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A Mediterranean Undercurrent Seeding Experiment (AMUSE): Part I: Program Description and Hydrographic Measurements

by

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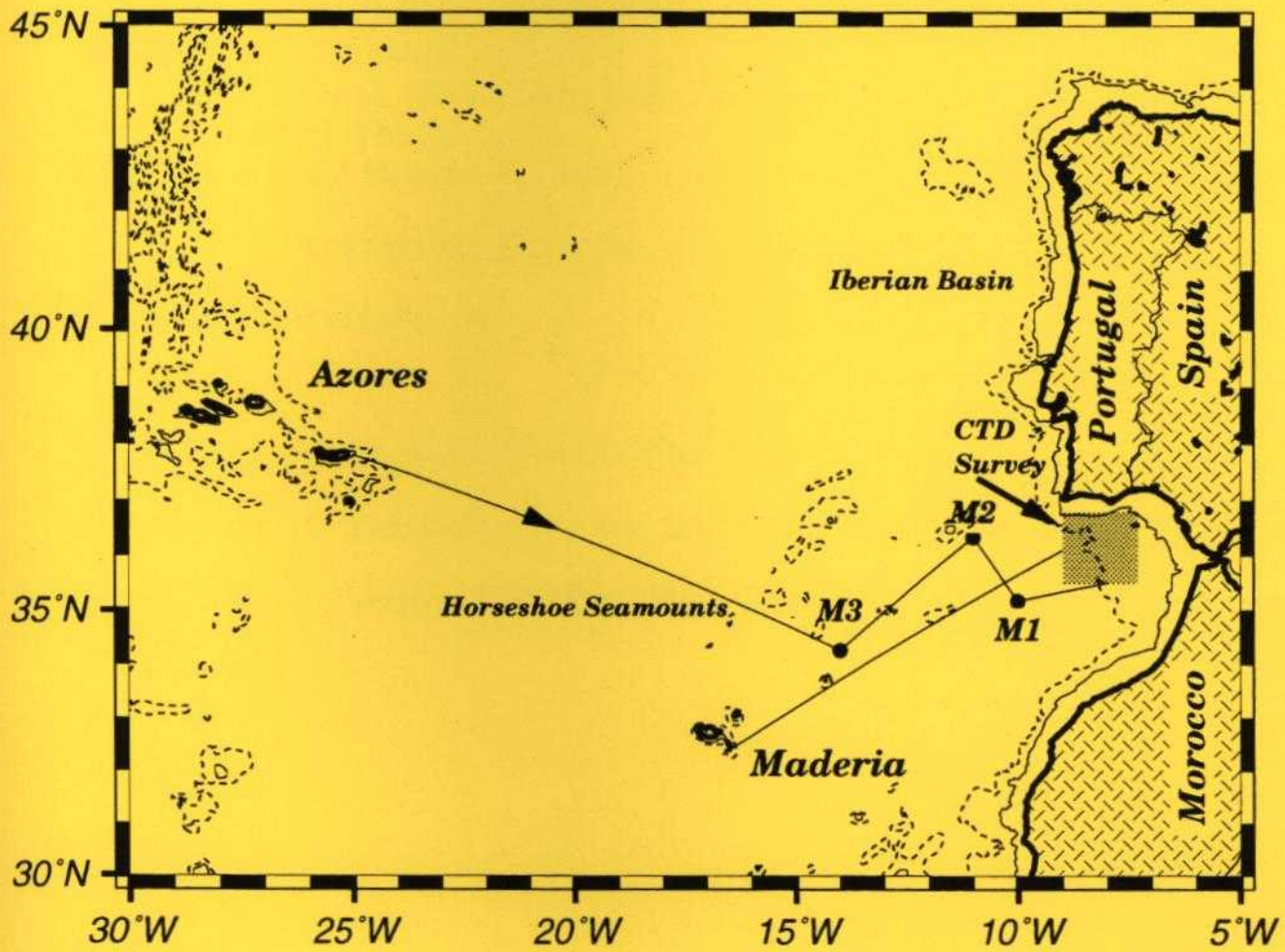

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Table of Contents

List of Figures

List of Tables

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Abstract

A Mediterranean Undercurrent Seeding Experiment (AMUSE) was undertaken to study the dispersion of Mediterranean Water into the North Atlantic via Mediterranean Water eddies (meddies) and other processes. The major field effort in AMUSE was the sequential deployment of acoustically-tracked, subsurface RAFOS floats in the Mediterranean Undercurrent south of Portugal between May 1993 and March 1994. The float deployments were accompanied by XBT sections across the Undercurrent. Before the float deployments, a detailed Conductivity-Temperature-Depth (CTD) survey of the Undercurrent was carried out to determine the best launch site for the RAFOS floats. Three acoustic sound source moorings (for tracking the floats) and two test floats were also deployed during the CTD cruise. This report represents Part 1: A basic description of the AMUSE program and the presentation of the 113 CTD stations from the hydrographic survey. Part 2 contains a summary and graphical presentation of the RAFOS float data collected during AMUSE.

