Cruise Report

R/V *Knorr* Cruise 161-6

7 April to 16 May 2000

Brazil Basin Tracer Release Experiment

James R. Ledwell, Terence Donoghue, Brian Guest,
Peter Lemmond, Cynthia Sellers, and Norbert Cortes*

Woods Hole Oceanographic Institution, Woods Hole Massachusetts, 02543 USA
*Institute Français de Recherche pour l'Exploitation de la Mer (IFREMER), Brest, FRANCE

TABLE OF CONTENTS

Cruise Report

R/V *Knorr* Cruise 161-6

7 April to 16 May 2000

Brazil Basin Tracer Release Experiment

James R. Ledwell, Norbert Cortes, Terence Donoghue, Brian Guest,
Peter Lemmond, and Cynthia Sellers

INTRODUCTION

The purpose of the Brazil Basin Tracer Release Experiment is to measure diapycnal (across isopycnal) mixing and epipycnal (along-isopycnal) mixing and stirring in the deep ocean. This cruise is the fourth in the overall experiment. In the first cruise in early 1996, 110 kg of sulfur hexafluoride (SF_6) were released on an isopycnal surface near 4000 meters depth in the eastern part of the basin on the flanks of the Mid-Atlantic Ridge (MAR). The location of the release was near 21.7 S, 18.4 W. The release site was over a zonal valley that leads to the MAR and is about 5000 m deep. The isopycnal surface of the release was defined as the surface on which the potential density anomaly, referenced to 4000 dbar pressure, was 45.9408 kg/m^3. The release streaks and results of initial sampling in 1996 are described in Polzin et al. [1997].

Surveys of the tracer patch were made in 1997 and 1998, with the results summarized in Ledwell et al. [2000]. The tracer was found to mix with a diapycnal diffusivity of 3 cm^2/s near the target density surface, and with an epipycnal diffusivity of 100 m^2/s. The diapycnal diffusivity appears to increase toward the bottom. There also appears to be a flow of about 1 cm/s toward the east in the region beneath the target isopycnal surface. This deep eastward flow had carried about 30% of the tracer east of the release site as of 1998, while the rest of the tracer was in a patch that had drifted west and a little south at a mean speed of about 0.3 cm/s. Tracer concentrations in the east tend to increase with depth until a thick layer of uniform tracer and weak stratification is found in the deep water. This layer can be hundreds of meters thick in the valleys and deep depressions. The concentration profiles in the west tend to be more Gaussian in shape, and centered near the target density surface.

Measurements were made of the dissipation rate of turbulent kinetic energy and temperature variance with the High Resolution Profiler in 1996 and 1997. Results from this instrument are reported in Polzin et al. [1997] and in Ledwell et al. [2000]. They indicate mixing which is enhanced at all depths in the eastern part of the basin where the bathymetry is rough and which increases strongly with depth. The diffusivities, adjusted for certain sampling biases, agreed with the tracer result at the target density surface, and increase to around 10 cm^2/s near the tops of the bathymetric ridges. Over smooth bathymetry that characterizes the western half of the basin the diffusivity inferred from the dissipation measurements is very low, on the order of 0.1 cm^2/s. The hypothesis for this pattern of mixing is that the tides running over the rough bathymetry generate internal waves which propagate upward into the water column where the associated shear intensifies, inducing turbulent mixing events.

Overall, the mixing in the eastern part of the basin appears to be strong enough to provide the heat flux necessary to balance the heat budget for the abyssal water of the Brazil Basin. Hogg et al. [1982] and Morris et al. [1997] infer from the net rate of Antarctic Bottom Water entering the basin in various temperature and density classes that the diapycnal diffusivity averaged over the whole basin is 2 to 4 cm^2/s. The tracer release experiment has found values this large at the target density surface in the eastern part of the basin. The dissipation data suggest that the lower diffusivity in the western part may well be compensated by higher values of diffusivity and of heat flux where the isopycnal surfaces come near the bottom in the east.

CRUISE OBJECTIVES

The objectives of the cruise were:

1.) To survey the tracer 51 months after deployment to continue to measure the diapycnal diffusivity, especially in new regions penetrated by the tracer, and to continue to measure the lateral dispersion which is due to a combination of diapycnal and epipycnal processes.

2.) To recover a current meter mooring that had been deployed in 1998 in the valley of the tracer release to measure the flows in the valley and the character of the internal waves in and above the valley.

3.) To survey the bathymetry with a multibeam system to provide input to models of internal wave generation, to explore the passages through the Mid-Atlantic Ridge at the latitude of the tracer patch, and to map the zonal valleys that appear to be acting as conduits for the deep tracer in the east.

4.) To deploy 6 shearmeter floats developed by Tim Duda and Webb Research Corp. to measure the statistics of the shear field between 3000 and 4000 meters depth in the region of the tracer release experiment over a period of one year. (One of these shearmeters was damaged irrevocably during deployment.)

5.) To deploy two sound source moorings for IFREMER in Brest, France. The purpose of these sound sources is to support the RAFOS program in the Brazil Basin. They will also provide trajectories for the shearmeter floats deployed on this cruise.

CRUISE STATISTICS, PERSONNEL AND SHIP SPECIFICATIONS

The cruise lasted 39 days, from 7 April to 16 May 2000, with Recife, Brazil, serving as the point of departure and return. The R/V *Knorr* is a research vessel operated by the Woods Hole Oceanographic Institution. Specifications of the ship are in Appendix 1. The crew members and members of the science party are listed in Appendices 2 and 3.

CRUISE NARRATIVE

The backbone of the cruise was a CTD/Rosette survey with samples drawn from the Niskin bottles for SF_6 and for salinity calibration. The cruise track is shown in Fig. 1. The main events of the cruise are listed in Table 1 and the CTD stations are listed in Table 2. Stations were 60 to 80 nautical miles apart along the track. The general layout of the cruise track was planned to sample all but the edges of the tracer patch, while emphasizing zonal rather than meridional lines to get the most useful bathymetric data from the SeaBeam system. Zonal lines were preferable to meridional lines in order to sample well the relatively short zonal scales of the abyssal hills, which are more effective at generating internal waves from the tidal currents than the longer meridional scales. The selection of actual stations during the survey was guided by weighing the following considerations: the distribution of the tracer in 1998; the findings as we went along; the desire to sample the abyssal hills zonally between stations; the desire to sample in relatively deep spots to get the full concentration profile; and the desire to sample the patch adequately in the available time. There were also specific features that we wanted to map with SeaBeam, namely the valley in which the tracer was released and which held the current meter mooring, the Rio de Janeiro Fracture Zone, and certain deep passages through the Mid-Atlantic Ridge.

CTD data were gathered from 5 meters below the surface to 20 meters above the bottom at each station. Most of the Niskin bottles were tripped between 2000 meters and the bottom, which varied from 3700 to 5800 meters depth. Bottle spacing varied from 50 to 200 meters with the usual spacing being 100 meters. Depths between 3000 meters and the bottom were covered on every cast, with no greater than 100-meter spacing between 3500 meters and 4800 meters depth. Every Niskin bottle was sampled for SF_6. Typically 7 of the 24 Niskin bottles were sampled for salinity calibration. The SeaBeam system was run continuously along the cruise track, but turned off during station occupations. There was very little down time for the SeaBeam system while underway.

