CRUISE REPORT

RED SEA OUTFLOW EXPERIMENT – REDSOX 1

R/V Knorr Cruises KN-162-10 and KN-162-11

February 5 – March 15, 2001

1. Introduction and Objectives

The Red Sea Outflow Experiment (REDSOX) is a joint effort between the University of Miami's Rosenstiel School of Marine and Atmospheric Science and the Woods Hole Oceanographic Institution. The purpose of the program is to conduct measurements of the outflow of high salinity water from the Red Sea and its mixing with ambient waters in the Gulf of Aden. The program is funded by the United States National Science Foundation (NSF).

The main objectives of REDSOX are:

1. To describe the pathways and downstream evolution of the descending outflow plumes of Red Sea Water in the western Gulf of Aden
2. To quantify the processes that control the final depth of the equilibrated Red Sea Outflow Water, and
3. To identify the transport processes and mechanisms that advect Red Sea Outflow Water and its properties through the Gulf of Aden and into the Indian Ocean.

In order to achieve these objectives, fieldwork will be carried out during two cruises. This report describes the scientific research conducted during the first project cruise from 5 February – 15 March 2001 aboard the R/V *Knorr* (REDSOX-1). This cruise was timed to take place during the period of maximum deep outflow from the Red Sea, which occurs in boreal winter. The shipboard scientific activities consisted of three main components. First, a high-resolution hydrographic and direct current survey of the western Gulf of Aden was conducted to describe the three-dimensional water property distributions and circulation characteristics. Second, direct measurements of turbulent mixing were made to study the bottom stress and mixing processes in the descending plumes. Third, acoustically-tracked RAFOS floats were launched to observe the rates and pathways of Red Sea Outflow Water spreading, including some floats that were deployed in delayed release mode.

REDSOX is intended to provide the first comprehensive description of the pathways, structure, and variability of the descending outflow plumes from the Red Sea and the equilibrated Red Sea Water mass as it enters the western Indian Ocean. Analysis of the experimental data will lead to a better understanding of mixing and spreading processes in dense overflows and a more detailed knowledge of the factors that control the final watermass characteristics of these outflows.

2. Cruise Dates and Personnel

Cruise 1: R/V Knorr: KN162-10 and KN162-11

The first cruise was carried out aboard the R/V *Knorr* from February 5 and March 15, 2001. The R/V *Knorr* departed from Durban, South Africa on February 5, 2001 and stopped in Mombasa, Kenya on February 11 to pick up scientific personnel. Thereafter the *Knorr* proceeded to the study area located in the western Gulf of Aden, and the cruise ended in Victoria, Seychelles on March 15, 2001. The cruise track is shown in Figure 1.

Cruise Participants:

1.	William E. Johns	RSMAS/U. Miami	Chief Scientist
2.	Hartmut Peters	RSMAS/U. Miami	Scientist
3.	Amy Bower	WHOI	Scientist
4.	David Fratantoni	WHOI	Scientist

5.	Fiammetta Straneo	WHOI	Post-Doc Scholar
6.	Rainer Zantopp	RSMAS/U. Miami	Senior Research Associate
7.	Deborah Glickson	WHOI	Research Associate
8.	David DuBois	WHOI	Senior Research Assistant
9.	George Knapp	WHOI	Senior Research Assistant
10.	Silvia Matt	RSMAS/U. Miami	Graduate Student
11.	Robert Jones	RSMAS/U. Miami	Technician
12.	Mark Graham	RSMAS/U. Miami	Technician
13.	David Fisichella	WHOI	Research Assistant

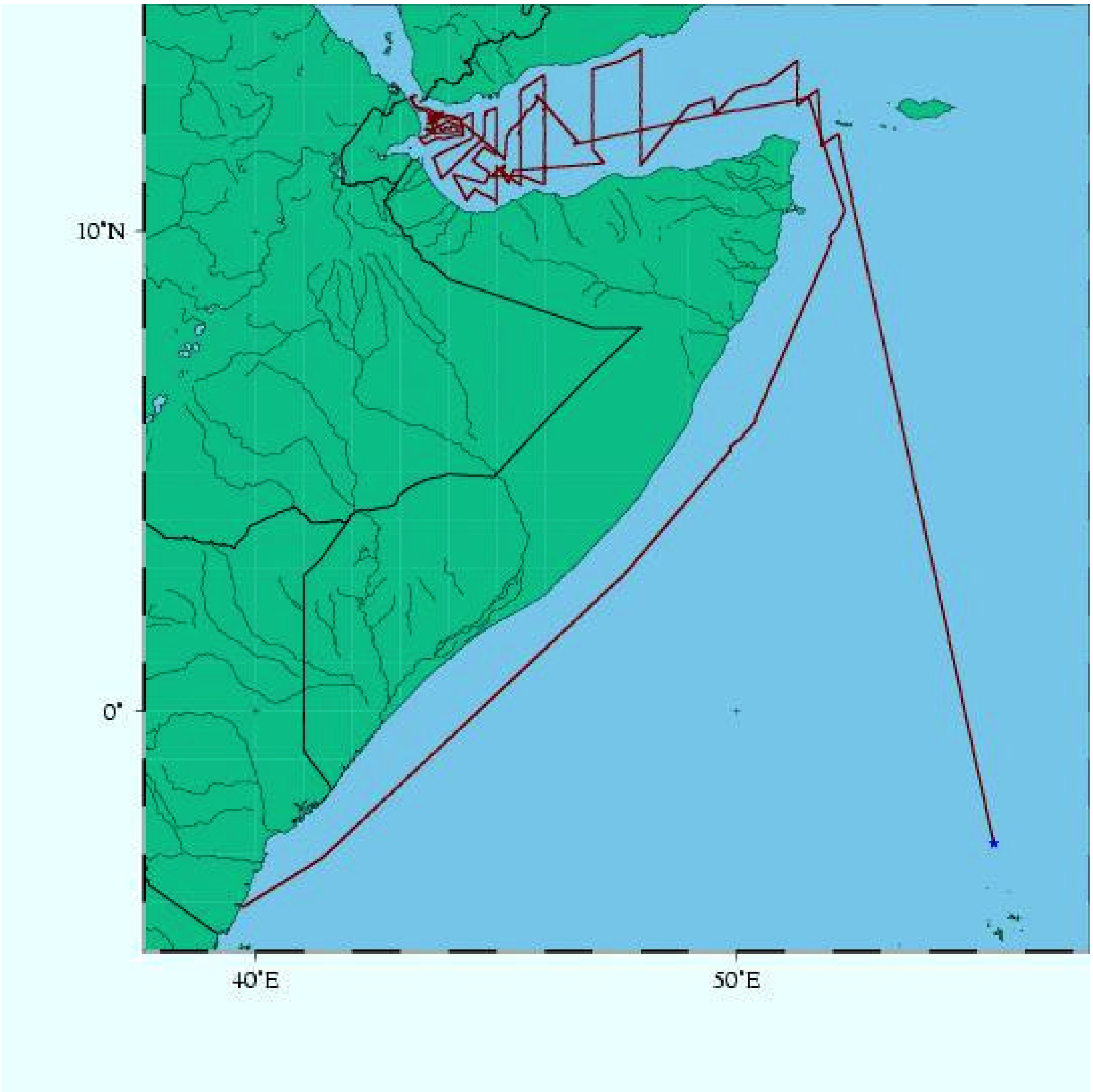

Figure 1. Cruise track of R/V Knorr during REDSOX-1

3. Scientific Activities

3.1 CTD/LADCP Stations

A total of 238 hydrographic (CTD) and direct current (LADCP) stations were occupied on the cruise. Appendix 1 contains the station locations, times and depths, and the stations are plotted in Figures 2 and 3. At each station, profiles of temperature, salinity (conductivity), and dissolved oxygen concentration were collected to a depth of 2000 m or to within approximately 10 m of the bottom at shallower depths, using a Sea-Bird SBE-9plus CTD system. Water samples for calibration of the salinity and dissolved oxygen profiles were collected at about half of these stations. Current profiles were also measured using a lowered 300 kHz R.D. Instruments Acoustic Doppler Current Profiler (LADCP).

3.2 Mooring Deployments

3.2.1 Short-term Bottom ADCP moorings

A specialized near-bottom moored package, referred to as a "Bottom Lander", was deployed three times during the cruise for a deployment period of about one day to collect measurements of the structure and variability of the descending outflow plumes. This package consisted of a syntactic foam float holding an upward-looking 600 kHz R.D. Instruments Acoustic Doppler Current Profiler and a Sea-Bird SBE-26 temperature/conductivity/pressure recorder. The ADCP measures the velocity profile and turbulence properties within the bottom 40 m of the water column while the SBE-26 measures the water properties near the bottom. The device was deployed at the locations and times listed in Table 1 and shown in Figure 3.

