
-3.3	wind speed	720	15m
-3.3	sonic anemometer	80	15m every 30m
-3.1	precipitation	001	3.75m
-3.1	precipitation	002	3.75m
-3.0	wind direction	704	15m
-3.0	wind direction	704	15m
-2.9	relative humidity	004	3.75m
-2.9	relative humidity	005	3.75m
-2.7	barometric pressure	46398 -704	15m
-2.7	barometric pressure	50252 -720	15m
-2.7	relative humidity	037-704	15m
-2.7	relative humidity	034 -720	15m
-2.6	air temperature	5811-704	15m
-2.6	air temperature	5812 -720	15m
1.0	sea surface temperature	5101 -720	15m
1.5	sea surface temperature	5115 -704	15m
2.0	seacat	927	7.5m
3.0	tension	43390	25m every 12h
4.0	mtr	3250	30m
4.5	vmcm	54	7.5m
7.5	seacat	1875	7.5m
10.0	vmcm	001	7.5m
12.5	seacat	1877	7.5m
15.0	vmcm	003	7.5m
20.0	vmcm	041	7.5m
25.0	seacat	1879	7.5m
30.0	vmcm	51	7.5m
35.0	seacat-p	885	15m

Table 2.2. Instrumentation Summary, Central Discus; instrument depths, serial numbers and timing.

Central Subsurface			
depth (m)	type	sn	sample rate
40.0	vmcm	27	7.5m
45.0	seacat	1882	45s *
50.0	vmcm	42	7.5m
55.0	vmcm	43	7.5m
57.5	seacat	73	7.5m
60.0	vmcm	50	7.5m
62.5	seacat	72	7.5m
65.0	vmcm	35	7.5m
67.5	seacat	1878	7.5m

*Seacat 1882 recorded at 45 seconds until 961030, then recorded at 7.5minutes until memory was filled.

Central Toroid (Temporary)			
depth (m)	type	sn	sample rate
tower	WeatherPak	648	5m every 15m
-3.1	wind	648	5m every 15m
-2.8	relativehumidity	648	5m every 15m
-2.8	air temperature	648	5m every 15m
-2.8	barometric pressure	648	5m every 15m
1.0	tpod	3274	30m
2.0	seacat	142	7.5m
7.0	chlam	126	

Table 2.3. Instrumentation Summary, Central Subsurface and Central Toroid; instrument depths, serial numbers and timing.

Inshore Toroid			
depth (m)	type	sn	sample rate
tower	WeatherPak	714	5m every 15m
-3.3	wind	714	5m every 15m
-3.0	relativehumidity	714	5m every 15m
-3.0	air temperature	714	5m every 15m
-3.0	barometric pressure	714	5m every 15m
1.0	tpod	3830	30m
2.0	seacat	146	7.5m
4.5	vmcm	10	7.5m
10.0	tpod	4493	30m
15.0	vmcm	45	7.5m
20.0	seacat	71	7.5m
25.0	tpod	3301	30m
30.0	vmcm	22	7.5m

Inshore Subsurface			
depth (m)	type	sn	sample rate
42.0	vmcm	28	7.5m
47.5	tpod	3271	30m
52.5	seacat	1874	45s*
55.5	adcp	100	3m
57.0	vmcm	30	7.5m
59.5	seacat	1880	7.5m
62.0	tidegauge	46	5m

*Seacat 1874 recorded at 45 seconds until 961030, then recorded at 7.5minutes until memory was filled.

Table 2.4. Instrumentation Summary, Inshore Moorings; instrument depths serial numbers and timing.

Offshore Toroid			
depth (m)	type	sn	sample rate
tower	WeatherPak	713	5m every 15m
-3.1	wind	713	5m every 15m
-2.8	relativehumidity	713	5m every 15m
-2.8	air temperature	713	5m every 15m
-2.8	barometric pressure	713	5m every 15m
1.0	tpod	3291	30m
2.0	seacat	141	7.5m
4.5	vmcm	34	7.5m
10.0	tpod	3763	30m
15.0	vmcm	23	7.5m
20.0	seacat	1873	7.5m
25.0	tpod	3308	30m
30.0	vmcm	17	7.5m
35.0	seacat-p	884	15m

Offshore Subsurface			
depth (m)	type	sn	sample rate
50.5	seacat	1881	45s*
64.0	vmcm	40	7.5m
69.5	tpod	4428	30m
74.5	seacat	70	7.5m
77.0	adcp	593	3m
79.0	vmcm	002	7.5m
81.5	seacat	1876	7.5m
84.0	tidegauge	45	5m

*Seacat 1881 recorded at 45 seconds until 961030, then recorded at 7.5minutes until memory was filled.