The first 5 CTD stations were outside of the tracer patch, as it turned out. During these casts, while we hunted for the western edge of the patch, we were improving the quality of sampling and analysis for very low concentrations. The lowest concentrations found in samples from outside of the tracer patch average around 0.03 fM, with a standard deviation of around 0.01 fM. This is close to the minimum detectable level. It is not known how much of this 0.03 fM is actually in the deep basin water and how much invades during sampling from the air. A new set of sample bottles had been brought, designed to take a Niskin sample with no contact with the ambient air. It turned out that blanks from these sampler bottles were no lower than for the normal sample bottles, and in most cases were higher. Their weakness may be the difficulty in clearing all air bubbles from the tubing used to connect the Niskin with the sample bottle. Some of the Niskins in Stations 1 and 2 were sampled with the old bottles and some with the new. Station 3 was sampled with all old bottles. Station 4, at the same location as Station 3, was sampled with all new bottles, as was Station 5. After Station 5 it was decided that the old bottles were showing less variability and were to be preferred. The old bottles were used for the remainder of the cruise, except that the new bottles were tried again in tests using the upper 4 Niskins, all tripped at 2800 dbar where no tracer was expected, in some of the shallower casts toward the end of the cruise.

The first sound source mooring was deployed near 24 S, 25 W, as requested by M. Ollitrault

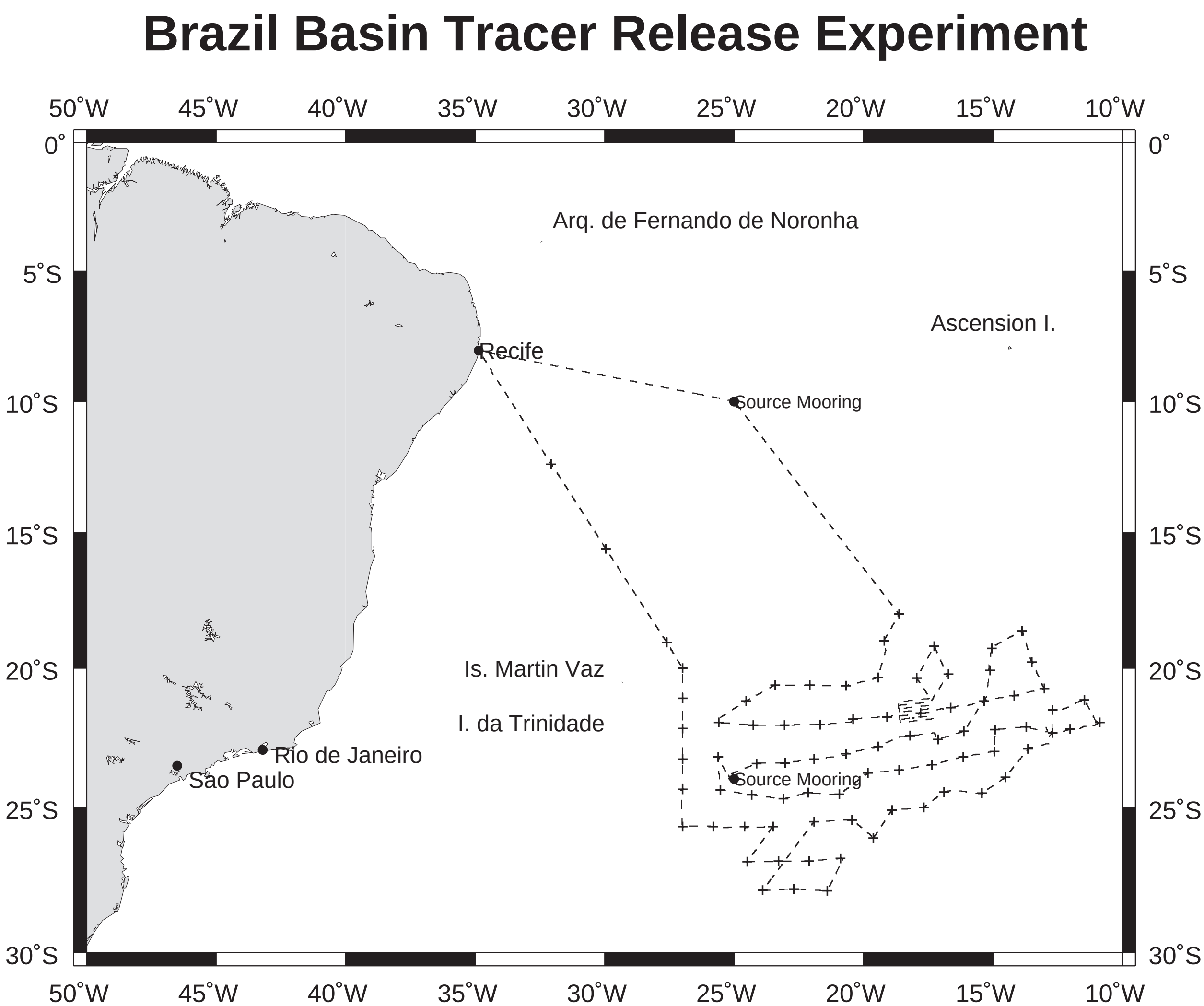


Figure 1. Cruise Track.

Table 1. Events of the Cruise

Date	Time (GMT)	Event	Lat (S)	Long (W)	Depth (m)
7-Apr		Depart Recife			
4/7-4/26		CTD Stations 1-49			
26-Apr	1533	Deploy Sound Source B7	23° 53.6'	25° 16.6'	5550
4/26-5/3		CTD Stations 50-66			
3-May	1030	Recover CM Mooring	21° 37.9'	17° 48.5'	5140
5/3-5/6		CTD Stations 67-69			
6-May	0755	Deploy Shearmeter 102	21° 51.4'	18° 35.2'	3500
6-May	1005	Deploy Shearmeter 100	21° 50.0'	18° 18.5'	3000
6-May	1020	Deploy Shearmeter 101	21° 50.0'	18° 18.5'	3500
7-May	0514	Deploy Shearmeter 99	21° 42.6'	18° 37.9'	4000
7-May	0519	Deploy Shearmeter 104	21° 42.7'	18° 37.8'	4000
5/7-5/10		CTD Stations 70-80			
13-May	0046	Deploy Sound Source B6	10° 00.1'	24° 58.9'	5575
16-May		Arrive Recife			

Table 2. CTD Station List

Station Number	Date mmdd	Time (GMT)	Lat. (°S)	Long. (°W)	Max. CTD Pressure (db)	Min. Altimeter HAB* (m)	SF_6 Column Integral (nmol/m²) **
1	0408	16:22:04	12.396	32.067	3802.82	28.4	Test
2	0409	15:28:26	15.591	29.954	5089.08	10	0
3	0410	15:10:56	19.066	27.599	5459.43	19	0
4	0410	18:44:33	19.067	27.600	5464.11	18.1	0
5	0411	2:54:55	20.000	26.999	5364.6	17.8	0
6	0411	11:08:08	21.102	26.999	5552.26	17.7	0.07
7	0411	19:12:32	22.201	26.999	5354.94	18.9	0.02
8	0412	3:16:06	23.299	26.998	5545.13	19.4	0.28
9	0412	11:04:16	24.370	27.000	5884.81	17.9	0.07
10	0412	20:51:17	25.667	27.000	5403.52	17.6	0.06
11	0413	4:56:45	25.666	25.799	5103.93	20.8	0.05
12	0413	13:11:43	25.666	24.600	5086.12	20.4	0.23
13	0413	20:54:15	25.667	23.499	5011.79	17.2	0.68
14	0414	6:54:27	26.900	24.501	5578.58	18	0.13
15	0414	14:48:12	26.883	23.299	5467.97	19.1	0.38
16	0414	22:32:21	26.868	22.099	5348.41	18.7	0.56
17	0415	6:46:28	26.784	20.900	5039.65	20.6	0.12
18	0415	15:23:53	27.900	21.399	4918.56	21.3	0.07
19	0415	23:32:06	27.832	22.699	4707.62	20.6	0.26
20	0416	6:59:35	27.884	23.901	5553.61	17.3	0.1
21	0417	0:28:08	25.499	21.916	5091.18	16.9	1.67
22	0417	9:32:04	25.434	20.451	4958.08	18.5	0.62
23	0417	17:19:53	26.110	19.544	2566.77	aborted	aborted
24	0417	18:50:25	26.078	19.622	4836.13	19.4	0.31
25	0418	2:49:50	25.099	18.913	4938.33	18.8	0.24
26	0418	10:27:33	25.000	17.708	238.73	aborted	aborted
27	0418	11:04:49	25.001	17.674	4597.55	16.6	0.34
28	0418	17:49:55	24.459	16.900	4680.72	16.3	0.48
29	0419	3:10:31	24.494	15.431	3975.72	20	0.15
30	0419	10:18:36	23.937	14.520	4089.72	17	0.32
31	0419	18:49:04	22.923	13.659	5492.02	17.7	1.46
32	0420	3:31:01	22.343	12.702	4408.4	18.8	0.88
33	0420	9:00:08	22.218	12.032	5417.3	16.7	1.43
34	0420	17:44:17	21.982	10.894	4662.83	18.7	0.82