Section 1: Introduction

A. Description of Scientific Program

"A Mediterranean Undercurrent Seeding Experiment" (AMUSE) was conducted to study the dispersion of Mediterranean Water into the North Atlantic. The Mediterranean Outflow represents a significant source of heat and salt to the North Atlantic Ocean, but the pathways by which the Outflow water spreads into the North Atlantic are not well-known. After the Outflow water exits the Mediterranean through the Strait of Gibraltar, it generally follows the continental slope south of Spain and Portugal in a coherent subsurface jet known as the Mediterranean Undercurrent. Along this path, the Outflow water sinks and entrains a significant amount of Atlantic water.

The goal of AMUSE was to determine where and how the Outflow water in the Undercurrent leaves the continental slope and enters the deep eastern North Atlantic. A significant fraction of the Outflow water enters the North Atlantic in small, subsurface eddies called Meddies, and a specific focus of AMUSE was to determine where and how often Meddies form.

The major field effort in AMUSE consisted of a sequential deployment of acoustically-tracked, subsurface RAFOS floats (Rossby, et al., 1986) in the Mediterranean Undercurrent south of Portugal, accompanied by Expendable Bathythermograph (XBT) observations across the Undercurrent. Before the float deployment began in July, 1993, a detailed Conductivity-Temperature-Depth (CTD) survey of the Undercurrent was conducted to determine the best launch site for the RAFOS floats. Three acoustic sound sources and two RAFOS floats were also deployed during the CTD survey to test the acoustic tracking system. This report contains a summary of the observations made during this CTD survey which was carried out on R/V *OCEANUS* in April-May, 1993. The results from the sequential float deployments will be presented in a later report.

B. Cruise Narrative

The R/V *OCEANUS* left Ponta del Gada, Azores on schedule on 30 April 1993 with 8 scientific personnel on board. The first sound source mooring (M3) was deployed on 2 May, mooring M2 on 3 May and M1 on 4 May (see Figure 1 for cruise track). The ship then steamed to the Gulf of Cadiz south of Portugal and began a detailed CTD survey of the Mediterranean Undercurrent on 4 May. The survey covered the area 35° 30' N to 36° 45' N and 7° 30' W to 9° 00' W. A total of 113 CTD stations were made with cast depths ranging from 500 to 2000 meters. Casts extended to within about 10 meters of the bottom or to 2000 meters (see Table 1 and Figure 2).

On 6 May a personnel transfer took place outside Faro Harbor in Portugal. The two mooring technicians on board disembarked and one Portuguese scientist embarked. The transfer was accomplished with the help of the Portuguese Navy. It was expected that two Portuguese scientists would board at Faro, but due to a family emergency, the second scientist was unable to join the cruise. On 11 May the CTD survey was completed and two RAFOS floats were launched at CTD stations 110 and 111.

At several times during the cruise, sonobuoys were deployed to listen for the sound sources. This turned out to be a very successful operation. All three sources deployed during the cruise were heard, and an additional source, deployed by German scientists in the same vicinity, was also heard.

Much of the CTD survey took place in the shipping lanes between Cape St. Vincent and the Strait of Gibraltar. In addition, NATO military exercises were being conducted in this region. In spite of significant ship traffic, the CTD survey was a complete success, due largely to the skill and patience of the officers and crew of R/V *OCEANUS* . Their efforts in this regard are gratefully acknowledged.