Table 1: Bottom Lander Moorings

Stn. No.	Launch Date	Time (Z)	Latitude N Deg	Latitude N min	Longitude E Deg	Longitude E min	Depth (m)	Release Date	Time (Z)	Duration (hours)
BL-1	21-Feb-01	1637	12	20.999	43	38.502	376	22-Feb-01	1058	18.350
BL-2	22-Feb-01	1412	12	23.496	43	50.000	460	23-Feb-01	1841	*
BL-3	24-Feb-01	0714	12	17.010	44	14.700	772	25-Feb-01	2330	40.267

* no data recovered

3.2.2 RAFOS Float Sound Source Moorings

Four RAFOS float sound source moorings were deployed during the cruise at the locations shown in Table 2 (see Figure 4). These sources are used to track the locations of the RAFOS floats as they drift through the area.

Table 2: Sound Source Moorings

Station	Sound Source	Launch Date	Time (Z)	Latitude N Deg	min	Longitude E Deg	min	Water Depth (m)	Mission Start Date
A	06	18-Feb-01	0454	11	28.804	45	10.813	1567	17-Feb-01
B	09	17-Feb-01	1806	12	44.991	45	52.004	1240	16-Feb-01
C	08	17-Feb-01	0736	11	48.495	46	41.732	1763	17-Feb-01
E	05	10-Mar-01	0637	12	24.930	49	33.780	2267	09-Mar-01

3.3 RAFOS Float Deployments

Acoustically tracked subsurface RAFOS floats were deployed at the locations listed in Table 3. The RAFOS floats were ballasted to drift at a nominal depth of 650m, which corresponds to the core of the Red Sea Water mass in the Gulf of Aden and in the Indian Ocean. The floats are programmed to drift for a period of one year and then surface to relay their data by satellite. At four locations, floats were anchored to the bottom and programmed to begin drifting after either two or four months. These floats are indicated as 'Dual Release' in Table 3.

Table 3: Float Releases

REDSOX – 1												Properties at 650 dbar (from CTD casts)		
Float	ARGOS ID	Launch Date	Time (Z)	Latitude Deg	min	Longitude Deg	min	Stn No.	Water Depth	Dual Rel.	Mission Start Date	theta	salinity	Sigma-theta
171	025611	25-Feb-01	0238	12	02.001	43	52.399	91	1182	N	25-Feb-01	18.341	37.596	27.234
146	025663	25-Feb-01	0243	12	02.014	43	52.460	91	1182	Y	01-May-01	18.341	37.596	27.234
208	022866	25-Feb-01	0247	12	02.024	43	52.506	91	1182	Y	01-Jul-01	18.341	37.596	27.234
173	025613	25-Feb-01	1158	11	54.990	43	45.800	96	784	N	25-Feb-01	18.450	37.649	27.248
174	026330	25-Feb-01	2008	12	05.200	44	18.000	100	1194	N	25-Feb-01	15.435	36.687	27.222
209	022867	25-Feb-01	2008	12	05.200	44	18.000	100	1194	Y	01-May-01	15.435	36.687	27.222
136	026332	25-Feb-01	2008	12	05.200	44	18.000	100	1194	Y	01-Jul-01	15.435	36.687	27.222
23	022865	28-Feb-01	1129	11	58.800	44	59.950	136	1170	N	27-Feb-01	15.974	36.856	27.231
147	026380	28-Feb-01	1145	11	58.800	44	59.950	136	1170	Y	01-May-01	15.974	36.856	27.231
144	025661	28-Feb-01	1140	11	58.800	44	59.950	136	1170	Y	01-Jul-01	15.974	36.856	27.231
168	024378	01-Mar-01	0337	11	22.014	44	36.948	144	960	N	27-Feb-01	19.105	37.929	27.296
166	022999	02-Mar-01	0942	10	41.960	45	00.130	160	1165	N	02-Mar-01	14.607	36.417	27.194
145	025662	02-Mar-01	0955	10	41.960	45	00.130	160	1165	Y	01-May-01	14.607	36.417	27.194

134	026331	02-Mar-01	0949	10	41.960	45	00.130	160	1165	Y	01-Jul-01	14.607	36.417	27.194
161	026383	02-Mar-01	1527	11	07.930	44	59.980	163	1462	N	03-Mar-01	15.979	36.817	27.200
170	024380	03-Mar-01	0721	11	29.898	45	30.022	169	1734	N	03-Mar-01	14.047	36.312	27.232
164	018605	03-Mar-01	1949	12	29.960	45	29.940	175	1196	N	03-Mar-01	13.861	36.272	27.220
163	018604	04-Mar-01	0657	13	00.002	46	00.016	179	1189	N	04-Mar-01	13.178	36.091	27.221
167	023000	04-Mar-01	1817	11	59.930	46	00.510	184	1490	N	04-Mar-01	13.530	36.227	27.255
162	018603	05-Mar-01	0913	10	58.050	45	59.600	191	986	N	04-Mar-01	14.309	36.368	27.200
165	022998	06-Mar-01	0615	11	14.287	45	05.374	199	1518	N	06-Mar-01	15.662	36.765	27.208
169	024379	07-Mar-01	1140	12	00.640	46	59.940	207	1901	N	08-Mar-01	13.894	36.267	27.209
172	025612	07-Mar-01	2307	13	00.000	46	59.970	211	1607	N	06-Mar-01	13.709	36.142	27.152
160	026382	08-Mar-01	1150	13	30.120	48	00.250	215	1852	N	06-Mar-01	13.161	36.014	27.165
159	026381	08-Mar-01	2254	12	13.100	47	59.860	219	1843	N	09-Mar-01	13.417	36.035	27.129
10	016185	09-Mar-01	1108	11	26.090	47	59.990	224	1240	N	09-Mar-01	11.895	35.715	27.181

3.3 Underway Measurements

Meteorological Data

Meteorological measurements were continuously recorded by sensors aboard the R/V Knorr, including wind speed and direction, barometric pressure, relative humidity, precipitation, and solar insolation. Wind speed and direction measured during the cruise are shown in Figure 5.

Thermosalinograph

Values of surface temperature and salinity were continuously measured and logged on the ships computer using a Sea-Bird temperature-conductivity recorder installed in the ship's seawater intake line. The data are shown in Figure 6.

Shipboard Acoustic Doppler Current Profiler

Upper ocean currents were continuously measured with a 150 kHz narrow-band Acoustic Doppler Current Profiler (ADCP) mounted in the ship's transducer well. The depth range of good velocity data typically extended to 350 m below the vessel, depending on sea state conditions. The data are shown in Fig. 9 and described below in connection with the scientific findings of the cruise.

4. Highlights of Preliminary Scientific Findings

During the first phase of the cruise (REDSOX-1), the downstream evolution of the descending outflow plumes was mapped out with CTD and LADCP measurements. Sections were obtained along the axis of both channels that lead from Bab el Mandeb Strait to the Gulf of Aden, as well as across the channels at several downstream locations. An example of one cross-section, spanning both channels, is shown in Figure 7a. Red Sea Water (RSW), indicated by high salinity, was flowing strongly toward the Gulf in the lower layer of both channels, while fresher Gulf of Aden water was flowing toward the Red Sea in the upper layer. This is typical of the winter monsoon circulation. Salinity and density of the deep RSW in the northern channel was generally higher than in the southern channel. There is also evidence of a shallow, equilibrated RSW layer at about 150 m depth. Preliminary calculations of the RSW transport indicate a value about half as large as previously observed during the winter monsoon.

The two channels that direct RSW toward the Gulf of Aden empty into the steep-sided Tadjura Rift. As the RSW pours into the rift, it reaches neutral buoyancy at several depths and densities, producing multiple salinity maxima. One result that clearly emerged from CTD measurements in the rift is that RSW exiting the northern channel equilibrates deeper and at a higher density than that coming from the southern channel. Figure 7b illustrates a salinity section along the axis of the rift. The deeper salinity maximum on the right originates from the northern channel.

After equilibrating in the rift, RSW spreads laterally into the Gulf of Aden. The spreading pathways were mapped out with an extensive array of CTD stations in the western and central gulf. Figure 8a shows the horizontal distribution of salinity at the central density level of RSW, sigma-theta = 27.15-27.25, as well as the pressure of that density layer during REDSOX-1. Immediately after entering the rift, the lateral spreading of RSW is confined by the walls of the rift. Outside the mouth of the rift, the most saline RSW, already diluted by lateral mixing processes, was found along the western boundary and in an arc or streak of patches turning cyclonically away from the western boundary. East of about 46°E, the salinity distribution was remarkably homogeneous, with values 36.00-36.25.

The most unexpected result of the Gulf survey was the observation of large, deep-reaching mesoscale eddies, both cyclonic and anticyclonic, that strongly impact the spreading pathways of the RSW. One indication of these eddies can be seen in Figure 8b, the pressure of the 27.15-27.25 density layer. Against the western boundary, the RSW density layer (and other layers as well) domes up significantly, revealing the presence of a strong cyclonic eddy. Comparing Figures 8a and 8b, one can see that the eddy is advecting the most saline RSW around its perimeter. Another cyclonic eddy was centered at 13°N, 46°E, and a strong anticyclonic eddy is evident at 48°E.