Table 2. CTD Station List (continued)

Station Number	Date mmdd	Time (GMT)	Lat. (°S)	Long. (°W)	Max. CTD Pressure (db)	Min. Altimeter HAB* (m)	SF_6 Column Integral (nmol/m²) **
35	0421	1:15:16	21.166	11.482	4052.67	18	0.32
36	0421	9:32:16	21.515	12.713	4593.73	16.7	1.41
37	0421	22:46:03	22.126	13.717	4395.72	17.8	0.9
38	0422	6:42:40	22.232	14.926	4457.35	17.1	1.24
39	0422	13:49:34	23.019	14.961	4971.64	16.3	1.54
40	0422	21:57:25	23.207	16.150	5034.7	18.3	1.41
41	0423	6:04:56	23.478	17.367	5258.5	16.8	1.23
42	0423	14:54:16	23.686	18.643	5309.7	16.7	1.07
43	0423	23:41:44	23.785	19.833	5675.2	18.5	1.4
44	0424	8:49:18	24.546	20.947	5090.48	16.8	1.94
45	0424	17:46:27	24.477	22.148	5037.86	16.9	2.35
46	0425	1:00:58	24.701	23.105	5443.43	20.1	2.87
47	0425	9:31:02	24.551	24.333	5654.17	19.5	1.59
48	0425	18:47:26	24.376	25.534	5711.69	19.9	0.51
49	0426	3:41:35	23.222	25.617	5723.06	18	1.45
50	0426	22:03:57	23.446	24.137	5726.2	16.6	0.84
51	0427	6:08:33	23.420	23.038	5615.21	16.3	1.97
52	0427	14:26:28	23.298	21.919	5548.6	15.6	2.11
53	0428	3:42:38	23.096	20.694	5401.39	40.8	1.63
54	0428	12:38:41	22.839	19.438	5172.86	16	1.5
55	0428	21:58:04	22.458	18.217	4987.77	19.4	1.54
56	0429	7:07:37	22.580	17.140	4833.02	13.7	1.76
57	0429	14:43:42	22.300	16.136	4512.57	14.1	1.6
58	0429	23:57:10	21.200	15.360	5185.54	18.1	2.66
59	0430	8:49:27	21.003	14.181	4942.5	17.6	2.1
60	0430	17:26:57	20.747	13.033	4466.1	17.2	1.39
61	0501	3:00:55	19.785	13.516	3756.72	16.5	0.19
62	0501	11:01:10	18.638	13.897	3858.02	14.9	0.1
63	0501	19:46:36	19.287	15.065	4240.5	16.2	0.41
64	0502	2:13:52	20.090	15.128	4121.63	16.4	0.43
65	0502	16:30:03	21.445	16.642	5052.08	16.9	1.95
66	0503	2:46:59	21.646	17.810	5146.32	18.1	1.6
67	0504	21:17:38	20.222	16.737	4485.89	17.1	0.83
68	0505	5:37:15	19.203	17.277	4199.04	16.9	0.38

Table 2. CTD Station List (continued)

Station Number	Date mmdd	Time (GMT)	Lat. (°S)	Long. (°W)	Max. CTD Pressure (db)	Min. Altimeter HAB* (m)	SF_6 Column Integral (nmol/m²) **
69	0505	14:28:36	20.369	17.956	5163.06	16.6	0.93
70	0506	8:22:16	21.768	19.103	5270.72	15.2	1.29
71	0506	16:36:40	21.848	20.403	5302.39	19.2	1.72
72	0507	1:03:46	22.050	21.672	5131.32	18.4	0.99
73	0507	9:44:11	22.069	23.067	6025.71	16.8	0.76
74	0507	17:52:11	22.069	24.271	5862.16	18.7	0.06
75	0508	2:33:22	21.977	25.603	5662.87	18.2	0.04
76	0508	11:59:38	21.203	24.550	5828.82	14.5	0.13
77	0508	20:57:30	20.623	23.426	5241.85	18.6	0.16
78	0509	5:59:16	20.634	22.091	5478.01	15.5	0.22
79	0509	15:28:10	20.645	20.683	5416.85	16.3	0.44
80	0510	0:17:06	20.356	19.443	5275.86	18.1	0.82
81	0510	9:40:57	19.008	19.208	5084.69	14.9	0.34
82	0510	17:56:33	18.020	18.630	4378.35	18.6	0.11

*HAB = Height above bottom from the altimeter at the maximum pressure of the CTD cast

** Column integrals should be multiplied by 0.851 for the best absolute accuracy.

of IFREMER. Mr. Norbert Cortes participated in the cruise as mooring specialist from IFREMER, and Brian Guest, of WHOI, ably orchestrated and led the deployment. The mooring was deployed smoothly and without incident, thanks to the crew of the *Knorr*. A diagram of this mooring is included in Appendix 9.

A search for sills in the passages through the Mid-Atlantic Ridge where the Rio de Janeiro Fracture Zone (RJFZ) passes through was undertaken with the SeaBeam system. The shallowest point over which water must pass in these passages is apparently on the west side of the MAR in the RJFZ near 13 W, 22.7 S, at 3900 meters depth. To the west of that sill, at Station 31, we found σ_4 = 45.896 20 meters above the bottom. In the rift valley at the center of the MAR, the relatively shallow Station 32 gave 45.879 near the bottom and just to the east at a deeper spot Station 33 gave 45.883. There is another series of sills east of Station 33 in the RJFZ with the shallowest near 22.1 S, 11.3 W, with a sill depth of 4250 m. To the east of that sill and well into the Angola Basin side, at Station 34, the bottom density was 45.871. Hence, it appears that water of density at least as great as 45.87 makes its way across the MAR from the Brazil Basin into the Angola Basin. This bottom water undoubtedly starts on the western side at a greater density, perhaps 45.90, but is modified by diapycnal mixing during the transit through the passages.

Other deep pathways through the MAR in the vicinity of the RJFZ were sought. The passage leading northwest from Station 32 was found to have a shallowest sill at about 3800 meters. A broad shallow saddle was found east of Station 36 with a sill depth no greater than 3700 meter, so there is no particularly deep passage here. In summary, it appears that the effective sill depth for the RJFZ is approximately 3800 meters and the density of the deepest water passing through is approximately σ_4=45.87.