Table 2.5. Instrumentation Summary, Offshore Moorings; instrument depths, serial numbers and timing.

AlongshoreToroid			
depth (m)	type	sn	sample rate
tower	WeatherPak	648	5m every 15m
-3.1	wind	648	5m every 15m
-2.8	relativehumidity	648	5m every 15m
-2.8	air temperature	648	5m every 15m
-2.8	barometric pressure	648	5m every 15m
1.0	tpod	3274	30m
2.0	seacat	142	7.5m
4.5	vmcm	53	7.5m
10.0	tpod	3837	30m
15.0	vmcm	55	7.5m
20.0	seacat	68	7.5m
25.0	tpod	3299	30m
30.0	vmcm	24	7.5m

AlongshoreSubsurface			
depth (m)	type	sn	sample rate
40.5	seacat	883	15min
50.0	vmcm	12	7.5m
55.5	tpod	3833	30m
60.5	seacat	882	15min
65.0	vmcm	44	7.5m
67.5	seacat	144	7.5m
70.0	tidegauge	49	5m

Table 2.6. Instrumentation Summary, Alongshore Moorings; instrument depths, serial numbers and timing.

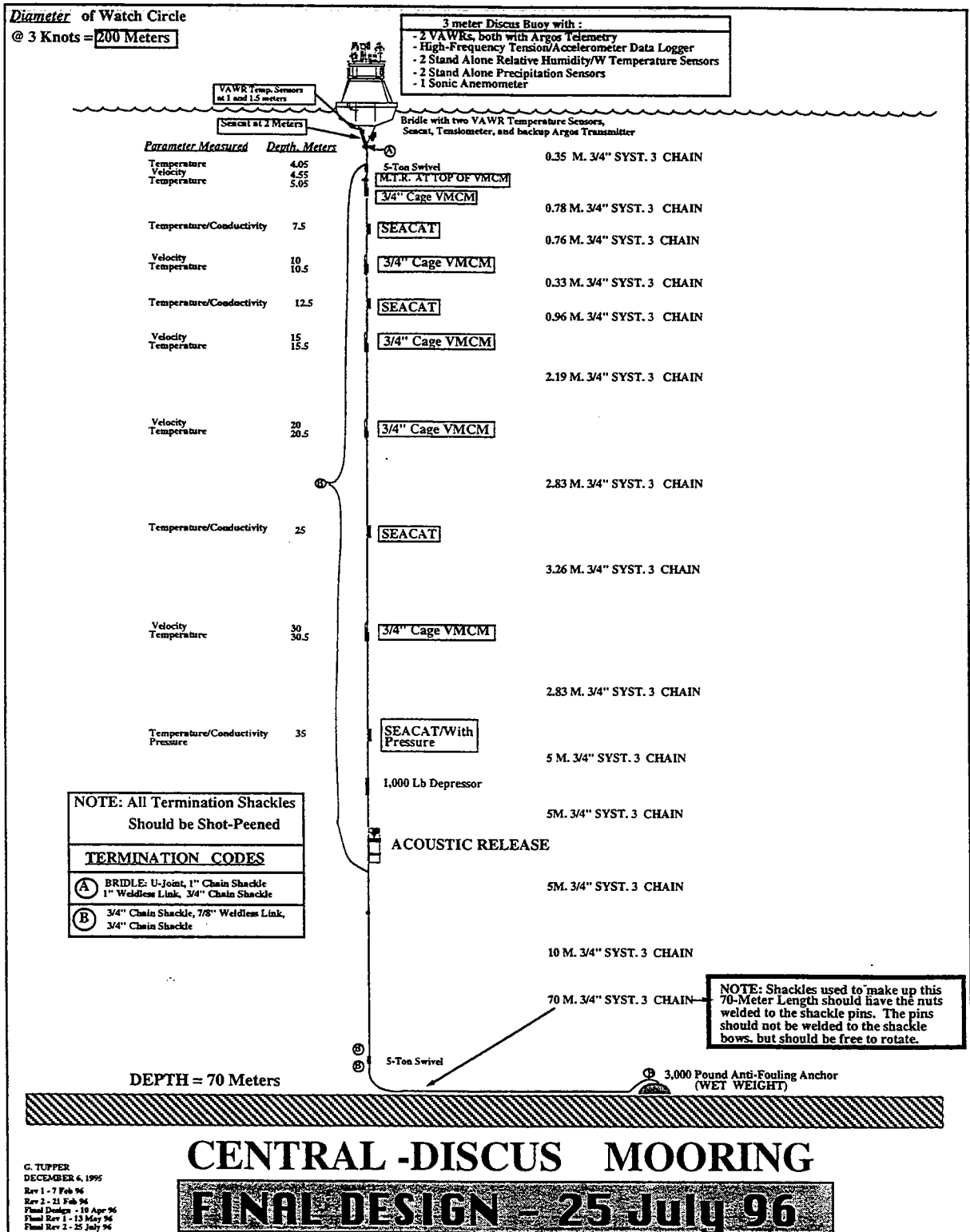


Figure 2.6. Mooring Diagram, Central Discus

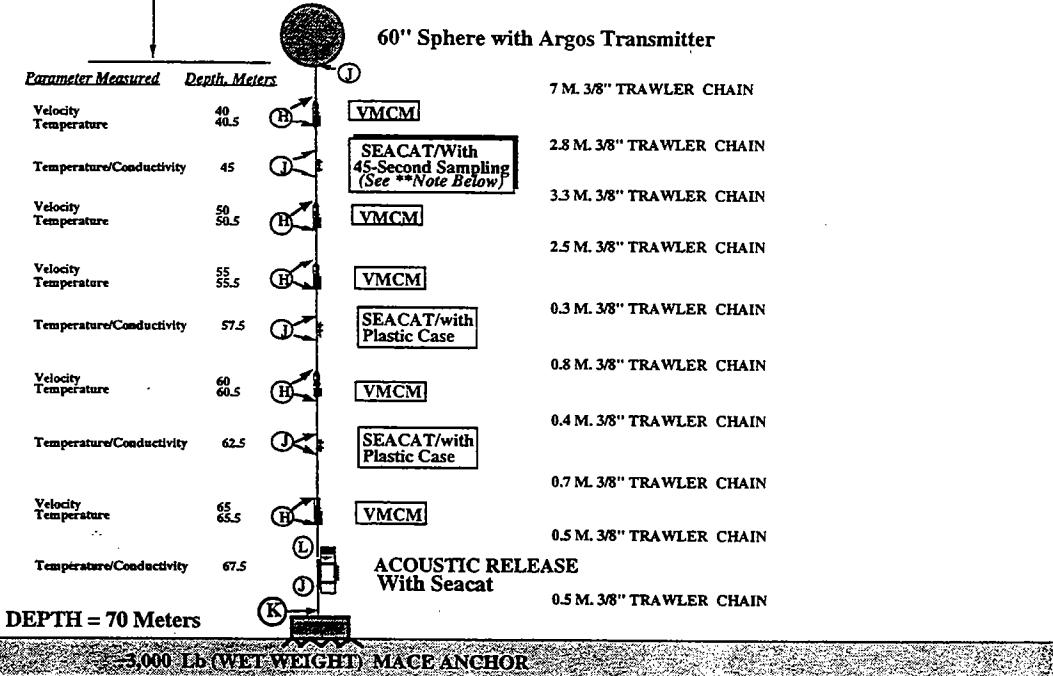
Diameter of Watch Circle

@ 3 Knots = 26 Meters



32 Meters

TERMINATION CODES	
(H)	3/4" Anchor Shackle, 5/8" Pear Ring, 1/2" Anchor Shackle
(J)	5/8" Anchor Shackle, 5/8" Pear Ring, 1/2" Anchor Shackle
(K)	1" Anchor Shackle, 5/8" Pear Ring, 1/2" Anchor Shackle
(L)	1/2" Anchor Shackle, 5/8" Pear Ring, 1/2" Anchor Shackle



** This instrument records one sample every 45 seconds until October 30, 1996, when it changes modes and records one sample every 7.5 minutes.