These eddies are evident in direct velocity measurements made with the hull-mounted ADCP and the lowered ADCP. For example, Figure 9a shows the surface velocity vectors from the shipboard ADCP during the Gulf survey. The cyclonic circulation around the western eddy is clearly apparent at the sea surface, as is the second cyclone at 46°E. The anticyclone at 48°E is not evident at the surface, but is present at deeper levels (Fig. 9b). This indicates that the surface and subsurface flows can sometimes be decoupled, and that these eddies have varying vertical structures. Eddy velocities were as high as 1 m/s in the upper ocean and 0.2 m/s at the depth of the RSW.

5. Release of Project Data

In accordance with the provisions specified in the cruise prospectus and application for foreign clearances, the full data results from this experiment will be provided to all clearance countries according to the following schedule:

Hydrographic Station Data, Mooring Data, and Underway Shipboard Measurements

All shipboard measurements, including underway data records and hydrographic station data, as well as the data recovered from the short-term bottom moorings in the area of the outflow plume, will be provided within 6 months of the termination of the cruise (September 15, 2001).

Subsurface Floats

Time series data and trajectories from the subsurface RAFOS floats will be provided within 18 months from the time when the last floats surface and complete their data transmissions. This is anticipated to occur in January 2003. Therefore we anticipate delivery of the final float data by July 2004.

6. Acknowledgements

The support and able assistance provided by the Captain and crew of the R/V *Knorr* is gratefully acknowledged. Financial support for this research was provided by the U.S. National Science Foundation under grants to the Woods Hole Oceanographic Institution and to the University of Miami. We wish to thank the Republic of Yemen, the Republic of Djibouti, and the State of

Eritrea for their cooperation on this project and for granting permission to carry out research in their territorial waters.

Appendix 1. CTDO/LADCP stations occupied during REDSOX-1 in February and March 2001.

Sta. No.	Date	Time (Z)	Latitude Deg	Latitude min	Longitude Deg	Longitude min	Depth (m)	Max. Pressure (dbar)
1	14-Feb-01	1211	05	27.39	049	52.05	3996	800.4
2	14-Feb-01	1524	05	30.29	049	51.52	3283	1198.3
3	17-Feb-01	0836	11	48.47	046	42.27	1775	1768.8
4	17-Feb-01	1858	12	45.34	045	52.23	1243	1224.5
5	18-Feb-01	0604	11	28.45	045	10.82	1576	1568.0
6	18-Feb-01	1152	12	1.65	044	31.22	1347	1342.5
7	18-Feb-01	1427	12	11.00	044	20.19	648	643.3
8	18-Feb-01	1603	12	10.99	044	17.92	719	715.5
9	18-Feb-01	1741	12	10.99	044	15.96	720	716.3
10	18-Feb-01	1925	12	10.98	044	13.97	614	608.9
11	18-Feb-01	2054	12	10.99	044	11.98	522	517.4
12	18-Feb-01	2258	12	13.13	044	4.65	498	494.0
13	19-Feb-01	0030	12	15.39	044	0.09	404	400.7
14	19-Feb-01	0217	12	12.77	043	54.03	470	457.6
15	19-Feb-01	0353	12	9.14	043	48.59	434	430.7
16	19-Feb-01	0545	12	8.34	043	46.59	613	608.0
17	19-Feb-01	0729	12	7.48	043	44.87	363	358.0
18	19-Feb-01	0856	12	6.92	043	43.34	466	462.0
19	19-Feb-01	1013	12	6.52	043	41.99	452	449.6
20	19-Feb-01	1133	12	6.05	043	40.59	331	326.8
21	19-Feb-01	1251	12	5.57	043	39.00	295	289.8
22	19-Feb-01	1406	12	5.70	043	36.57	253	247.9
23	19-Feb-01	1527	12	6.02	043	33.26	207	203.3
24	19-Feb-01	1636	12	6.48	043	30.34	157	143.3
25	19-Feb-01	1858	11	59.96	043	43.74	1561	1552.9
26	19-Feb-01	2051	12	3.32	043	42.77	961	949.2
27	19-Feb-01	2316	12	13.07	043	40.18	452	448.7
28	20-Feb-01	0134	12	22.10	043	37.79	384	380.0
29	20-Feb-01	0340	12	27.42	043	32.23	290	284.0
30	20-Feb-01	0518	12	31.64	043	25.15	320	289.0
31	20-Feb-01	0658	12	34.44	043	18.07	313	303.0
32	20-Feb-01	1049	12	46.29	043	16.59	207	205.1
33	20-Feb-01	1155	12	45.61	043	15.03	179	175.5
34	20-Feb-01	1258	12	45.08	043	13.74	177	167.9
35	20-Feb-01	1632	12	30.47	043	35.72	356	340.6
36	20-Feb-01	1837	12	23.70	043	46.99	491	487.2
37	20-Feb-01	2111	12	22.71	044	1.80	552	545.0
38	21-Feb-01	2350	12	16.24	044	14.99	798	794.0
39	21-Feb-01	0159	12	7.28	044	17.02	925	920.0
40	21-Feb-01	0347	12	2.19	044	17.69	1281	1278.0
41	21-Feb-01	0612	12	2.21	044	5.88	1276	1264.0
42	21-Feb-01	0822	12	1.23	043	54.51	1228	1222.0
43	21-Feb-01	1012	12	5.05	043	50.49	911	906.8
44	21-Feb-01	1730	12	20.99	043	38.51	379	375.1
45	21-Feb-01	1920	12	18.57	043	33.09	230	225.1
46	21-Feb-01	2016	12	19.20	043	34.52	302	299.2
47	21-Feb-01	2122	12	19.86	043	35.80	362	359.0
48	21-Feb-01	2256	12	20.45	043	37.36	320	307.0
49	21-Feb-01	2348	12	20.92	043	38.51	379	374.0
50	22-Feb-01	0113	12	21.44	043	39.30	312	308.0

51	22-Feb-01	0235	12	18.56	043	33.16	233	229.0
52	22-Feb-01	0324	12	19.25	043	34.49	306	301.3
53	22-Feb-01	0420	12	19.70	043	35.76	369	364.0
54	22-Feb-01	0540	12	20.47	043	37.41	319	311.0
55	22-Feb-01	0636	12	21.05	043	38.55	378	375.0
56	22-Feb-01	0742	12	23.06	043	37.09	398	392.0
57	22-Feb-01	0915	12	18.81	043	39.29	390	384.6
58	22-Feb-01	1228	12	23.69	043	50.08	475	468.3
59	22-Feb-01	1541	12	19.02	043	48.89	239	233.8
60	22-Feb-01	1639	12	21.03	043	49.37	288	283.9
61	22-Feb-01	1800	12	22.48	043	49.67	401	396.2
62	22-Feb-01	1908	12	23.52	043	49.98	470	462.1
63	22-Feb-01	2047	12	24.57	043	50.42	450	447.2
64	22-Feb-01	2305	12	20.98	043	49.40	289	276.0
65	23-Feb-01	0018	12	22.47	043	49.66	399	396.2
66	23-Feb-01	0133	12	23.49	043	50.03	467	461.4
67	23-Feb-01	0315	12	24.63	043	50.38	413	409.2
68	23-Feb-01	0500	12	23.71	043	47.05	495	490.0
69	23-Feb-01	0635	12	23.67	043	52.82	504	501.3
70	23-Feb-01	0814	12	17.60	043	47.17	361	357.0
71	23-Feb-01	0925	12	15.54	043	44.58	335	330.9
72	23-Feb-01	1054	12	14.12	043	42.23	359	354.3
73	23-Feb-01	1202	12	12.97	043	40.24	451	446.2
74	23-Feb-01	1344	12	12.28	043	38.72	342	337.1
75	23-Feb-01	1500	12	12.02	043	36.00	233	226.0
76	23-Feb-01	1617	12	11.94	043	32.46	187	179.3
77	23-Feb-01	2013	12	26.15	043	42.72	296	292.1
78	23-Feb-01	2134	12	25.20	043	42.20	420	415.0
79	23-Feb-01	2254	12	23.99	043	41.64	351	341.4
80	24-Feb-01	0015	12	22.01	043	40.50	323	318.0
81	24-Feb-01	0447	12	16.97	044	14.72	780	768.2
82	24-Feb-01	0903	12	20.83	044	8.19	649	644.3
83	24-Feb-01	1114	12	18.32	044	13.54	708	703.7
84	24-Feb-01	1406	12	13.50	044	16.57	721	719.6
85	24-Feb-01	1539	12	11.02	044	17.76	718	716.9
86	24-Feb-01	1706	12	7.57	044	18.17	780	776.6
87	24-Feb-01	1851	12	5.85	044	9.66	990	974.6
88	24-Feb-01	2035	12	9.58	044	3.04	502	494.4
89	24-Feb-01	2236	12	5.88	044	1.97	985	980.6
90	25-Feb-01	0023	12	7.67	043	55.48	525	518.2
91	25-Feb-01	0156	12	2.00	043	52.38	1182	1164.0
92	25-Feb-01	0452	12	0.01	043	34.88	1004	995.0
93	25-Feb-01	0600	11	55.66	043	30.84	1616	1595.0
94	25-Feb-01	0819	11	55.95	043	23.38	1024	1020.8
95	25-Feb-01	0959	11	47.41	043	30.22	415	379.5
96	25-Feb-01	1205	11	54.99	043	45.77	809	788.7
97	25-Feb-01	1424	11	53.80	043	56.00	539	519.3
98	25-Feb-01	1608	11	56.92	044	6.11	876	827.8
99	25-Feb-01	1819	11	57.52	044	18.30	886	874.1
100	25-Feb-01	2005	12	5.17	044	18.05	1194	1171.1
101	25-Feb-01	2217	12	17.01	044	14.76	768	778.4
102	26-Feb-01	0300	12	19.96	044	29.98	544	534.3
103	26-Feb-01	0427	12	14.98	044	29.99	743	740.9
104	26-Feb-01	0543	12	10.00	044	30.00	754	737.1
105	26-Feb-01	0725	12	2.47	044	29.99	1360	1373.7
106	26-Feb-01	0923	11	56.01	044	29.81	787	783.5