A nearly continuous SeaBeam map was made of the RJFZ from 19.83 W to 11.48 W, the only gap being between 14.96 W and 13.66 W. Also, a continuous SeaBeam map was obtained for the valley of the tracer release from 20.40 W to 14.18 W. These valleys are dramatic bathymetric features, often with a sharp straight escarpment about 500 meters high to the south. The valley floors are not flat, however. The abyssal hills intrude across the valley floors from the north and sometimes the south. There are occasionally deep flat depressions between these hills.

In one such depression in the valley of the tracer release, a current meter mooring had been deployed in 1998. This mooring was recovered successfully on 3 May 2000, with all instruments but one in good condition. One of the current meters had been slightly damaged, presumably during recovery, as the mooring came to the surface in a big tangle. Again, the recovery was orchestrated by Brian Guest, and ably executed by him and the ship's crew and members of the science party.

During most of the cruise SeaBeam data were gathered from just a single swath along the track between CTD stations, with a few extra digressions taken in the passages at the MAR. However, a more extensive SeaBeam survey was made in a rectangular region which included both the site of the original tracer release and the current meter mooring. A set of 7 parallel swaths were occupied in this rectangle, 13 to 14 km apart and about 130 km long, to give a rectangle 100 km x 130 km in size. This survey reveals the close spacing of the abyssal hills in the zonal direction and their great length scales in the meridional direction (Fig. 2).

The shearmeter floats were deployed in the southwest part of this box, and southeast of the site of the original tracer release. These neutrally buoyant floats were designed by Tim Duda and built by Webb Research, Inc. They are tubes 9 meters long with a set of vanes at each end designed to make the tube rotate in response to a difference in velocity at the two ends, i.e., the shear magnitude. The number of rotations is recorded periodically, along with temperature at each end and pressure. The arrival times of acoustic signals from the sound source moorings deployed on this cruise will also be recorded, enabling the float trajectory to be determined. The floats use RAFOS technology in most of the design details, the enhancement being the shear vanes and the compass to measure rotations. They are described in more detail in Appendix 8.

One of the floats was irrevocably damaged during deployment. The other 5 were deployed successfully. Times and positions are listed in Appendix 8. The floats will surface one year after deployment and relay the internally stored data by the ARGOS satellite system. They will then be allowed to drift away, the cost of recovery being too great.

The tracer survey was continued to the west and north after the last shearmeter float was deployed. The northern edge of the patch was delimited at about the same level as the west and southern edges, i.e., at a column integral of less than 0.5 $nmol/m^2$, compared with the maximum values of nearly 3 $nmol/m^2$. In mapping it will be necessary but straightforward to extrapolate to the very fringes of the patch. A preliminary view of the results of the survey is shown in Fig. 3.

The final scientific event of the cruise was the deployment of the second sound source for IFREMER at 10 S, 25 W, two days after the end of the tracer survey and two days before arrival in Recife.

KNORR Voyage 161 Leg 6

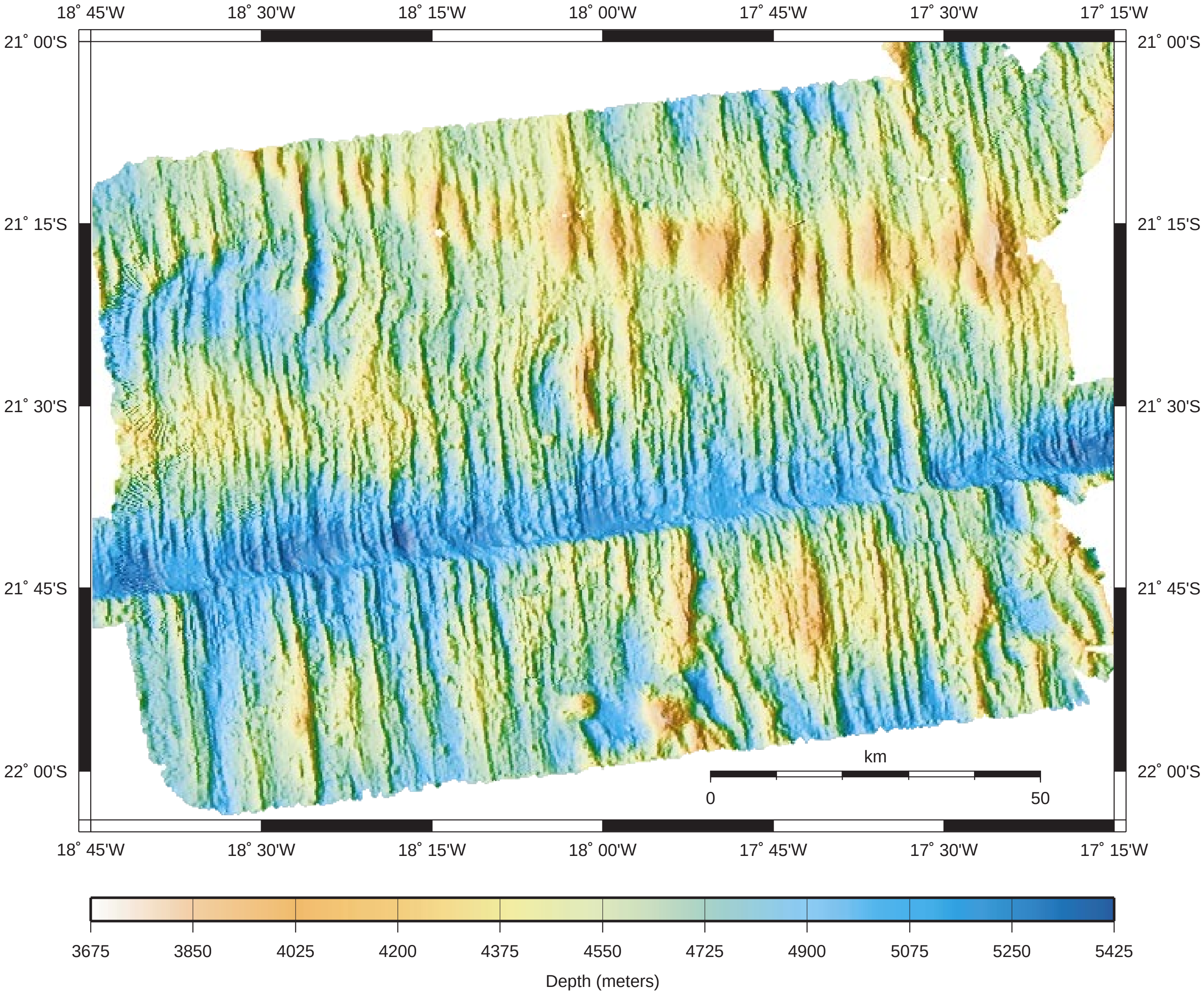


Figure 2. SeaBeam box survey. The shift in the bathymetry on the southern edge of the valley is real, and not an artifact. The tracer was released over this valley at 21.7 S, 18.4 W. The current meter mooring was in the valley to the east of this point at 21.6 S, 17.8 W. The abyssal hills, elongated in the meridional direction and steep in the zonal direction are believed to be responsible for the generation of internal waves, which in turn lead to mixing.