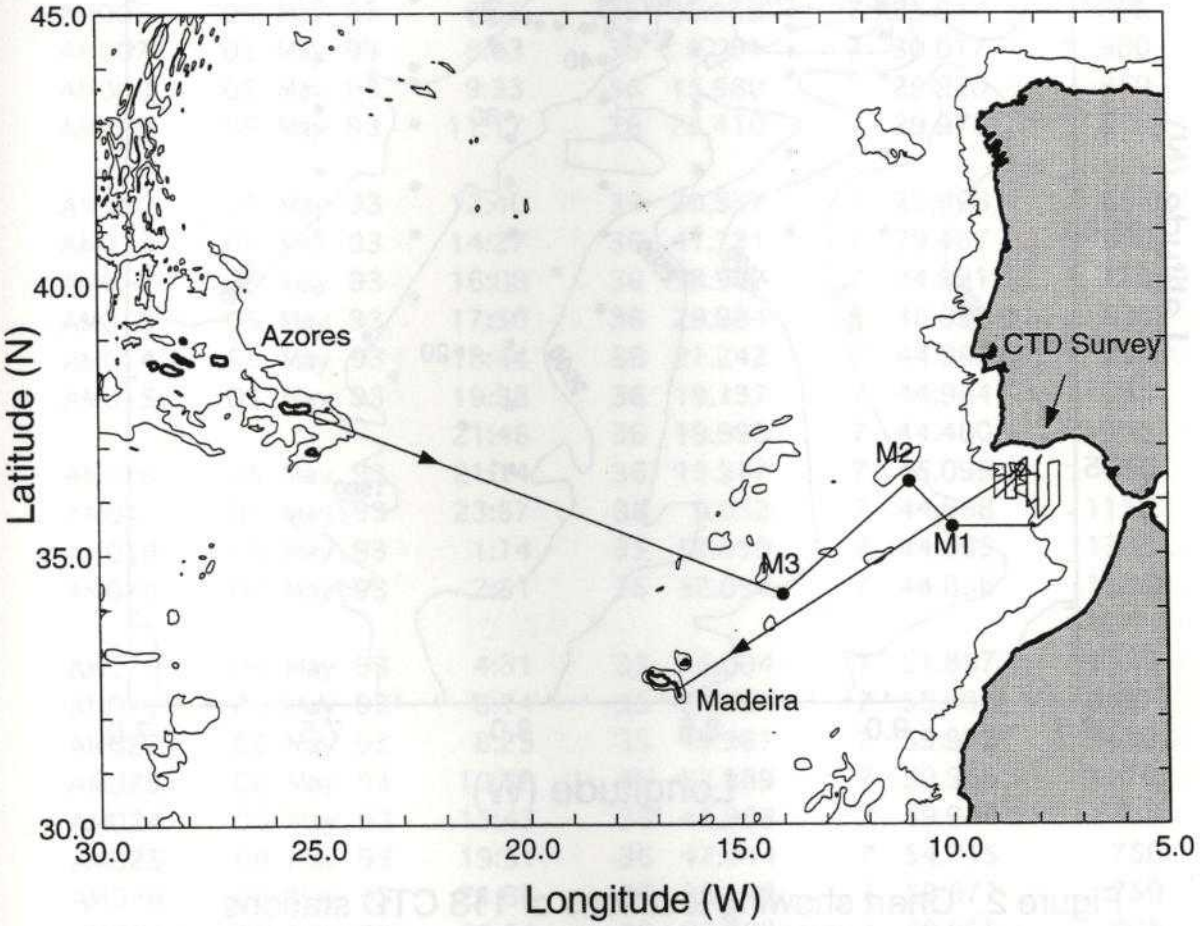

Figure 1. Chart showing cruise track for OC258 (30 April - 14 May 1993). Locations of three sound source moorings are shown by solid dots (M1, M2 and M3). Coastline (land masses are shaded) and 2000 meter isobath are also shown.