CENTRAL -SUBSURFACE MOORING

FINAL DESIGN - 25 July 96

G. TUPPER
 DECEMBER 6, 1995
 Rev 1-7 Feb 96
 Rev 2 - 21 Feb 96
 Final Design - 8 Apr 96
 Final Rev 1 - 13 May 96
 Final Rev 2 - 25 July 96

Figure 2.7. Mooring Diagram, Central Subsurface

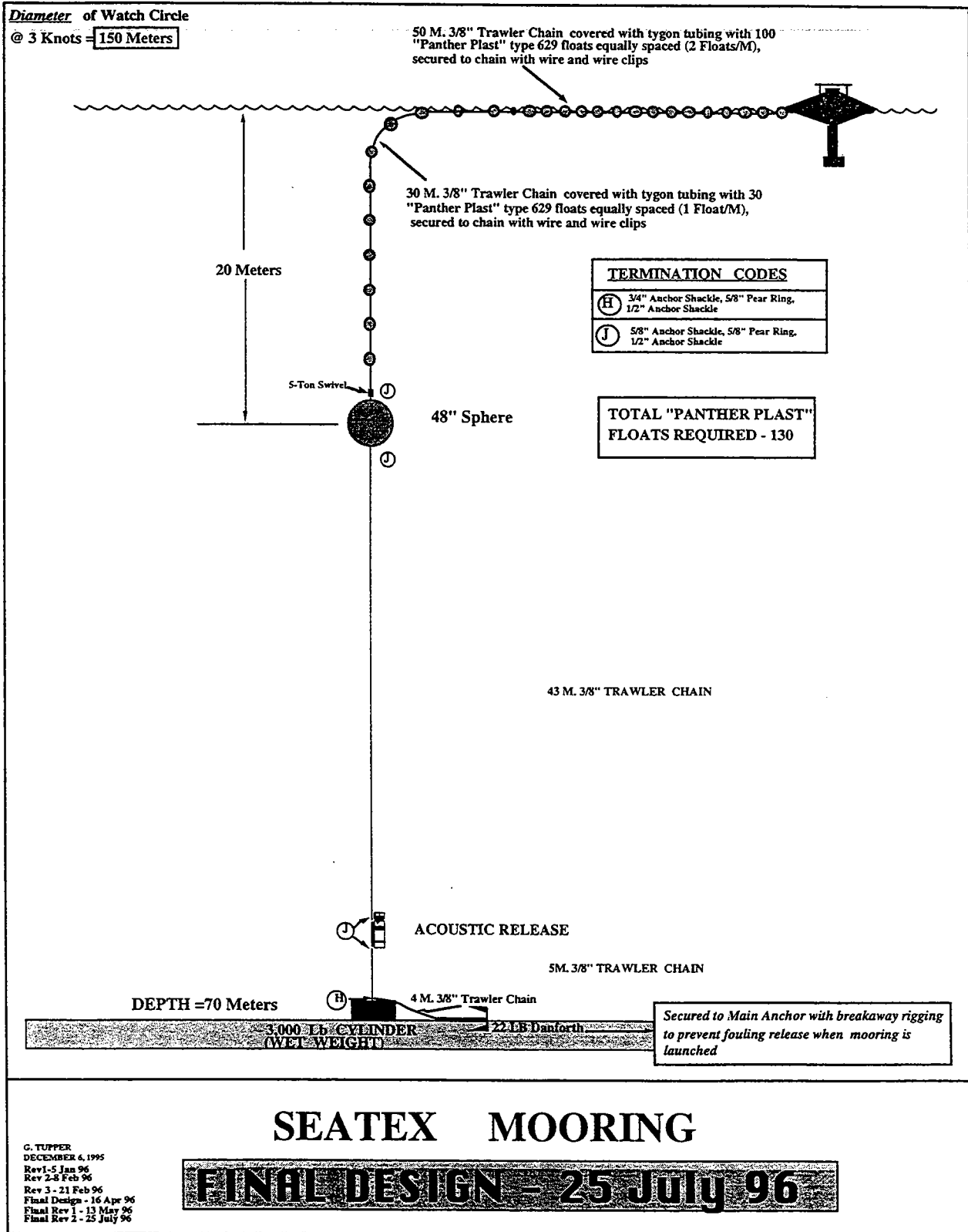
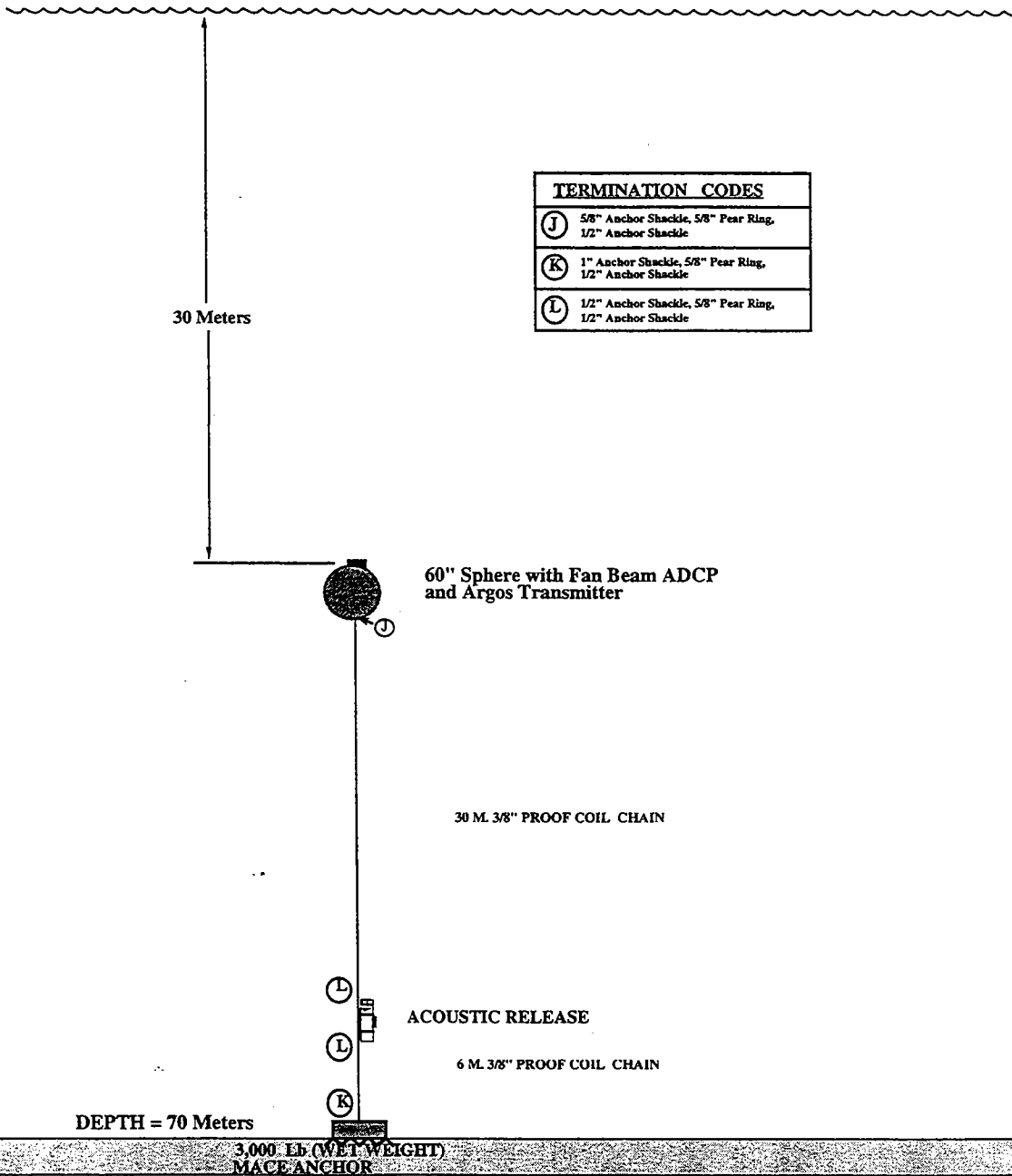