107	26-Feb-01	1042	11	53.78	044	27.69	845	833.0
108	26-Feb-01	1218	11	50.46	044	20.08	766	760.1
109	26-Feb-01	1417	11	46.44	044	11.66	686	678.7
110	26-Feb-01	1555	11	42.14	044	2.45	578	567.6
111	26-Feb-01	1736	11	37.84	043	53.64	470	458.7
112	26-Feb-01	1853	11	35.11	043	48.21	415	400.6
113	26-Feb-01	2002	11	32.99	043	43.89	305	300.1
114	26-Feb-01	2049	11	31.00	043	41.01	247	241.3
115	26-Feb-01	2358	11	5.01	043	50.01	264	244.5
116	27-Feb-01	0101	11	7.55	043	53.17	426	417.9
117	27-Feb-01	0202	11	8.37	043	54.40	525	509.6
118	27-Feb-01	0315	11	12.12	043	58.14	569	560.0
119	27-Feb-01	0506	11	19.93	044	6.12	586	580.5
120	27-Feb-01	0645	11	26.79	044	13.82	690	677.5
121	27-Feb-01	0841	11	34.25	044	21.38	784	771.0
122	27-Feb-01	1032	11	41.38	044	28.70	837	826.0
123	27-Feb-01	1234	11	48.01	044	36.60	892	882.2
124	27-Feb-01	1417	11	52.62	044	42.16	906	890.8
125	27-Feb-01	1549	11	56.69	044	44.93	908	890.8
126	27-Feb-01	1715	11	59.25	044	44.98	1184	1169.3
127	27-Feb-01	1844	12	2.17	044	45.06	1290	1280.8
128	27-Feb-01	2010	12	7.53	044	45.08	1190	1176.3
129	27-Feb-01	2153	12	13.49	044	45.02	916	904.8
130	27-Feb-01	2330	12	22.53	044	44.96	702	686.7
131	28-Feb-01	0108	12	25.81	044	45.60	512	498.8
132	28-Feb-01	0312	12	32.43	044	59.94	529	503.0
133	28-Feb-01	0440	12	26.59	045	0.05	814	800.8
134	28-Feb-01	0558	12	18.33	045	0.05	977	964.4
135	28-Feb-01	0831	12	4.25	044	59.86	1032	1015.3
136	28-Feb-01	1022	11	58.89	044	59.96	1190	1185.8
137	28-Feb-01	1306	11	53.35	044	59.85	920	917.0
138	28-Feb-01	1458	11	44.09	044	59.84	1138	1124.1
139	28-Feb-01	1718	11	33.92	044	59.96	1439	1434.6
140	28-Feb-01	1907	11	38.48	044	52.44	1160	1149.4
141	28-Feb-01	2053	11	43.69	044	44.28	996	992.2
142	28-Feb-01	2251	11	35.74	044	36.93	912	897.6
143	01-Mar-01	0114	11	27.47	044	29.99	870	868.1
144	01-Mar-01	0254	11	22.00	044	37.01	976	964.3
145	01-Mar-01	0453	11	16.99	044	44.22	1111	1107.0
146	01-Mar-01	0641	11	11.47	044	50.96	1331	1320.7
147	01-Mar-01	0904	10	59.21	044	45.73	1341	1332.1
148	01-Mar-01	1058	11	1.60	044	37.11	1125	1111.7
149	01-Mar-01	1252	11	4.01	044	28.21	927	916.6
150	01-Mar-01	1437	11	6.12	044	19.84	785	771.2
151	01-Mar-01	1617	11	7.99	044	13.92	715	704.4
152	01-Mar-01	1747	11	9.88	044	5.80	643	632.5
153	01-Mar-01	2008	10	53.57	044	14.53	781	771.4
154	01-Mar-01	2241	10	37.67	044	21.91	688	680.0
155	01-Mar-01	2359	10	40.82	044	24.42	817	805.6
156	02-Mar-01	0121	10	44.51	044	27.03	911	903.5
157	02-Mar-01	0308	10	51.77	044	32.30	1084	1074.0
158	02-Mar-01	0535	10	43.81	044	47.21	1189	1171.0
159	02-Mar-01	0815	10	32.31	045	0.15	603	570.0
160	02-Mar-01	0941	10	41.81	045	0.02	1165	1157.5
161	02-Mar-01	1136	10	48.47	045	0.01	1347	1338.1
162	02-Mar-01	1323	10	55.83	044	59.99	1413	1393.1

163	02-Mar-01	1536	11	7.55	044	59.92	1485	1473.7
164	02-Mar-01	1739	11	18.57	044	59.96	1478	1466.0
165	02-Mar-01	2241	10	57.47	045	29.90	1365	1348.4
166	03-Mar-01	0018	11	2.34	045	29.96	1483	1479.0
167	03-Mar-01	0209	11	8.65	045	29.96	1622	1603.5
168	03-Mar-01	0430	11	18.05	045	29.90	1725	1711.7
169	03-Mar-01	0634	11	30.07	045	30.00	1765	1747.0
170	03-Mar-01	0905	11	42.04	045	29.98	1724	1713.9
171	03-Mar-01	1120	11	53.61	045	30.02	1159	1156.5
172	03-Mar-01	1401	11	58.96	045	29.94	1150	1145.9
173	03-Mar-01	1555	12	7.34	045	29.98	1044	1034.1
174	03-Mar-01	1749	12	18.03	045	30.00	1180	1177.0
175	03-Mar-01	2003	12	30.01	045	29.97	1205	1198.8
176	03-Mar-01	2206	12	41.87	045	30.00	1009	1003.5
177	03-Mar-01	2359	12	52.48	045	29.95	499	481.3
178	04-Mar-01	0421	13	12.17	045	59.79	1107	1089.7
179	04-Mar-01	0625	13	0.03	045	59.84	1195	1191.9
180	04-Mar-01	0837	12	47.97	045	59.99	1360	1354.5
181	04-Mar-01	1055	12	35.85	045	59.96	1452	1449.6
182	04-Mar-01	1305	12	24.05	046	0.11	1499	1497.5
183	04-Mar-01	1523	12	11.96	046	0.02	1329	1326.2
184	04-Mar-01	1735	11	59.90	046	0.11	1523	1508.5
185	04-Mar-01	1958	11	47.95	045	59.88	1650	1648.8
186	04-Mar-01	2225	11	36.22	045	59.97	1865	1861.7
187	05-Mar-01	0111	11	24.06	045	59.89	1844	1840.4
188	05-Mar-01	0340	11	12.02	045	59.96	1718	1714.5
189	05-Mar-01	0543	11	5.01	045	59.96	1548	1545.7
190	05-Mar-01	0722	11	0.02	045	59.91	1326	1322.9
191	05-Mar-01	0917	10	57.83	045	59.72	994	972.7
192	05-Mar-01	1302	11	8.77	045	30.15	1606	1601.7
193	05-Mar-01	1504	11	8.24	045	22.46	1612	1600.1
194	05-Mar-01	1658	11	8.13	045	14.91	1575	1572.1
195	05-Mar-01	1858	11	7.52	045	8.02	1525	1520.2
196	05-Mar-01	2143	11	7.57	045	0.02	1470	1467.3
197	05-Mar-01	2350	11	7.06	044	52.86	1399	1395.9
198	06-Mar-01	0308	11	22.51	045	10.95	1561	1558.2
199	06-Mar-01	0534	11	14.36	045	5.39	1532	1526.4
200	06-Mar-01	0831	10	59.95	045	14.02	1487	1485.2
201	06-Mar-01	1255	11	15.07	045	20.98	1648	1643.1
202	06-Mar-01	2335	11	24.01	047	14.12	1869	1865.9
203	07-Mar-01	0225	11	27.63	047	11.06	1932	1926.0
204	07-Mar-01	0436	11	33.97	047	5.78	2034	2005.8
205	07-Mar-01	0651	11	40.53	046	59.97	2093	2001.7
206	07-Mar-01	0900	11	50.04	046	59.98	2114	2000.0
207	07-Mar-01	1128	12	0.10	046	59.97	1912	1900.4
208	07-Mar-01	1404	12	15.08	046	59.90	2555	1991.0
209	07-Mar-01	1649	12	30.15	046	59.86	2130	1994.9
210	07-Mar-01	1938	12	45.08	046	59.95	1715	1711.2
211	07-Mar-01	2209	13	0.46	047	0.02	1617	1613.5
212	08-Mar-01	0041	13	10.99	047	0.11	1429	1424.3
213	08-Mar-01	0228	13	19.33	047	0.07	889	886.7
214	08-Mar-01	0847	13	44.88	048	0.00	914	908.3
215	08-Mar-01	1117	13	30.00	048	0.10	1868	1863.2
216	08-Mar-01	1401	13	14.97	047	59.96	2090	1953.2
217	08-Mar-01	1652	12	59.97	047	59.98	2120	1995.9
218	08-Mar-01	1929	12	44.94	047	59.93	1517	1506.5