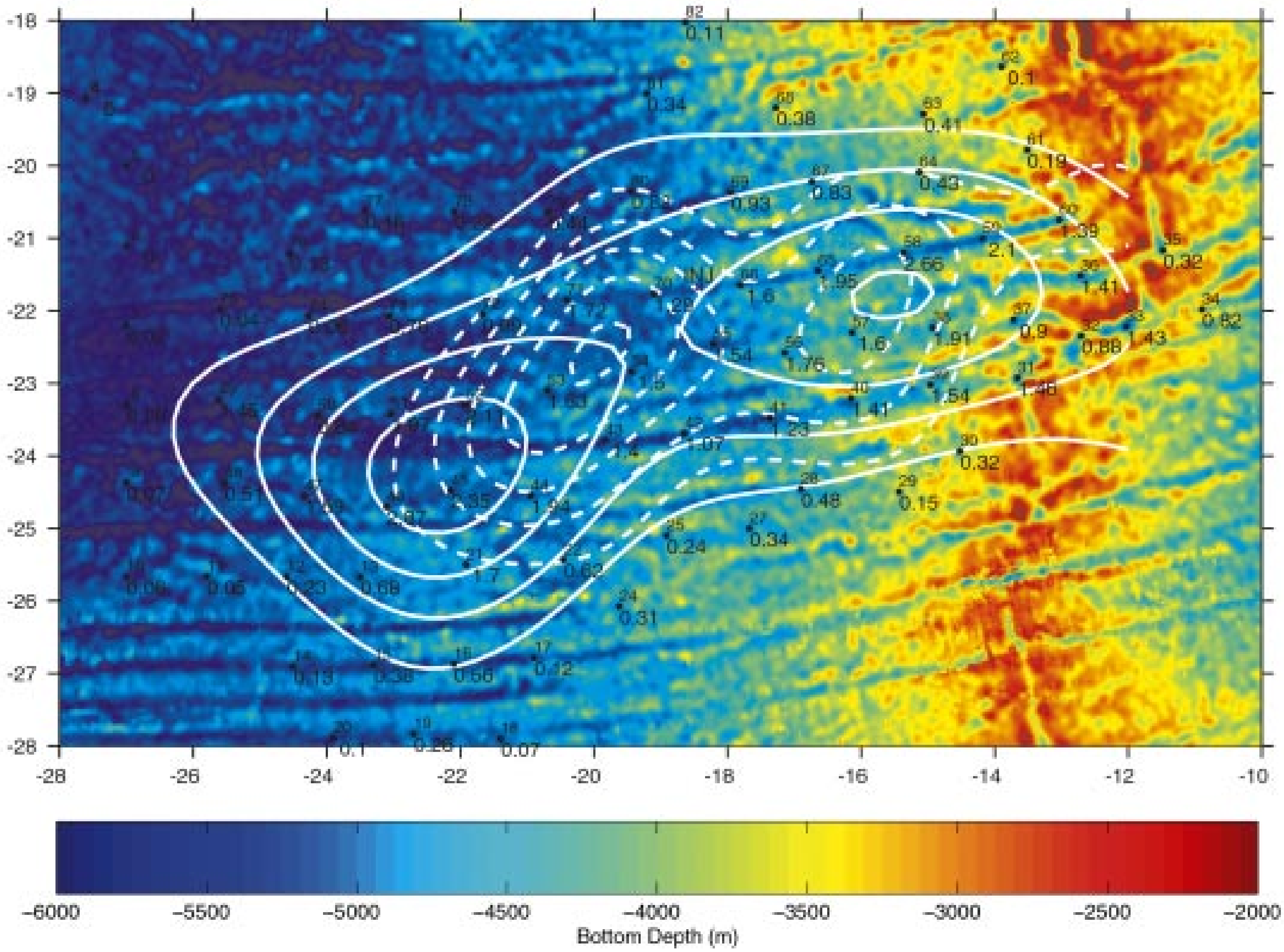


Figure 3. Station Map and SF_6 Distribution. The top number at each station is the Station number, the bottom number is the column integral of SF_6 found, in nmoles/m². The dashed contours are a map of the tracer distribution found in 1998. The solid contours are a map of this year's distribution (contour interval 1 nmol/m² for 1998 and 0.5 nmol/m² for 2000). The shading gives the bottom depth, in meters. Although it appears that the tracer field passes through the Mid-Atlantic Ridge, this is exaggerated by sampling only in the deep passages, which are very narrow. However, it is true that perhaps 2 or 3% of the tracer is on the Angola Basin side of the MAR. The release point is shown as "INJ," and this is surrounded by the box survey.

DATA SETS

Surface Data

Surface seawater and meteorological data are gathered routinely by R/V *Knorr*. No attention was paid to the quality of these data by the science party, so these should be received with caution. The variables recorded are:

Ship’s position

Ship’s speed

Ship’s heading

Sea surface temperature

Sea surface salinity

Sea surface chlorophyll fluorescence*

Air temperature

Relative humidity

Cumulative precipitation

Shortwave radiation

Atmospheric pressure

Wind speed

Wind direction

*The Chlorophyll Fluorometer was apparently not working properly during the entire cruise.

These data are supplied on the compact disk labeled “BB Athena/CTD.” Raw surface and meteorological data in the ship’s format are in a folder called “Athena” where there are separate files for each day’s data. In a folder called “CTD” there are .asc files containing the salinity corrected CTD data files along with the methods and figures outlining the salinity correction. Readme files in respective folders detail the contents of each file type.

ADCP Data

150Khz Acoustic Doppler Current Profiles (ADCP) were also taken along the ship track. These data were not of concern to the scientific mission of this cruise and so the quality has not been examined. In fact, it has subsequently been discovered that the transducer mounting is out by 18 degrees. As a result the ship motion was being badly aliased into a transverse current. The physical mounting was never changed. Changing the software offset from 45 to 30 on 5/3/00 at about 1711 gmt resulted in great improvement. An additional 3 degree correction was made on 5/8/00 at about 1225 gmt, changing the offset to 27 degrees, which yielded even better results, judging from the continuity in the velocities between those obtained on station and just afterward with the ship underway. That brought the total correction to 18 degrees, where it remained for the rest of the trip.

The compact disk “RV *Knorr* Science data: KN161-6” contains, among other things, a folder called “ADCP.” This has files of the format pingdata.xxx where xxx ranges from 001 on Apr 8 to 044 on May 16. These are the raw ping data files for each day.

SeaBeam Data

A multibeam sonar system was used to measure bathymetry along the entire cruise track, with only a few interruptions. The multibeam system on R/V *Knorr* is a SeaBeam 2100. The useful swath width is about 3 times the water depth, so at 4000 meters depth we map a swath 12 km wide. There are 120 beams two degrees wide, at one degree intervals between –60 and +60 degrees in the direction transverse to the ship track. Typically a new sounding is produced every 12 or 13 seconds. With the ship underway at a speed of 5.5 m/s a data point is obtained every 60 or 70 meters in the along-track direction. The resolution in the cross-track direction varies with beam angle and with water depth. In 5000 meters of water the absolute resolution would be less than 100 meters directly beneath the ship, but would increase to more than 300 meters at the outer edge of the swath. Hence, the spacing of individual data points for most of our cruise is 100 to 300 meters.

A box survey was done with SeaBeam in a region 100 km north-south by 130 km east-west surrounding the site of the tracer release and the site of the current meter mooring. Both of these sites are in the valley of the tracer release. The results are shown in Fig. 2.

Data products from the SeaBeam operation are as follows:

Raw data files, in SeaBeam vendor format. These files contain ping time, position, bathymetry, beam amplitude and sidescan data, and additional sonar information (system settings, sound velocity profile used, and so forth). Edited data files, also in SeaBeam vendor format. These files are produced from the raw data files, and are in the same format. In some cases, navigation adjustments have been made when needed. Individual pings have also been edited to remove beams containing bathymetric artifacts. Both the raw and edited files are contained on a 6.4Gb exabyte tape. Software needed to look at SeaBeam data is available and documented at:

http://www.ldeo.columbia.edu/MB-System

A number of bathymetry grids were produced, in GMT NetCDF format, for some areas where overlapping SeaBeam data were obtained. Grids and postscript versions of contour plots of the grids are on the exabyte tape in the “plots” directory. There is also a Readme file on the tape that generally explains the data file structure. The tape is written in Unix tar format, Exabyte 8500 density with compression.