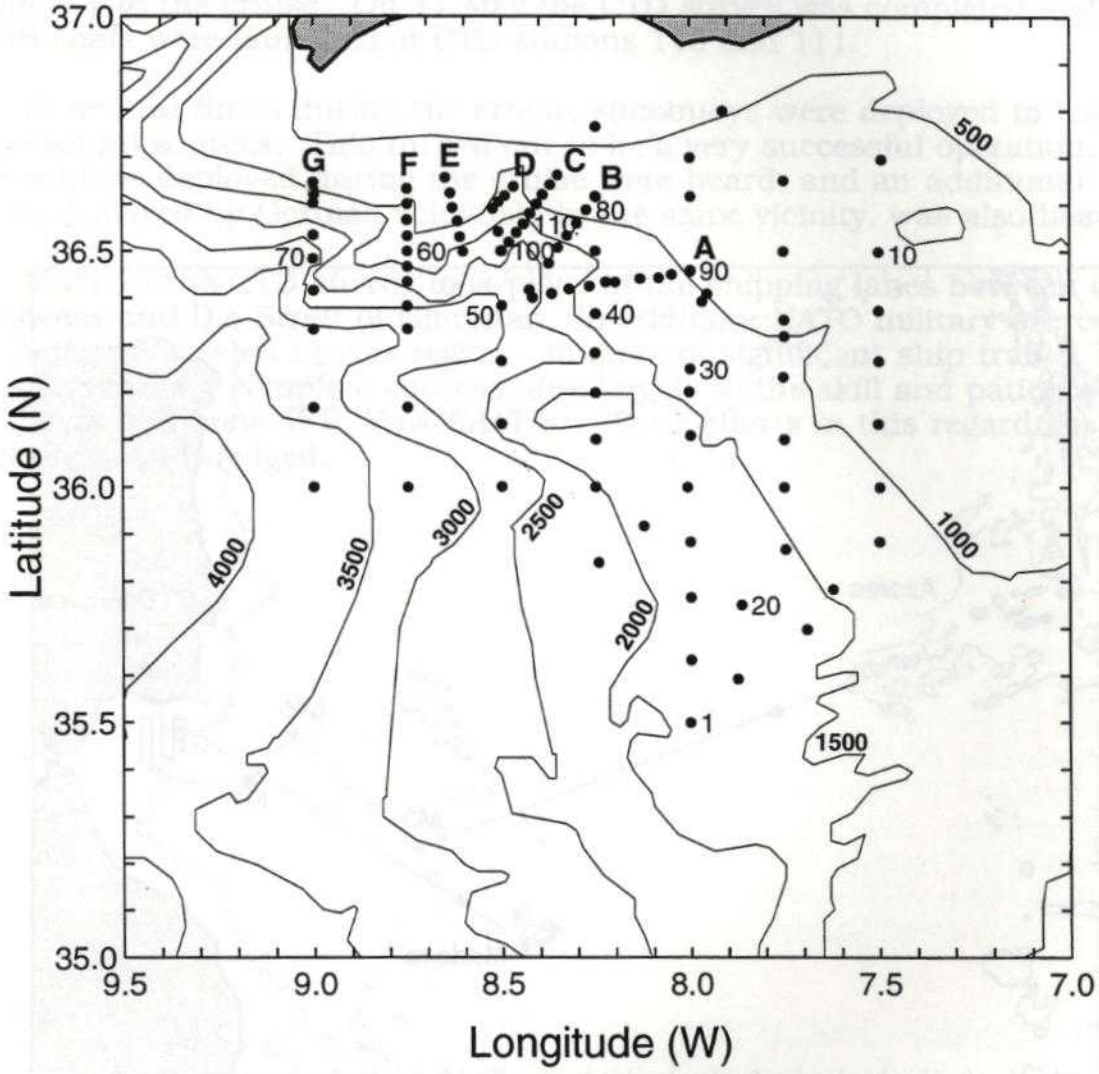

Figure 2. Chart showing locations of 113 CTD stations occupied during OC258 (solid dots), with every tenth station labeled. High-resolution sections are labeled A-G. Coastline (shaded area at top) and bathymetry at 500 meter intervals are also shown.

Table 1: AMUSE Cruise CTD Station Information

Station number	Date	Time UTC	Latitude N	Longitude W	Depth (m)
AM001	04 May 93	21:55	35 29.970	8 0.040	1660
AM002	04 May 93	23:46	35 35.560	7 52.500	1500
AM003	05 May 93	1:33	35 41.865	7 41.480	1470
AM004	05 May 93	3:00	35 46.960	7 37.360	1465
AM005	05 May 93	5:05	35 52.990	7 29.930	1290
AM006	05 May 93	6:31	35 59.949	7 29.847	1215
AM007	05 May 93	8:03	36 8.001	7 30.017	980
AM008	05 May 93	9:33	36 15.980	7 29.920	850
AM009	05 May 93	11:17	36 22.410	7 29.975	825
AM010	05 May 93	12:40	36 29.937	7 29.968	685
AM011	05 May 93	14:27	36 41.731	7 29.467	580
AM012	05 May 93	16:08	36 38.987	7 44.991	775
AM013	05 May 93	17:30	36 29.984	7 45.058	635
AM014	05 May 93	18:44	36 21.242	7 44.968	750
AM015	05 May 93	19:38	36 19.137	7 44.964	1095
		21:46	36 18.990	7 44.480	1080
AM016	05 May 93	21:14	36 13.977	7 45.099	960
AM017	05 May 93	23:57	36 6.032	7 44.968	1150
AM018	06 May 93	1:14	35 59.950	7 44.995	1305
AM019	06 May 93	2:51	35 52.034	7 44.856	1435
AM020	06 May 93	4:31	35 45.004	7 51.867	1650
AM021	06 May 93	6:14	35 37.964	7 59.932	1627
AM022	06 May 93	8:25	35 45.961	7 59.932	1650
AM023	06 May 93	10:32	35 52.989	7 59.969	1770
AM024	06 May 93	15:43	36 41.963	7 59.947	730
AM025	06 May 93	19:51	36 47.944	7 54.715	750
AM026	06 May 93	21:35	36 36.978	7 59.877	750
AM027	06 May 93	22:54	36 27.389	7 59.955	825
AM028	07 May 93	0:17	36 24.537	7 57.256	830
AM029	07 May 93	1:01	36 23.567	7 58.046	1050
		3:44	36 20.096	8 2.780	
AM030	07 May 93	4:22	36 15.014	7 59.967	1240
AM031	07 May 93	5:43	36 12.083	8 0.118	1500
AM032	07 May 93	7:10	36 6.514	7 59.913	1700
AM033	07 May 93	8:46	36 0.000	8 0.400	1500