219	08-Mar-01	2213	12	29.98	047	59.87	1899	1894.2
220	09-Mar-01	0106	12	14.94	047	59.90	2279	2001.5
221	09-Mar-01	0355	11	59.95	048	0.01	2207	2000.3
222	09-Mar-01	0642	11	44.95	048	0.02	2021	2000.5
223	09-Mar-01	0904	11	34.01	047	59.98	1678	1670.9
224	09-Mar-01	1059	11	25.99	048	0.01	1248	1246.2
225	09-Mar-01	1231	11	21.61	047	59.97	961	957.1
226	09-Mar-01	2216	12	33.53	049	0.02	2627	1991.0
227	10-Mar-01	0219	12	43.03	049	30.04	2178	2001.6
228	10-Mar-01	1030	12	52.03	050	0.18	2466	1995.5
229	10-Mar-01	1450	13	1.56	050	37.19	2022	1993.0
230	10-Mar-01	1936	13	29.02	051	15.07	1673	1663.0
231	10-Mar-01	2235	13	11.58	051	15.23	4213	1995.0
232	11-Mar-01	0158	12	57.05	051	14.77	2325	1999.0
233	11-Mar-01	0456	12	34.83	051	15.26	939	929.0
234	11-Mar-01	0828	12	53.18	051	40.12	2218	2001.9
235	11-Mar-01	1545	11	47.21	051	47.57	680	673.9
236	11-Mar-01	1707	11	51.25	051	53.56	1138	1135.9
237	11-Mar-01	1831	11	55.04	051	59.56	1124	1118.0
238	11-Mar-01	1959	11	59.41	052	6.06	1089	1079.0

REDSOX-1 Stations

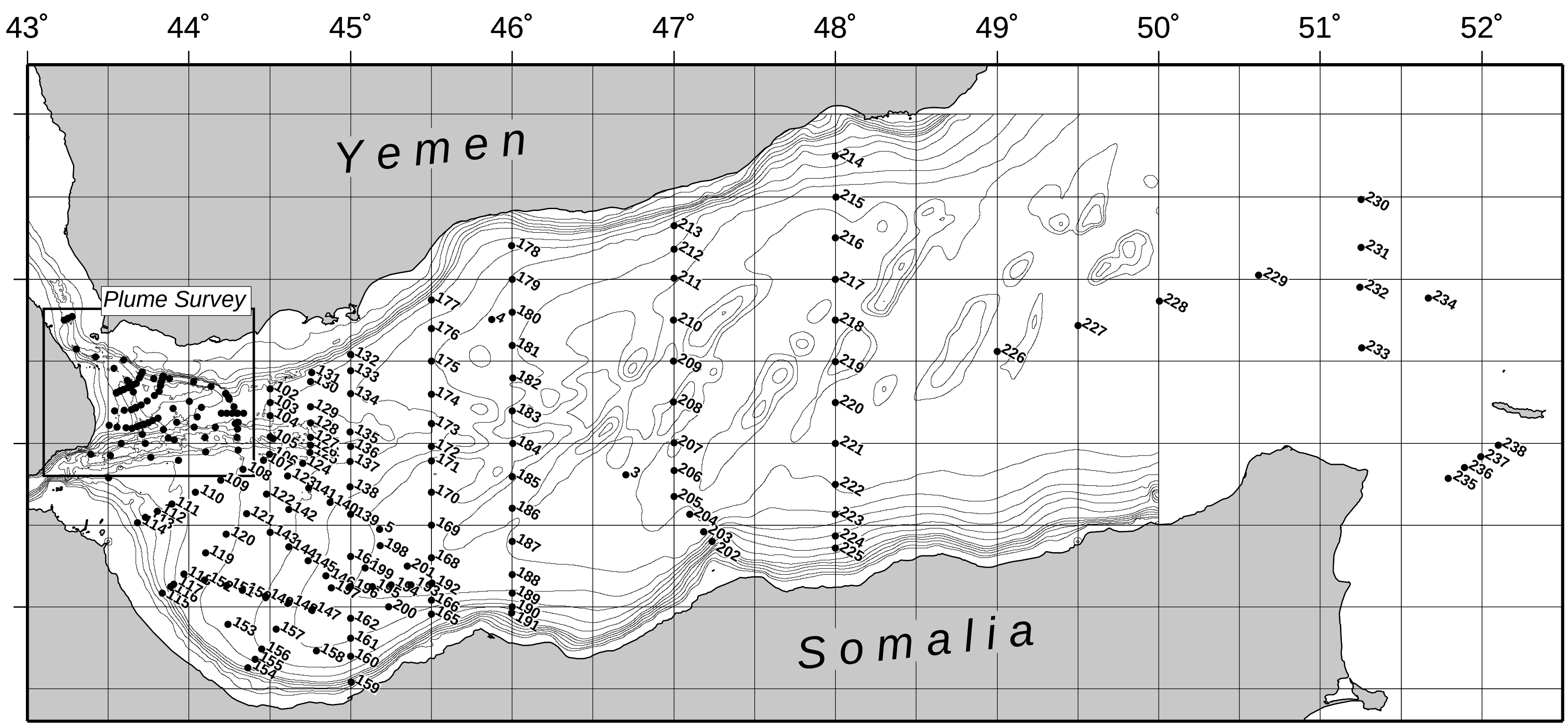

Figure 2. Location of CTDO/LADCP stations during REDSOX-1 in the Gulf of Aden. An extended view of the Plume Survey in the western Gulf of Aden is shown in Figure 3.