Files of time, position, and depth for every beam of every ping were generated from the edited data files. These files are grouped to correspond to the intervals between each CTD station, and are in both compressed ASCII format and MatLab .mat format on compact disks named “KN161-6/SeaBeam/text” and “KN161-6/SeaBeam/mat” respectively. A Matlab m-file contained on the /mat CD outlines the method of extraction from the vendor formatted files described above.

CTD Data

The CTD Rosette system included a SeaBird 911 CTD, with two pairs of pumped C/T sensors, a SeaBird rosette pylon for tripping the bottles, a Datasonics altimeter, a pinger made by Ocean Instrument Systems, and 24 four-liter Niskin bottles. The frame was relatively small in diameter and weighted with over 400 kg of lead weights to keep tension in the CTD cable during downcasts at 90 meters/minute. The system weighs 600 kg in the water and has a terminal velocity of more than 300 m/min. One of the C/T pairs, the "secondary" pair by SeaBird's convention, was positioned near the bottom of the frame to provide data during the downcasts with minimal disturbance from the wake of the package. The "primary" pair was positioned near the top of the frame to improve the data during the upcast. The primary data for the bottles is from this upper pair.

The C/T sensors were calibrated at SeaBird in December, 1999 and in June 2000. Calibrations of the salinity from the C/T sensors were performed with a Guildline Autosal salinometer during the cruise. Typically seven salinity samples were taken from each cast. Details of the calibrations at SeaBird and of the Autosal results are included in Appendix 6. Also, the lower conductivity sensor failed at the bottom of Cast 71. An attempt was made to clean it, but it was malfunctioning throughout Cast 72. Hence, the upper C/T pair, i.e., the primary pair, must be used for valid data from cast 72. This failed sensor was replaced prior to Cast 73. Additional discussion of the temperature and conductivity calibrations is contained in Appendix 6.

CTD data were obtained at every station from 5 meters below the surface to 20 meters above the bottom, with the exceptions of Station 1 which was a test cast, and Stations 23 and 26, which were aborted because the depth was not great enough. The best data were gathered during the downcasts because the upcasts were interrupted 24 times by tripping of the Niskin bottles. For the downcasts, the best data are from the lower sensor pair, i.e., the secondary pair. Temperature and salinity from this pair are called T2 and S2 in the data files, while those from the upper, primary pair are called T1 and S1.

Most of the CTD data are relatively unprocessed beyond initial parsing performed by SeaBird's SeaSoft software. These steps are outlined in the file "GO_161_6.bat." The underwater unit sends data to the deck unit at 24 scans per second. The deck unit was set to average over 12 scans, so it passes 0.5-second averaged data to the acquisition computer at a rate of 2 records/second. Most of the data have not been corrected for salinity or temperature offset, nor have they been averaged further or interpolated to standard pressures. An exception is the data set on the compact disk "BB/Athena/CTD" which has had the salinity correction described in Appendix 6 applied.

SF_6 Data

SF_6 samples were drawn from the Niskin bottles into 500-ml glass bottles with ground-glass stoppers in much the same way as oxygen samples are taken. The water first entering the bottle comes into much contact with air, and so the bottles are allowed to overflow by about 500 ml before the stopper is put in. Bubbles are avoided in the samples. Some contamination of the sample from exchange with the air is inevitable, however. This is particularly noticeable for water that should have little or no SF_6. The mean concentration for such samples was 0.03 fM, as mentioned earlier, and this is attributed to invasion from the air. The standard deviation of the concentration was around 0.015 fM, and occasionally samples are found with absolutely no detectable SF_6, which means less than 0.01 fM.

The samples were analyzed with a gas chromatograph equipped with an electron capture detector. The system is similar to that described by Law et al. [1994]. Blanks are created to test the soundness of the system by equilibrating a very low sample with about 50 ml of nitrogen in a 500 ml bottle before taking the sample into the system. This water should be devoid of SF_6, and for a carefully prepared blank there was virtually no response of the GC at the retention time of SF_6. That is, the system blank was less than 0.01 fM throughout the cruise.

The sparging system did not remove 100% of the tracer during analysis. The amount left behind was determined by sparging a sample a second time. The average amount left in these resparged samples was 5.9 %, with a standard deviation of 0.9 %, and this was taken into account in analyzing the data.

The precision of the whole process, from closing the Niskin bottle to analysis, was tested by tripping duplicate Niskin bottles at the same depth on several occasions. The average difference for 24 duplicate samples for which the concentration was greater than 0.2 fM was 0.032 fM, which implies a standard deviation for individual samples of 0.022 fM. This value is quite consistent with the expected sources of error, including especially variations in sparge efficiency and noise in the output of the electron capture detector. The uncertainty usually assigned to a sample was approximately 0.02 fM plus 2.5 % of the estimated concentration.

Concentrations are calculated by comparison with a standard amount of SF_6 in nitrogen. The nominal mixing ratio of this standard was 91.3 parts per trillion. However, measurements of the concentration in the air over the South Atlantic by comparison with this standard gave a mixing ratio in dry air of 5.37 +- 0.03 parts per trillion on 12 May 2000. This value is nearly 18% higher than the value of 4.57 ppt estimated for the mean surface value for the Southern Hemisphere by extrapolating the formulas of Maiss and Brenninkmeijer [1998], based on data from Cape Grimm at 41˚S. The calibration of these latter data is far more accurate than our own, so all of our SF_6 concentrations should be multiplied by 0.851. This correction has not been made in the data sets from the cruise.

There is one other effect that should be accounted for in the SF_6 concentrations. It is known that SF_6 dissolved in water will readily adsorb onto plastic surfaces containing the water. Containers of typical geometry with smooth surfaces will end up with approximately 6% of the SF_6 on the walls. It is probable that some SF_6 from our samples is lost to the walls of the PVC Niskin bottles. Some more may be lost to the walls of the glass sample bottles. In both cases, the adsorbed SF_6 will be lost to the air as soon as the water leaves the container, so contamination of subsequent samples should not be a problem. However, it is desirable to better quantify the amount lost to both the Niskin bottles and the glass bottles in further laboratory tests.

Nominally 82 stations were occupied during the cruise. However, Station 1 was a test station and Stations 23 and 26 were aborted because they were started at too shallow a location. So there are 79 real CTD casts. Stations 2 through 6 are considered tests for the SF_6 sampling system, and so there are 73 useful SF_6 profiles, although it is true that we can place very low upper limits on the SF_6 in the first 6 stations. All but two of these 73 stations have measurable SF_6 from the tracer patch in them. Most of the profiles are shown together in miniature in Figure 4. The profiles in the west are sharply peaked near the target density surface. As one moves east, one sees broader profiles, often with two peaks, a new one appearing below the target density surface. In the far east of the survey the concentration increases monotonically toward the bottom, and for the deep stations there is a layer hundreds of meters thick with fairly uniform concentration.

The bottle data are contained on a zip disk labeled "KN161-6: Data Vol. 1" in a folder called "SF6." The SF_6 profiles are included in the bottle data, and can be readily plotted as a function of pressure, σ_4, potential temperature or density. It should be remembered that the accompanying hydrographic data are uncorrected.