Figure 2.8. Mooring Diagram, Seatex Wavescan

Diameter of Watch Circle
 @ 3 Knots = 16 Meters



CENTRAL -Fan Beam Mooring

C. TUPPER
 13 Aug 96
 Rev 1 - 16 Sep 96

Figure 2.9. Mooring Diagram, Central Fan Beam

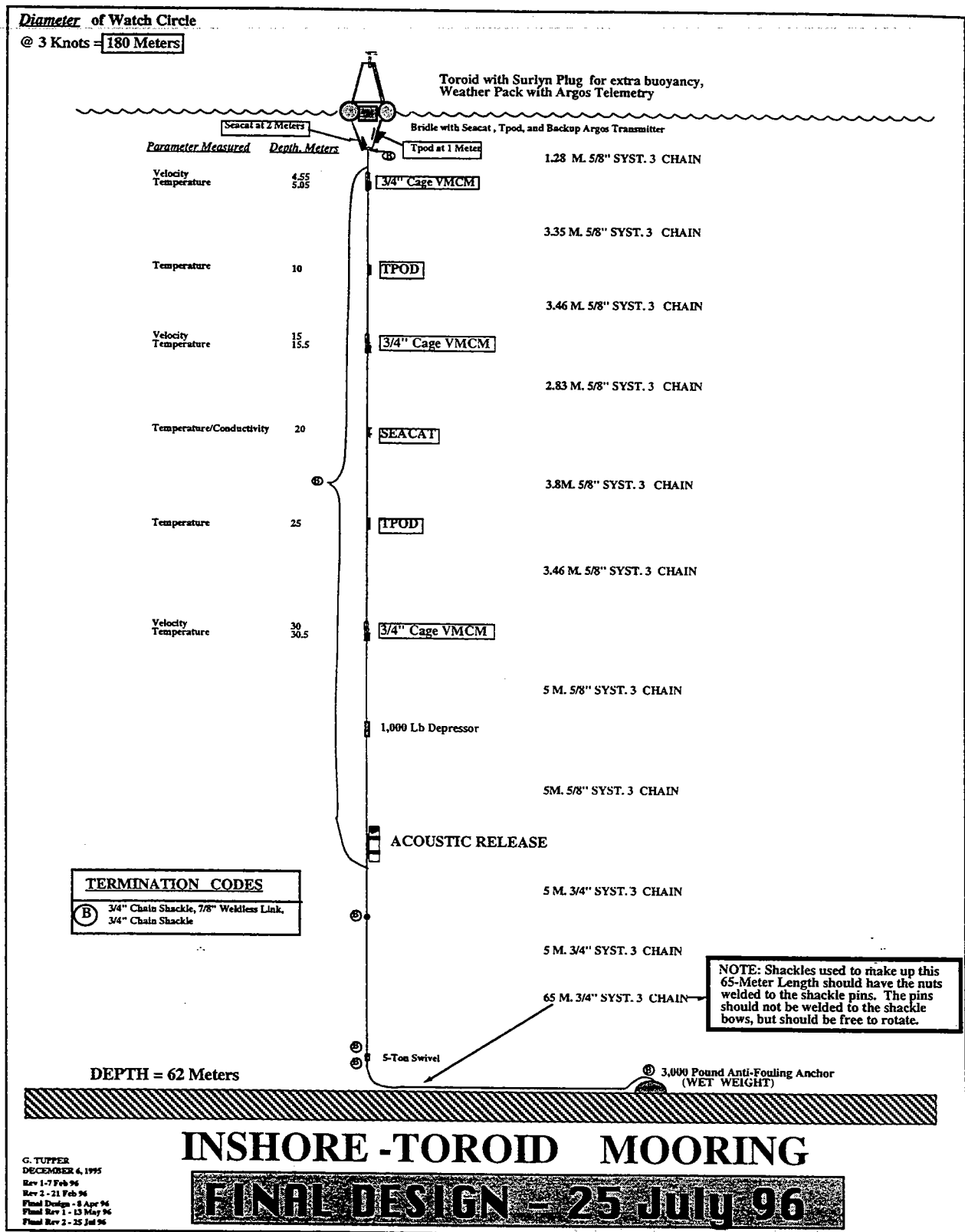
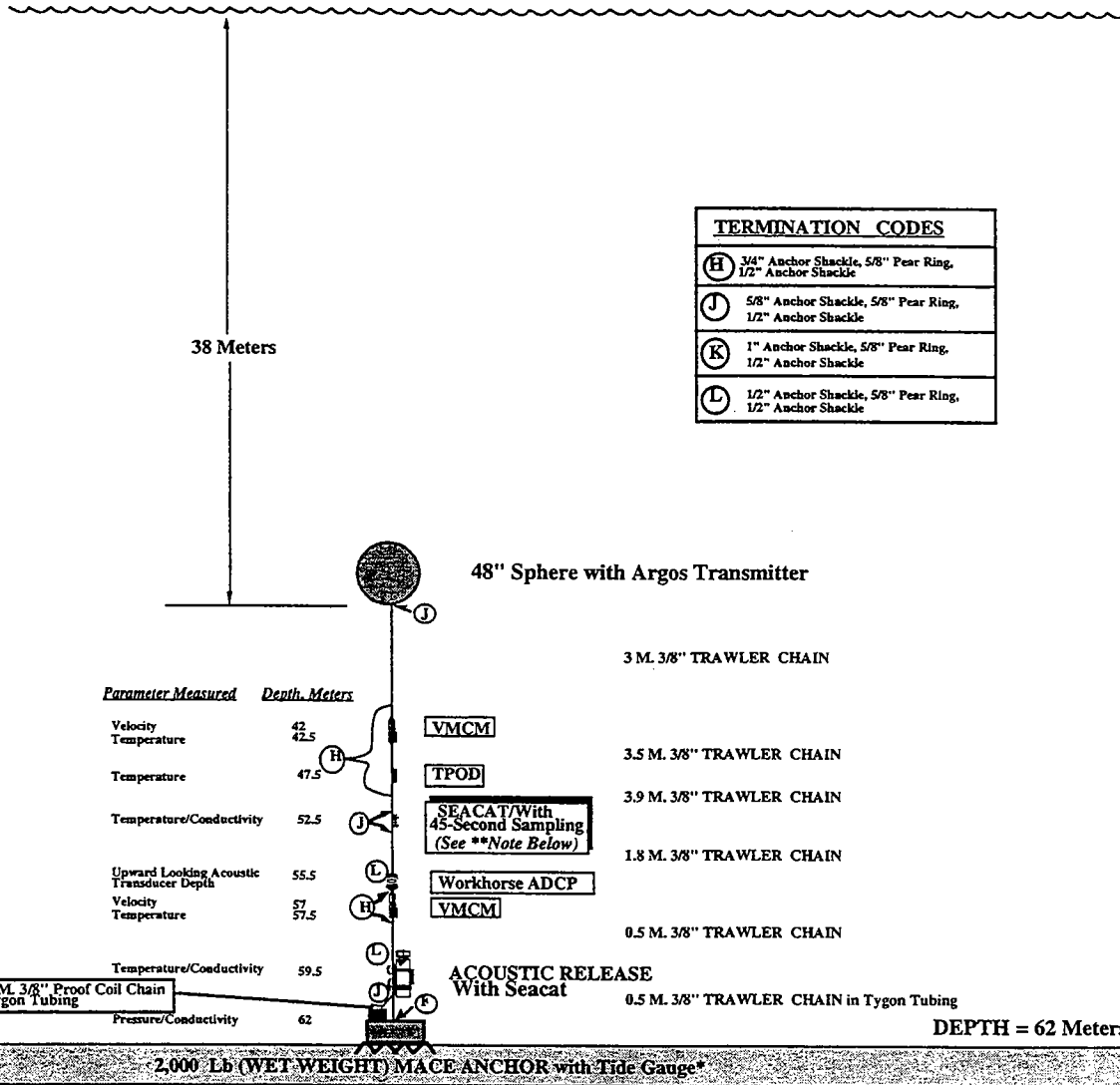