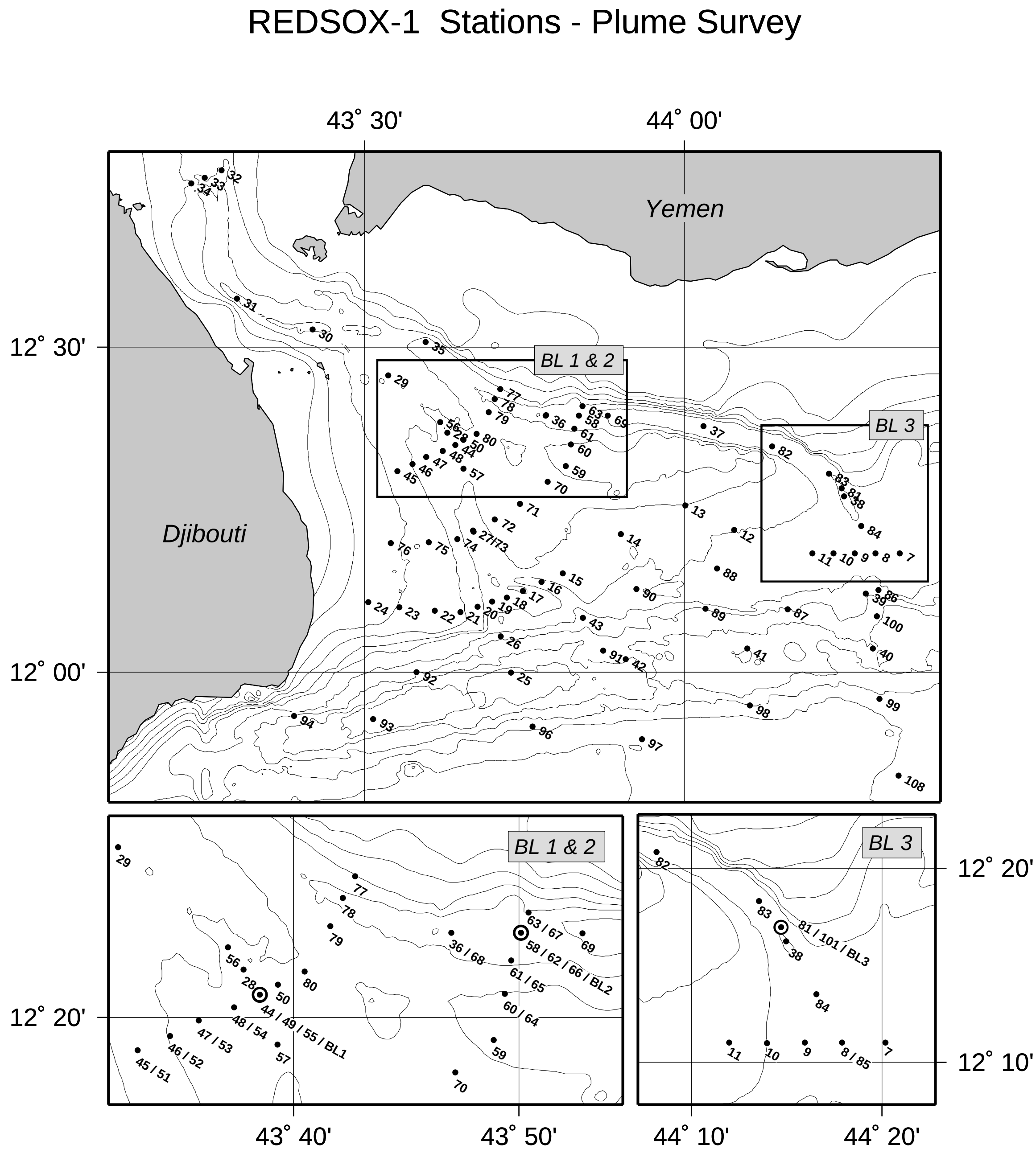

Figure 3. Expanded view of CTDO/LADCP stations during the Plume Survey in the western Gulf of Aden, including additional enlargements of Bottom Lander sites BL1 and BL2 (bottom left) and BL3 (bottom right).

REDSOX-1 Float Launches

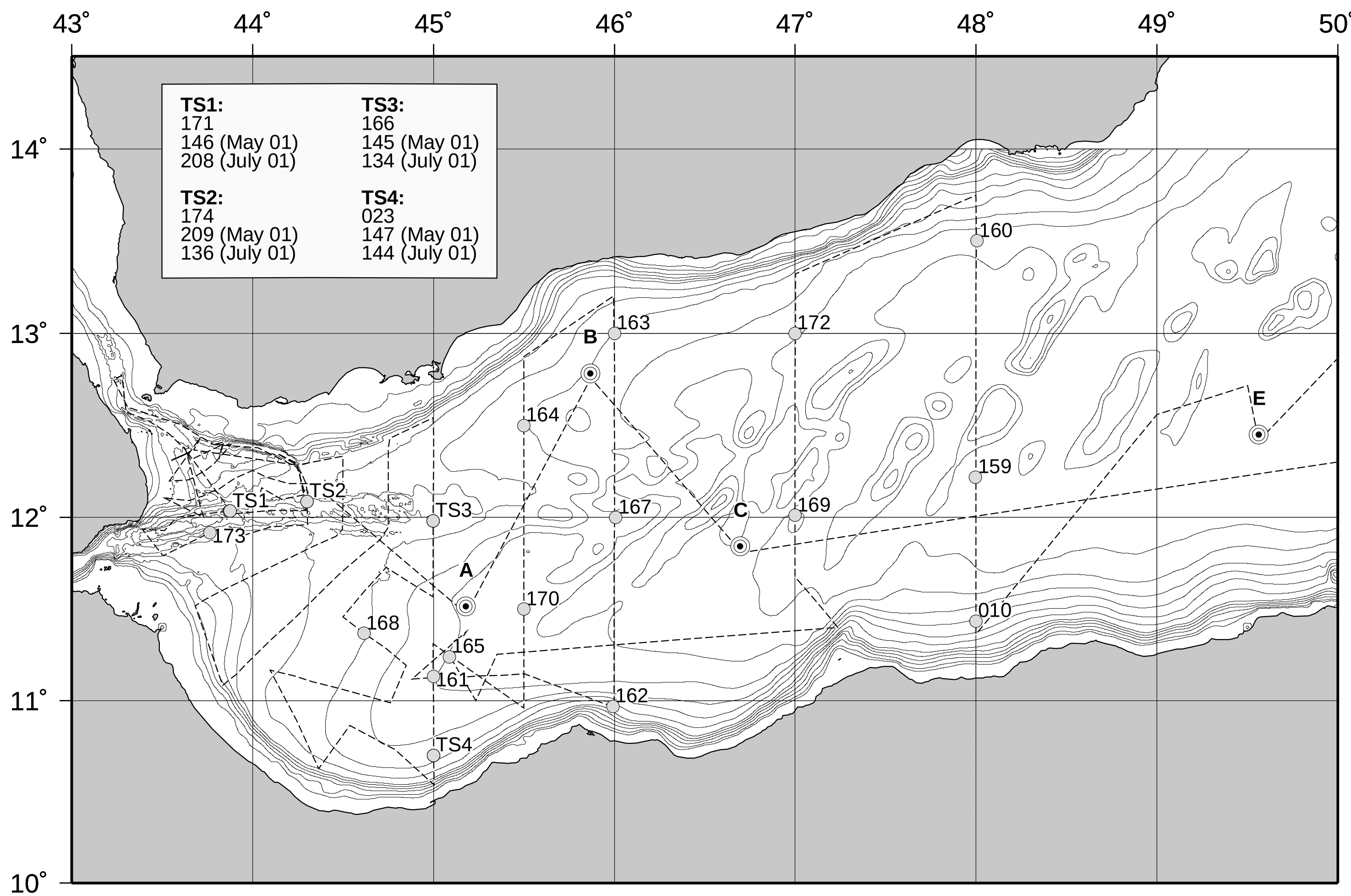

Figure 4. Launch locations of 650 m RAFOS floats (numbered) and 780 Hz sound sources (lettered). Timed-release floats were deployed at four time-series stations (TS1-4). One float at each TS station began drifting immediately. Two others were anchored to the sea floor and will begin drifting at 650 m on the date indicated. Sound source "D" (nominal location 13N, 48E) was not deployed due to an instrument malfunction.