Other Data

The compact disk "RV *Knorr* Science Data:KN161-6" has a folder called "Images" which contains AVHRR images taken during the cruise in .JPG format. The same disk has folders called "Centerbe" which has daily files of SeaBeam's centerbeam (underhull bottom depth); "CTD/process" with seasoft data converted to ascii (.cnv) and split into up (.cup) and down (.cdn) cast files; "CTD" with seasoft data (.dat), header (.hdr), bottle (.bl), and configuration (.con) files for each cast; and "CTD/SeaSave" which has the SeaSoft software and the "GO_161_6.bat" batch file used in initial data processing. Refer to the SeaSoft manual for an explanation of these file types and the processing programs used to create them.

Ascii niskin bottle data for each cast along with a readme file is contained on a zip disk labeled "KN161-6: Data Vol. 1" in a folder called "Bottle." The folder "sal_cal" duplicates the salinity correction data and figures. Also therein is a readme and matlab m-files describing the correction analysis. The folder "salt" has all the raw salt sample data in both ascii and MS Excel formatted cast files along with a readme file.

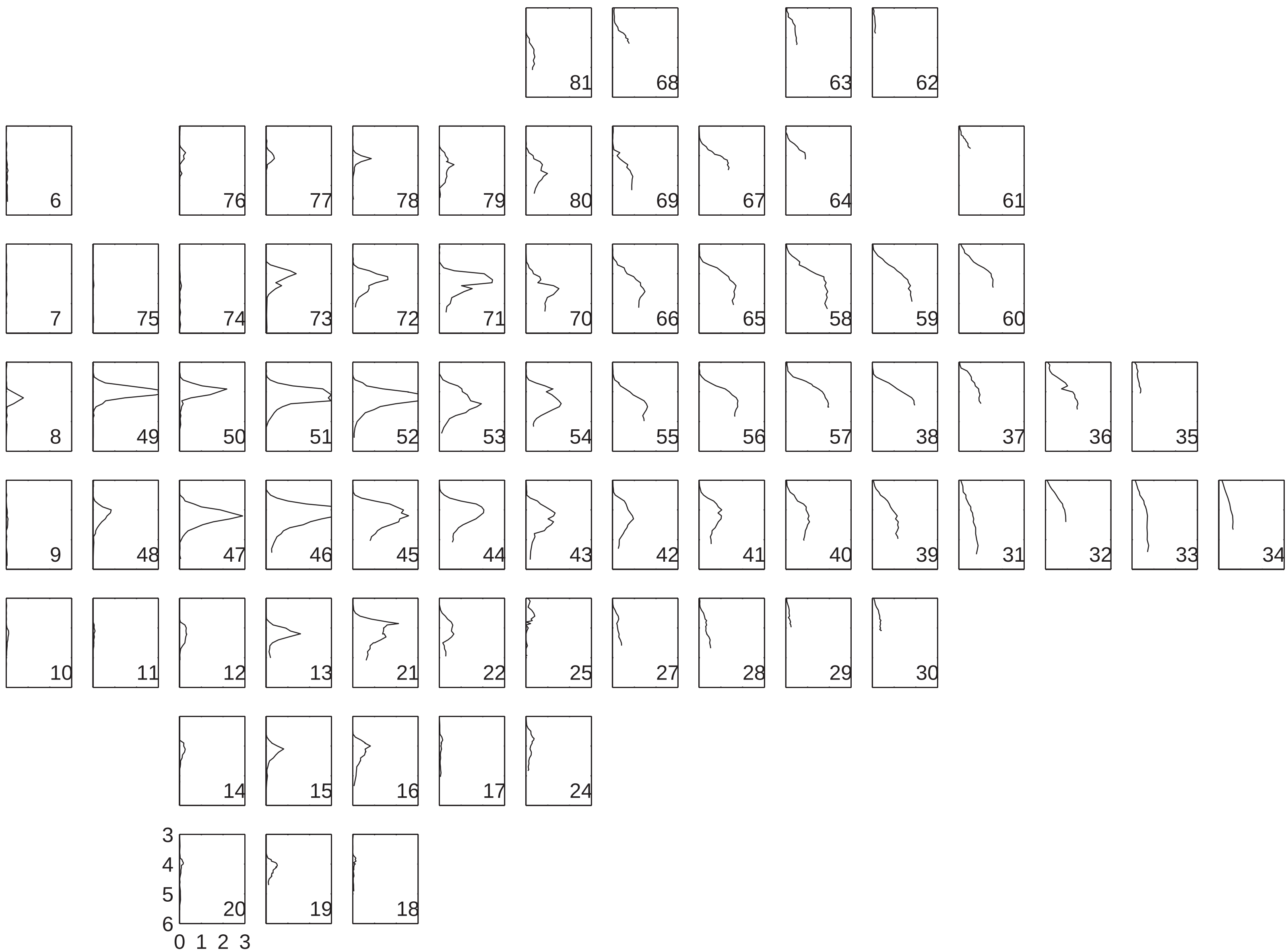


Figure 4. Mosaic of SF_6 Profiles. The station number is shown on each graph. The horizontal axis is concentration, from 0 to 3 fM for each plot, and the vertical scale is pressure from 3 to 6 thousand dbar. The plots are arranged roughly by position, from 28 S to 19 S along the vertical and from 27 W to 13 W along the horizontal axis of the page. A few profiles to the extreme north and east have been omitted.

REFERENCES

Hogg, N., P. Biscaye, W. Gardner and W. J. Schmitz, Jr., On transport and modification of Antarctic bottom water in the Vema Channel. J. Mar. Res., 40, (Suppl.), 231-263, 1982.

Law, C. S., A. J. Watson, and M. I. Liddicoat, Automated vacuum analysis of sulfur hexafluoride in seawater: derivation of the atmospheric trend (1970-1993) and potential as a transient tracer, Marine Chemistry, 48, 57-60, 1994.

Ledwell, J. R., E. T. Montgomery, K. L. Polzin, L. C. St. Laurent, R. W. Schmitt, and J. M. Toole, Evidence for enhanced mixing over rough topography in the abyssal ocean, *Nature*, 403, 179-182, 2000.

Maiss, M., and C. A. M. Brenninkmeijer, Atmospheric SF_6: Trends, sources and prospects, Eniviron. Sci. Technol., 32, 3077-3086, 1998.

Morris, M., N. Hogg, and W.B.Owens, Diapycnal mixing estimated from advective budgets in the deep Brazil Basin. International WOCE Newsletter 28, p23-25., 1997.

Polzin, K. L., J. M. Toole, J. R. Ledwell, and R. W. Schmitt, Spatial variability of turbulent mixing in the abyssal ocean, *Science*, 276, 93-96, 1997.