Table 1 (cont'd): AMUSE Cruise CTD Station Information

Station number	Date	Time UTC	Latitude N	Longitude W	Depth (m)
AM034	07 May 93	10:25	35 55.000	8 7.500	1965
AM035	07 May 93	12:41	35 50.352	8 14.550	2150
AM036	07 May 93	14:24	36 0.020	8 15.033	2050
AM037	07 May 93	15:46	36 6.037	8 14.943	1970
AM038	07 May 93	17:12	36 11.953	8 15.019	1400
AM039	07 May 93	18:28	36 17.017	8 15.038	1710
AM040	07 May 93	19:46	36 22.011	8 14.989	1240
AM041	07 May 93	21:14	36 30.018	8 14.980	1325
AM042	07 May 93	22:35	36 36.997	8 14.968	810
AM043	08 May 93	0:07	36 45.896	8 14.963	650
AM044	08 May 93	1:48	36 38.205	8 28.033	900
			36 37.800	8 28.734	1030
AM045	08 May 93	3:16	36 37.026	8 29.409	1195
AM046	08 May 93	4:16	36 36.263	8 30.440	1695
AM047	08 May 93	6:32	36 35.426	8 31.337	2002
AM048	08 May 93	7:02	36 32.500	8 30.480	2190
AM049	08 May 93	8:16	36 29.993	8 29.936	2280
AM050	08 May 93	9:59	36 23.016	8 29.960	2410
AM051	08 May 93	11:39	36 15.975	8 30.009	1800
AM052	08 May 93	13:14	36 7.979	8 30.003	1785
AM053	08 May 93	14:48	36 0.021	8 29.990	2570
AM054	08 May 93	16:50	35 59.948	8 44.962	3250
AM055	08 May 93	18:39	36 10.060	8 44.990	2775
AM056	08 May 93	20:26	36 20.033	8 44.970	3000
AM057	08 May 93	21:51	36 26.048	8 45.017	2325
AM058	08 May 93	23:00	36 22.943	8 45.025	2825
AM059	09 May 93	0:21	36 27.972	8 44.961	1620
AM060	09 May 93	1:38	36 29.975	8 45.002	1350
AM061	09 May 93	2:43	36 31.935	8 44.967	1260
AM062	09 May 93	3:49	36 33.964	8 45.059	1035
AM063	09 May 93	4:48	36 36.014	8 45.023	965
AM064	09 May 93	5:48	36 37.942	8 45.061	840
AM065	09 May 93	7:47	36 37.960	9 0.051	1190
AM066	09 May 93	8:43	36 38.786	9 0.010	870
AM067	09 May 93	9:26	36 37.180	8 59.881	1405
AM068	09 May 93	10:27	36 36.142	8 59.993	1725

Table 1 (cont'd): AMUSE Cruise CTD Station Information

Station number	Date	Time UTC	Latitude N	Longitude W	Depth (m)
AM069	09 May 93	11:54	36 32.034	8 59.977	2130
AM070	09 May 93	13:04	36 28.994	9 0.010	1500
AM071	09 May 93	14:15	36 24.948	8 59.920	2250
AM072	09 May 93	15:32	36 20.002	8 59.988	3220
AM073	09 May 93	17:23	36 10.013	8 59.970	3400
AM074	09 May 93	19:03	35 59.994	8 59.968	3680
AM075	09 May 93	23:33	36 28.440	8 22.472	1570
AM076	10 May 93	0:48	36 24.988	8 25.540	1800
AM077	10 May 93	2:18	36 30.490	8 20.937	1725
AM078	10 May 93	3:20	36 31.977	8 19.499	1500
AM079	10 May 93	4:21	36 33.546	8 17.943	1200
AM080	10 May 93	5:18	36 35.284	8 16.424	500
AM081	10 May 93	6:14	36 36.894	8 14.897	855
AM082	10 May 93	8:05	36 24.034	8 25.050	1800
AM083	10 May 93	9:13	36 24.551	8 21.997	1260
AM084	10 May 93	10:12	36 25.130	8 19.194	1150
AM085	10 May 93	11:06	36 25.492	8 15.930	1120
AM086	10 May 93	12:12	36 26.036	8 11.885	1090
AM087	10 May 93	13:03	36 26.050	8 13.380	1130
AM088	10 May 93	14:27	36 26.579	8 5.012	1210
AM089	10 May 93	15:26	36 27.020	8 2.913	1100
AM090	10 May 93	16:16	36 27.536	7 59.897	810
AM091	10 May 93	17:25	36 26.472	8 7.976	1165
AM092	10 May 93	19:43	36 39.681	8 21.032	730
AM093	10 May 93	20:56	36 38.457	8 22.226	830
AM094	10 May 93	21:37	36 37.184	8 23.505	1000
AM095	10 May 93	22:56	36 35.951	8 24.499	1230
AM096	11 May 93	0:08	36 34.789	8 25.467	1230
AM097	11 May 93	1:04	36 33.455	8 26.515	1630
AM098	11 May 93	2:10	36 32.391	8 27.600	1820
AM099	11 May 93	3:23	36 31.169	8 28.789	2045
AM100	11 May 93	4:34	36 30.042	8 29.947	2290
AM101	11 May 93	6:15	36 29.922	8 36.167	2420
AM102	11 May 93	7:22	36 31.798	8 36.665	1860
AM103	11 May 93	8:29	36 33.803	8 37.031	1570