Figure 2.10. Mooring Diagram, Inshore Toroid

Diameter of Watch Circle
 @ 3 Knots = 12 Meters



2,000 Lb (WET WEIGHT) MACE ANCHOR with Tide Gauge*

* Tide Gauge secured to anchor with breakable straps. Chain connects tide gauge to top of release. When release fires and mooring ascends, tide gauge breaks free from anchor.

** This instrument records one sample every 45 seconds until October 30, 1996, when it changes modes and records one sample every 7.5 minutes.

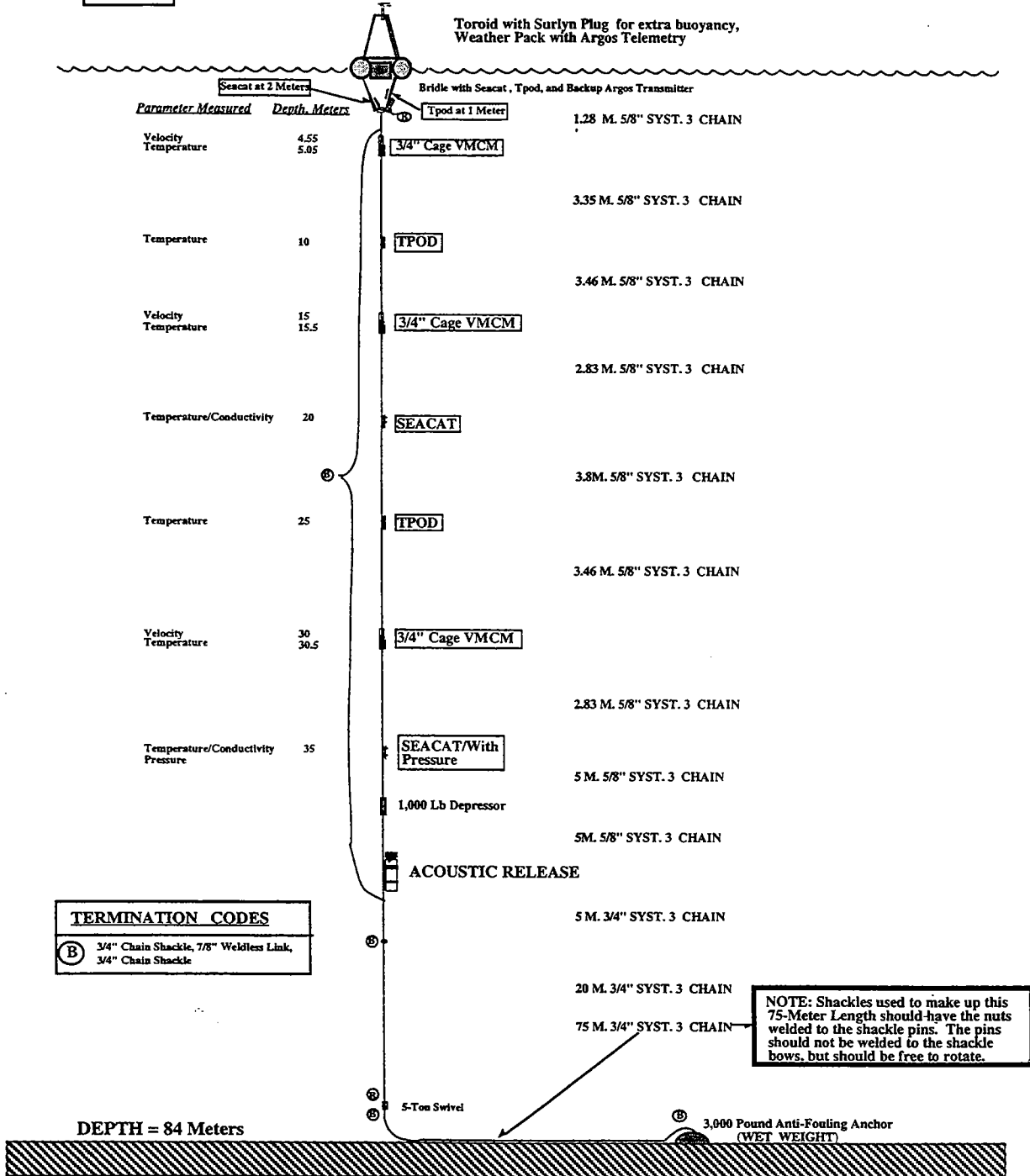
INSHORE -SUBSURFACE MOORING

G. TUPPER
 DECEMBER 6, 1995
 Rev 1-1 Feb 96
 Rev 2 - 21 Feb 96
 Final Design - 12 Apr 96
 Final Rev 1 - 13 May 96
 Final Rev 2 - 25 July 96

FINAL DESIGN - 25 July 96

Figure 2.11. Mooring Diagram, Inshore Subsurface

Diameter of Watch Circle
 @ 3 Knots = 216 Meters



OFFSHORE -TOROID MOORING

FINAL DESIGN - 25 July 96

G. TUPPER
 DECEMBER 4, 1995
 Rev 1 - 1 Feb 96
 Rev 2 - 21 Feb 96
 Final Design - 10 Apr 96
 Final Rev 1 - 13 May 96
 Final Rev 2 - 25 July 96

Figure 2.12. Mooring Diagram, Offshore Toroid