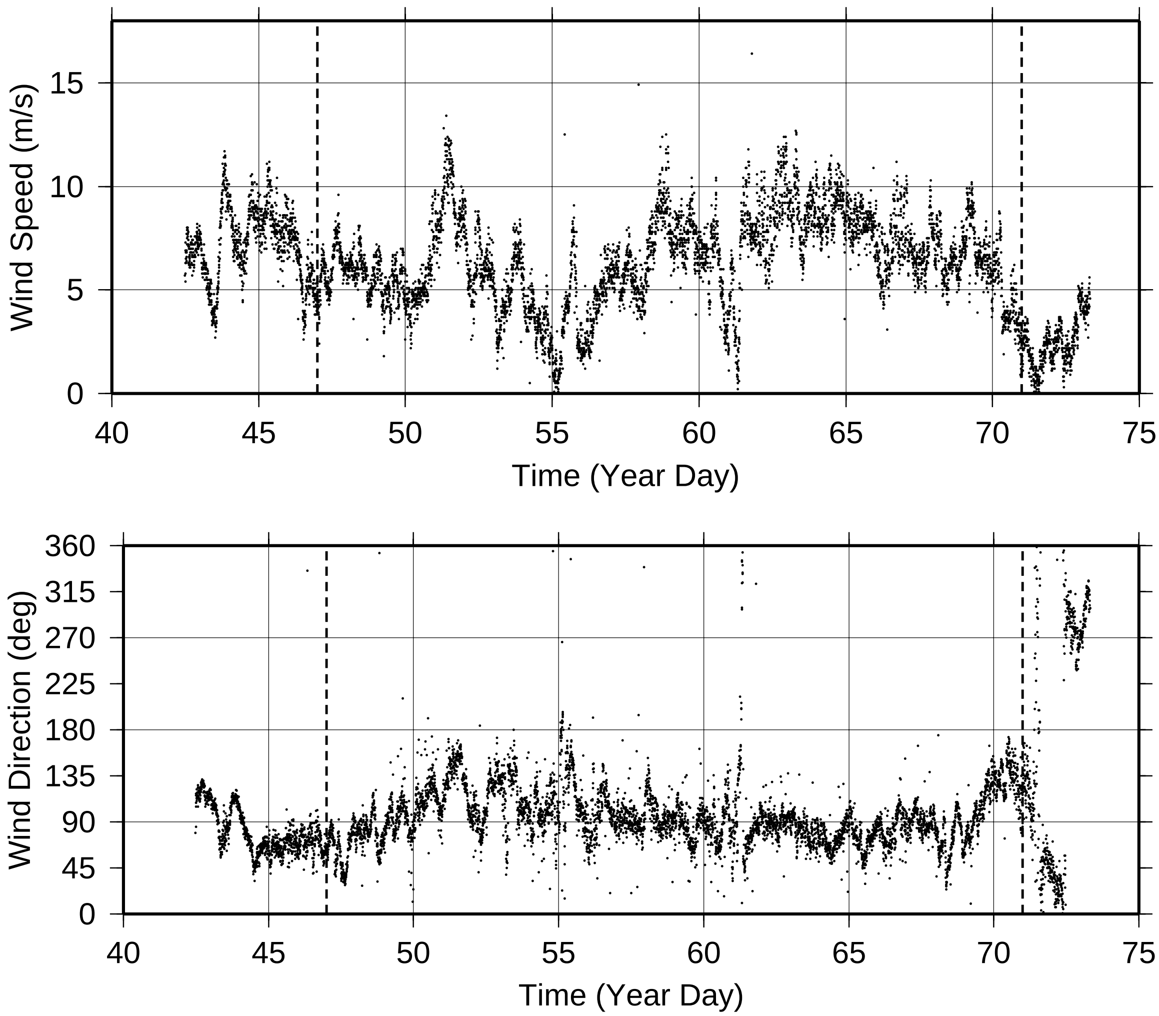

Figure 5. Wind speed (top) and direction (bottom) as recorded by the meteorological sensors aboard the R/V Knorr during REDSOX-1. Vertical lines on JD 47 and 71 indicate entry to and departure from the Gulf of Aden proper.

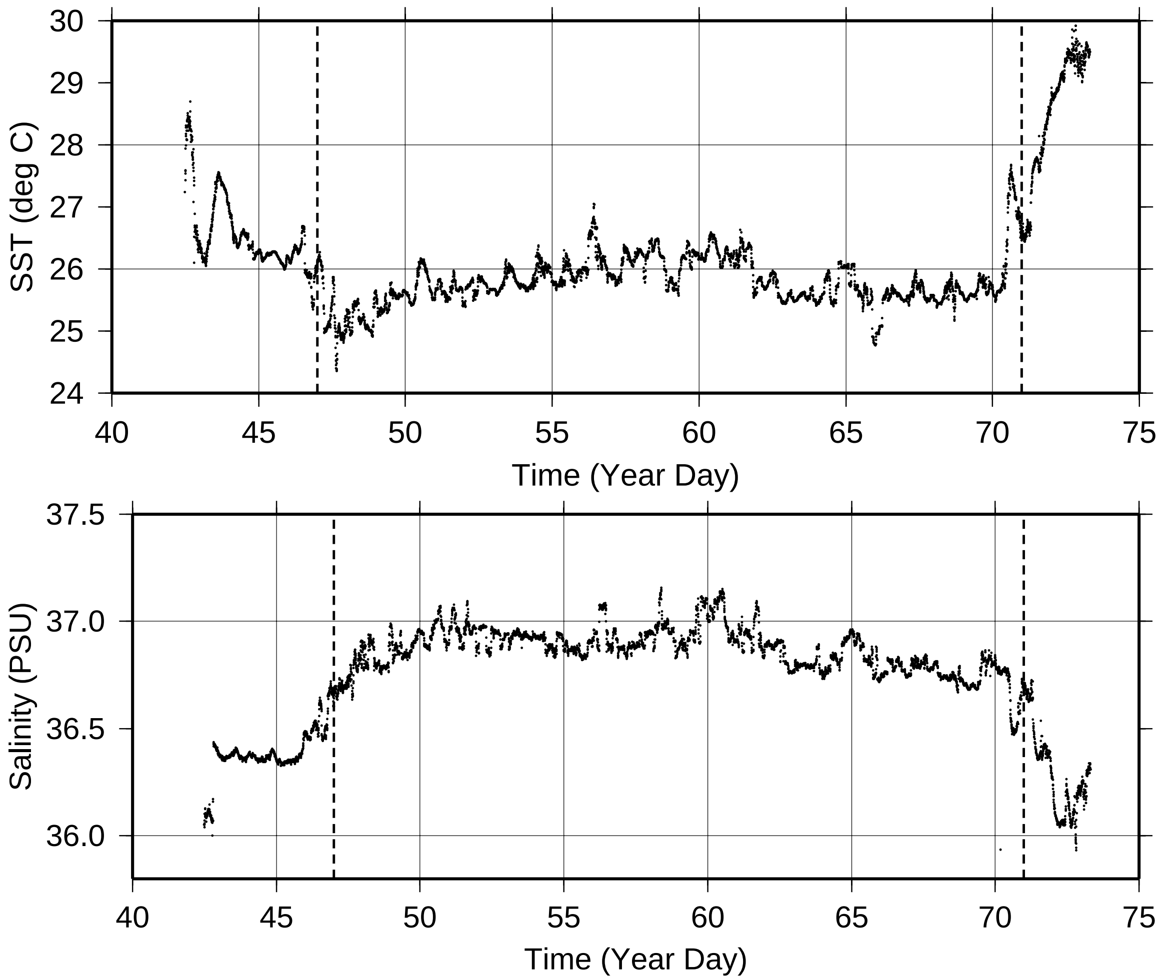

Figure 6. Sea surface temperature (top) and salinity (bottom) as recorded by the thermosalinograph aboard the R/V Knorr during REDSOX-1. Vertical lines on JD 47 and 71 indicate entry to and departure from the Gulf of Aden proper.

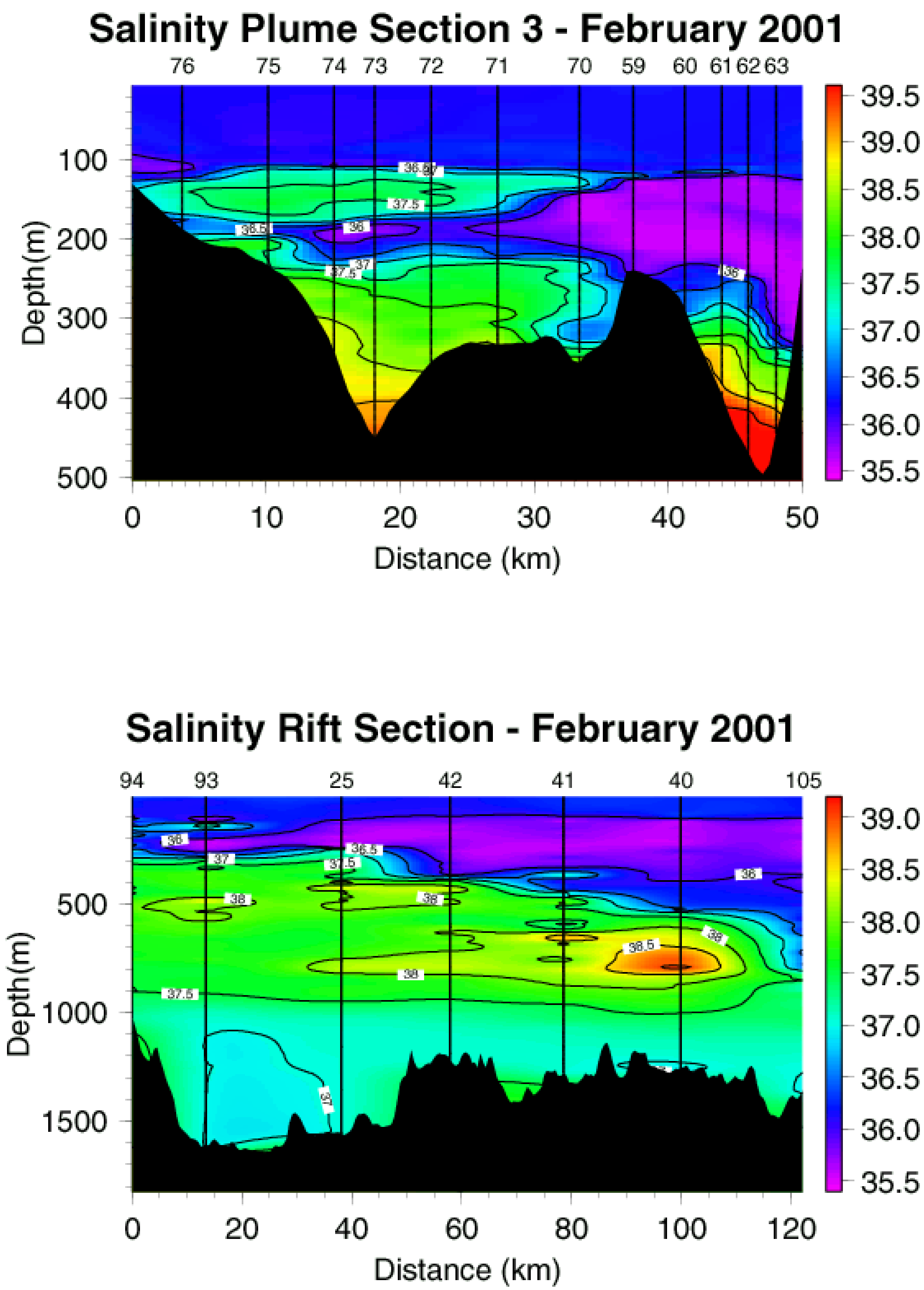

Figure 7. (a) Salinity section across the two main outflow channels from the Red Sea. The station numbers comprising the section are shown at the top (see Figs. 2 and 3 for station locations). The northern channel (on the right) carries the highest salinity waters and produces the densest product waters, as shown in the section along the Tadjura Rift (b).