Table 1 (cont'd): AMUSE Cruise CTD Station Information

Station number	Date	Time UTC	Latitude N	Longitude W	Depth (m)
AM104	11 May 93	9:46	36 35.543	8 37.836	1130
AM105	11 May 93	10:52	36 37.390	8 38.160	860
AM106	11 May 93	11:49	36 39.381	8 38.992	750
AM107	11 May 93	13:39	36 37.187	8 23.376	1040
AM108	11 May 93	14:48	36 36.020	8 24.360	1060
AM109	11 May 93	15:42	36 34.800	8 25.400	1208
AM110	11 May 93	16:37	36 33.473	8 26.447	1600
AM111	11 May 93	17:49	36 32.344	8 27.581	1800
AM112	11 May 93	19:16	36 31.117	8 28.741	2090
AM113	11 May 93	20:23	36 29.988	8 30.074	2250

Section 2: Methods

A. CTD Data Collection and Processing

The CTD used during this cruise was borrowed from the SeaSoar group at Woods Hole Oceanographic Institution (WHOI). It is a Sea-Bird Model 911 with redundant sensors for temperature and conductivity. An oxygen sensor was attached but samples were not taken for oxygen analysis and oxygen data were ignored. At each station, the CTD and rosette, with two Niskin bottles, were lowered to within 10 meters of the sea floor or 2000 meters, whichever was deeper. Water samples were generally taken for salinity calibration at the bottom or in isohaline layers. The data were logged at 24 Hz on a shipboard PC.

Basic processing was done on the ship using the Sea-Bird software package. Based on the good match between temperature sensors, and the small mean difference between sensor-derived and water sample salinity (~0.006 PSU), no calibration corrections were made to either temperature or salinity. Altogether, 113 CTD stations were occupied ranging in depth from 500 to 2000 meters. These included three short tow-yo stations (stations 15, 29 and 44).

Data processing continued back at WHOI, where Julie Pallant removed bad data points not identified during shipboard processing. The same parameters were used to reprocess the data, which were averaged in 2 decibar bins and stored in ASCII format.

As part of the CTD processing, tests were done to check alignment of temperature and conductivity records for the AMUSE CTD data set. Basically the correlation function was computed between temperature and conductivity using the MATLAB routine "xcov(t,c,'coeff')." When the whole record was used, the function was dominated by the low-frequency signal, and the function was not useful for determining lags on the order of one to three scans. The records were then broken up into 100-scan pieces, the correlation function was computed for each piece and the average of all pieces was estimated.

Results showed the highest correlation occurred at zero time lag for both the raw data and the data that had been aligned by one scan (conductivity moved ahead one scan). The shapes of the functions were different, and the correlation at zero lag was just slightly higher for the one-scan lagged data.

We concluded that either a no lag or one-scan lag was sufficient. Since the data had already been processed with the one-scan lag, no reprocessing was done.

The CTD data are presented in this report in plot form: vertical profiles of potential temperature, salinity and density (sigma -1) at each station are shown in Appendix A; T/S plots for each station are shown in Appendix B; and vertical sections of potential temperature, salinity and sigma-1 are shown in Appendix C.

B. RAFOS floats

Toward the end of the cruise, a tentative site was chosen for the sequential float deployments that would take place over the next six months, and two RAFOS floats (made by SeaScan, Inc.) were launched near that site to test the acoustic tracking system. Table 2 contains the launch and surface information for these two floats. One of them, AM113, sank below the target pressure (1100 dbars) and terminated its mission prematurely. No useful data was obtained from this float. Figures 3 and 4 show the trajectory and temperature and pressure records, respectively, for AM101. This float successfully completed a 30-day mission, collecting acoustic tracking, temperature and pressure data at 8-hour intervals.

Table 2: RAFOS float launch and surface information.