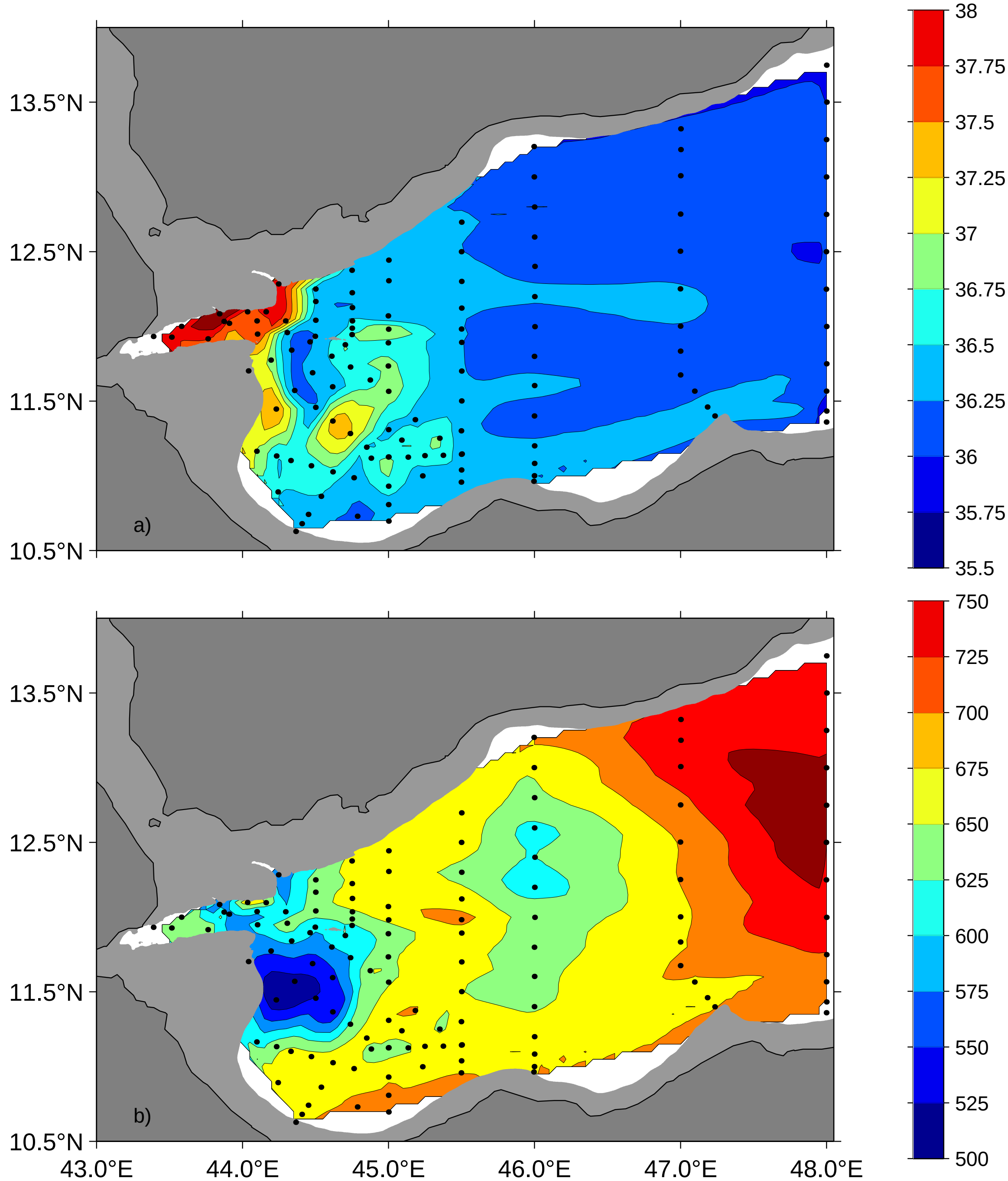

Figure 8. (a) Horizontal distribution of mean salinity in the Gulf of Aden at the main Red Sea Water spreading level (density layer 27.15-27.25 sigma-theta) during REDSOX-1. (b) same as a) but showing mean pressure (dbars).

Figure 9a. Surface current vectors measured by the underway Acoustic Doppler Current Profiler, showing the strong eddy field in the Gulf of Aden during the REDSOX-1 cruise.

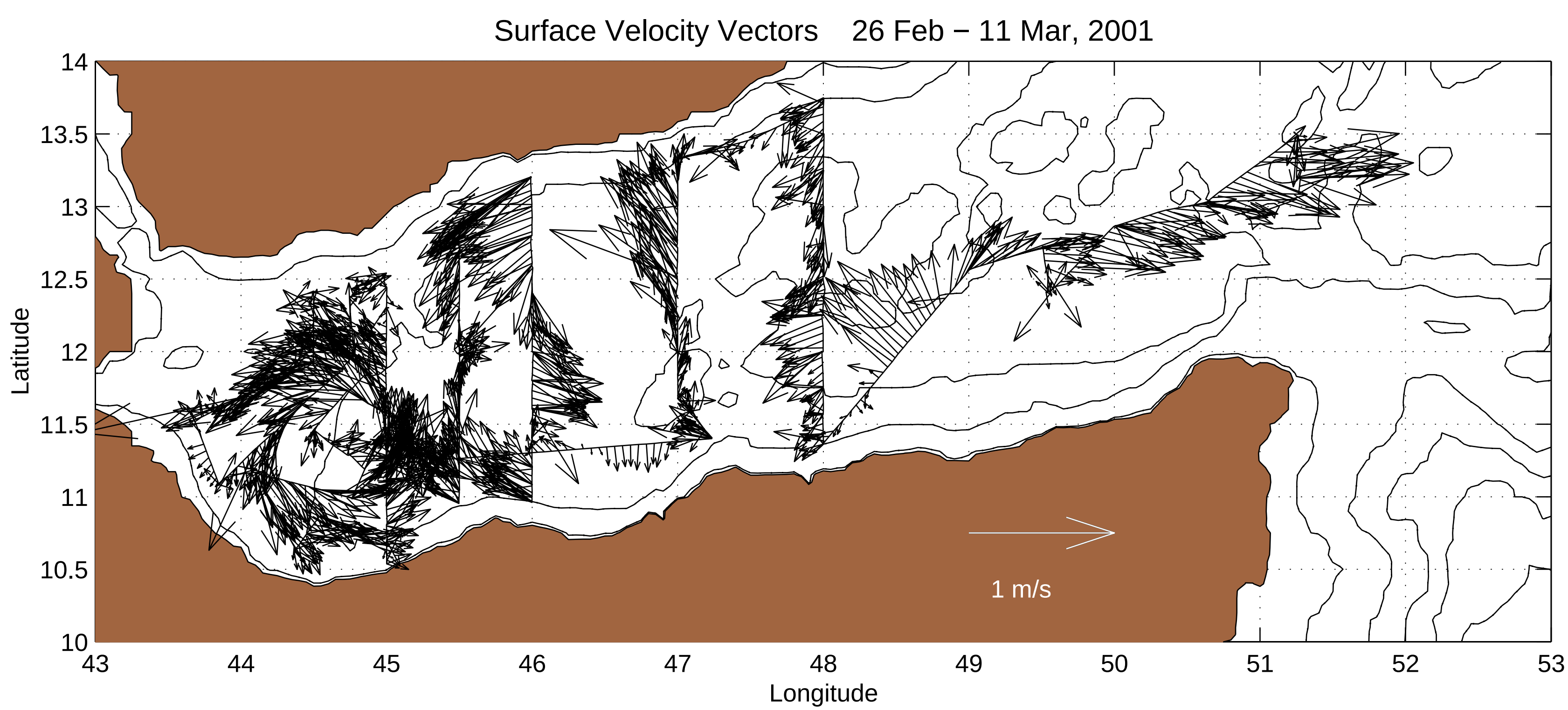

Figure 9b. Current vectors at 300 m measured by the underway Acoustic Doppler Current Profiler, showing the strong eddy field in the Gulf of Aden during the REDSOX-1 cruise.