Float #	CTD Station	Launch Date (yymmdd)	Launch Site (N)	(W)	Surface Date	Surface Site (N)	(W)	Days
101	110	930511	36 33.36	8 26.28	930610	37 41.52	10 3.84	30
113	111	930511	36 32.16	8 27.48	930512	36 31.98	8 26.82	1

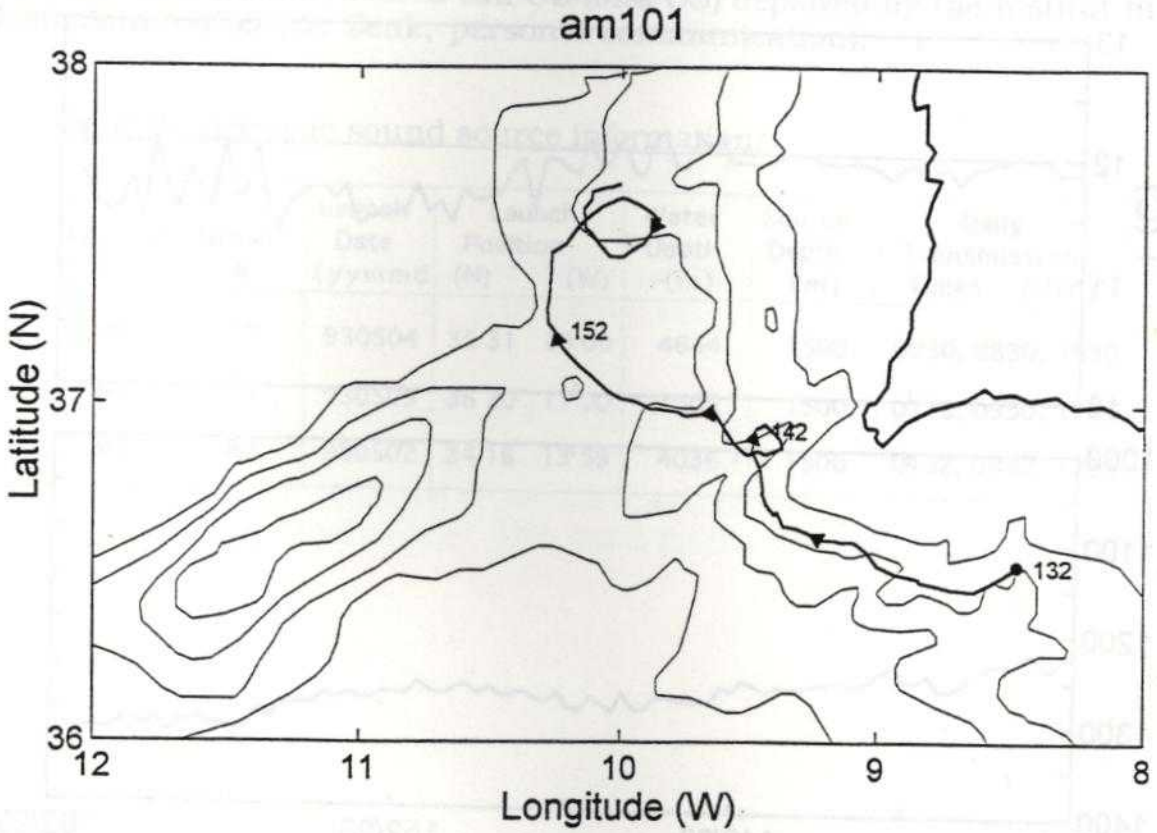

Figure 3. Track of RAFOS float AM101. The track connects position of the float at 8-hour intervals and positions are marked with an arrow every five days. Numbers along the track are dates in yeardays, 1993. The coast of Portugal is also shown with bathymetric contours every 1000 meters.

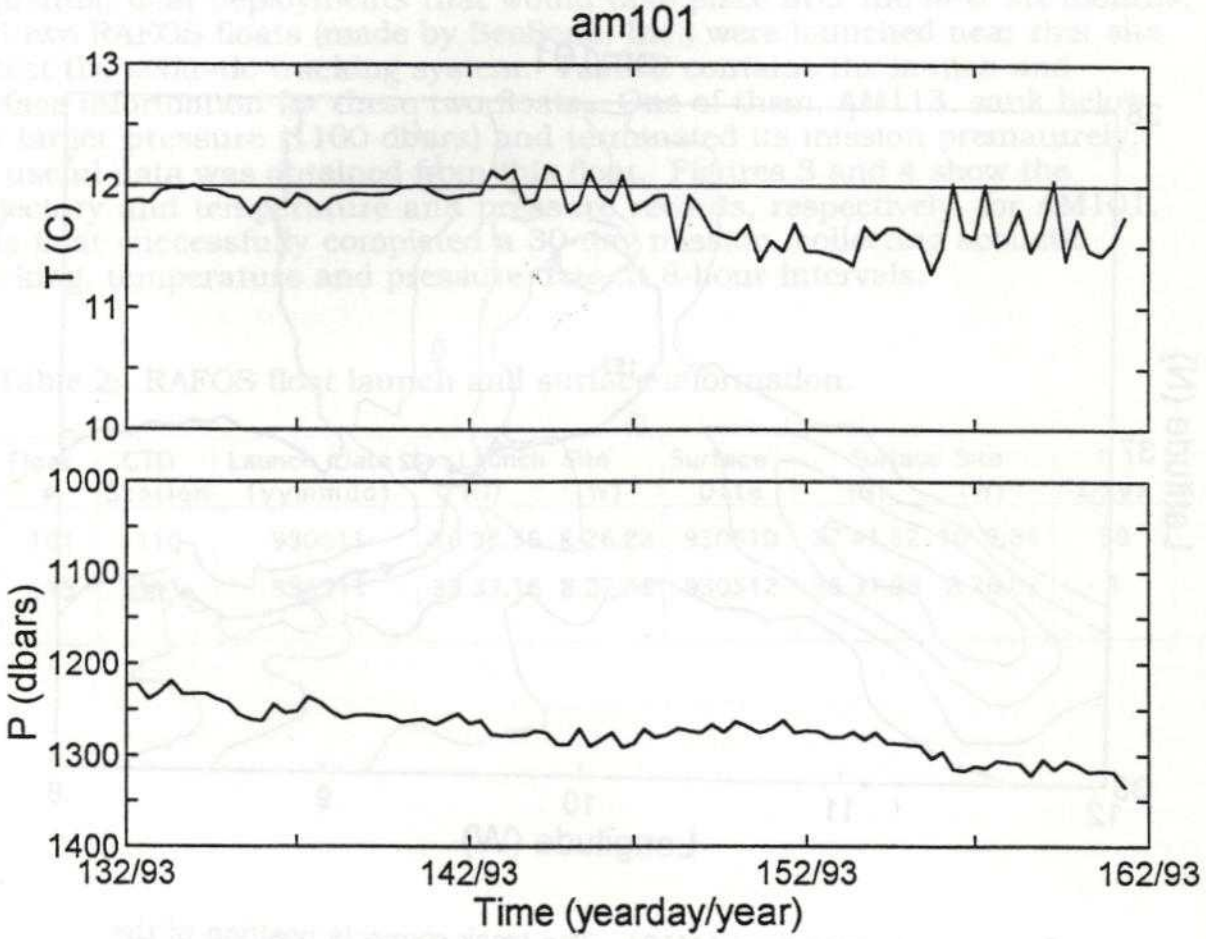

Figure 4. Time series of temperature (upper panel) and pressure (lower panel) along the track of RAFOS float AM101.

C. Acoustic Sound Sources

Three acoustic sound sources, manufactured by Webb Research Corporation, were moored at the sites listed in Table 3 and shown in Figure 1. The sources were suspended in the water column at a depth of 1500 meters (nominal) and programmed to transmit three times per day. Their nominal life expectancy is 3.5 years. They were deployed without acoustic releases since there were no plans to recover the moorings.

During the fall of 1993, the clock in M3 started to drift and it was thereafter not used for tracking floats. This drift was revealed in the time-of-arrival data from a moored RAFOS (MAFOS) deployed by the Institut fur Meereskunde-Kiel (W. Zenk, personal communication).

Table 3: Acoustic sound source information.

Mooring	Serial #	Launch Date (yymmd	Launch Position (N)	(W)	Water Depth (m)	Source Depth (m)	Daily Transmission Times (UTC)
M1	72	930504	35 31	10 00	4644	1500	0030, 0830, 1630
M2	73	930503	36 20	11 00	4605	1500	0130, 0930, 1730
M3	80	930502	34 16	13 59	4036	1500	0132, 0932, 1732

Section 3: Acknowledgements

The AMUSE project was funded by the National Science Foundation through Grant No. OCE-91-01033 to Woods Hole Oceanographic Institution, Grant No. OCE-91-00724 to Scripps Institution of Oceanography and by the Luso-American Foundation for Development (FLAD) through Grant No. 54/93 to the University of Lisbon. On behalf of the science party of R/V *OCEANUS* Voyage 258, Leg II, we wish to express our sincere thanks and appreciation to Captain Paul Howland and the crew of R/V *OCEANUS* , and we are grateful for the support and cooperation we received from the Government of Portugal. We also gratefully acknowledge the students and staff from the Oceanography Group of the University of Lisbon for their participation on the cruise. The CTD used on the cruise was loaned to us by Jim Luyten and the WHOI SeaSoar group. Without their support, this survey would not have been possible.

Section 4: References

Rossby, T., D. Dorson and J. Fontaine, 1986. The RAFOS System. *Journal of Atmospheric and Oceanic Technology*, **3**: 672-679.