APPENDICES

APPENDIX 1. R/V *KNORR* SHIP'S SPECIFICATIONS

Built:	1969	**Mid-Life Overhaul:**	1989-91
Length:	279 feet	**Beam:**	46 feet
Draft:	16.5 feet	**Gross Tons:**	2,518 T
Displacement:	2,685 LT	**Endurance:**	60 days
Range:	12,000 NM	**Fuel Capacity:**	160,500 gallons
Laboratories:	3,175 sq. feet		

Speeds:
Cruising - 12.0 knots
Maximum - 14.5 knots
Minimum - 0.1 knot

Complement:
Crew - 22
Scientists - 32
Technicians - 2

Propulsion:
Twin Lips diesel-electric, azimuthing stern thrusters, 1500 SHP each

Bow Thruster:
Lips retractable azimuthing 900 SHP

Ship Service Generators:
None - integrated with propulsion

Portable Van Space:
At least six 20 ft. vans

Winches:
Trawl - 30,000' 9/16" wire
Cranes - two 60,000 lbs. capacity

Heavy Equipment:
Hydro (2) - 33,000' 3-cond. EM/1/4" wire|
HIAB crane, midships hydro boom

Ownership:
Title held by U.S. Navy; operated under charter agreement with ONR

Sewage System:
3,600 gallons/day
7,000 gal. holding capacity

Other Features:
Two instrument hangars, fully equipped machine shop, fume hoods, underwater bow observation chamber, uninterruptable power supply, air conditioning, library/lounge, copy machine, laundry, one rigid-hull inflatable rescue/work boat

APPENDIX 2. CREW LIST KN161-6

Name	Rating	Nationality
Colburn, A. D.	Master	USA
Soukhanov, Alexander	Chief Mate	USA
Mayer, Douglas	Second Mate	USA
Emrich, Deidra	Third Mate	USA
Donovan, John	Com/ET	USA
Dunn, William	Bosun	USA
Graham, Edward	Able Seaman	USA
Hopkins, Alan	Able Seaman	USA
Popowitz, Edward	Able Seaman	USA
Liarikos, Peter	Ordinary Seaman	USA
Kane, Andy	Ordinary Seaman	USA
Walsh, Stephen	Chief Engineer	USA
Morgan, Christopher	First Asst. Eng.	USA
Marczak, Piotr	Second Asst. Eng.	USA
Vigeaut, Jeffrey	Third Asst. Eng.	USA
Wright, Wesley	Electrician	USA
Wagner, Herman	Oiler	USA
Mayes, Joseph	Oiler	USA
Bean, Harold	Oiler	USA
Miller, Mirth	Steward	USA
Corbett, Tori	Cook	USA
Adapon, Jockey	Messman	USA

APPENDIX 3. SCIENCE PARTY LIST KN161-6

Name	Rating	Nationality	Email
Ledwell, James	Chief Scientist	USA	jledwell@whoi.edu
Guest, Brian	Scientist	USA	bguest@whoi.edu
Donoghue, Terence	Scientist	USA	tdonoghue@whoi.edu
Lemmond, Peter	Scientist	USA	plemmond@whoi.edu
Sellers, Cynthia	Scientist	USA	csellers@whoi.edu
Cortes, Norbert	Scientist	France	ncortes@ifremer.fr
Silva, Luiz	Scientist	Brazil	l.c.cosendey@zipmail.com.br
Oliveira, Joao	Scientist	Brazil	jlmoliveira@hotmail.com
Michelli, Maximiliano	Scientist	Brazil	maxmichelli@aol.com.br
Lanzillotta, Handerson	Scientist	Brazil	hoceano@ig.com.br
Da Silva, Robson	Naval Observer	Brazil	robmone@ig.com.br
Laird, Robert	SSSG	USA	sssg@knorr.whoi.edu
Plourde, Eric	SSSG	USA	sssg@knorr.whoi.edu

APPENDIX 4. ACADEMIC AGREEMENT

Agreement of Academic Exchange and Cooperation

PARTICIPANTS:
Prof. Friedrich W. Herms, Universidade do Estado do Rio de Janeiro
Dr. James R. Ledwell, Woods Hole Oceanographic Institution
Dr. John Toole, Woods Hole Oceanographic Institution

1.) Space will be provided for at least 3 scientists from the University of Rio de Janeiro to participate in the cruise of R/V Knorr, approximately 7 April to 16 May 2000, Recife to Recife. A copy of the approximate cruise track is attached.

2.) Within 6 months of the end of the cruise preliminary profile data on temperature, salinity, and pressure from the cruise will be made available to Prof. Herms and appropriate Brazilian authorities.

3.) Within one year of the end of the cruise, final versions of data on temperature, salinity, pressure, sulfur hexafluoride, and bathymetry will be made available to Prof. Herms and appropriate Brazilian authorities. This includes all data to be taken within Brazilian waters as well as all of the data of general interest to be taken in international waters in the Brazil Basin.

4.) Further collaborations between Prof. Herms and Dr. Ledwell can be established as the project evolves by mutual agreement.

Dr. James R. Ledwell Woods Hole Oceanographic Institution	3/2/00 Date
Dr. John Toole Woods Hole Oceanographic Institution	3-2-2000 Date
Prof. Friedrich W. Herms Universidade do Estado do Rio de Janeiro	3-3-2000 Date

APPENDIX 5. ACADEMIC AGREEMENT

Agreement of Academic Exchange and Cooperation

Participants:
Dr. Monica Costa - Federal University of Pernambuco
Dr. James R. Ledwell - Woods Hole Oceanographic Institution

1. Space will be provide for two postgraduation students from the Oceanography Department of the Federal University of Pernambuco to go on a training program and participate in a cruise on board of the *R/V KNORR* from approximately April 7th to may 16th 2000, from Recife and back to Recife. A copy of the approximate cruise track is attached.

2. The parts agree to exchange cruise reports and preliminary data within six months of the end of the cruise.

3. Dr. Ledwell will make available to Dr. Costa data on positioning salinity, temperature, pressure, bathymetry and SF6 concentrations within one year of the end of the cruise.

4. Further collaboration between Dr. Ledwell and Dr. Costa can be established as the project evolves by mutual agreement.

Dr. James R. Ledwell
Woods Hole Oceanographic Institution

6/4/2000
Date

Dr. Monica Costa
Federal University of Pernambuco

6/4/2000
Date

APPENDIX 6. CTD CALIBRATION

The Sea-Bird CTD had two sets of temperature/conductivity sensors collecting data during each deployment. The serial numbers of the sensors are listed in the table below. SeaBird software was used to compute salinity from temperature, pressure, and conductivity.

Sensor Serial Numbers

Cast	T1	C1	T2	C2	P
1-72	1085	224	1080	763	59933
72-82	1085	224	1080	107*	59933

Temperature sensors were calibrated prior to the cruise in December 1999. These calibrations were used throughout the data processing. Post cruise calibration of T1 and T2 in June 2000 showed the sensors reading 0.00440 and 0.00077 Celcius higher respectively. These offsets were not applied to the data.

In addition, twenty-four Niskin style water sampling bottles were triggered at various depths, usually between 3000 m and 5000 m, during each deployment. Water from several of these bottles from most casts was sampled and processed using a Guildline Autosal salinometer.

Conductivity sensor 107 was provided by the WHOI SSSG. The other sensors are part of the CTD system maintained by Ledwell et al. for the tracer release experiments.

Salinity data from the CTD sensors from the same depth as the water sample were compared to the Autosal data for each sample processed. Five seconds of sensor data were averaged by the Sea-Bird software to determine the salinity for each Niskin bottle. Figure A6-1a shows the difference between the salinity computed from the first CTD sensor pair and the salinity determined by the Autosal for each bottle of each cast. Figure A6-1b shows difference between the second sensor pair and the Autosal data for each bottle. Figure A6-1c shows the difference between the salinities determined by the first and second sensor pair for each bottle. There is not a correlation between the order of the differences and the order of the bottles in each cast. The dashed lines in Figure A6-1 indicate where changes were made to the conductivity sensors. The dashed line in Figure A6-1a between casts 69 and 70 indicates when sensor 1 was cleaned with 1% Triton solution as recommended by the manufacturer of the sensor. The dashed line in Figure A6-1b between casts 64 and 65 indicates when sensor 2 was cleaned. The solid line in Figure A6-1b drawn between casts 72 and 73 indicates when sensor two was replaced. Figure A6-1c shows all three vertical lines. The symbols in Figure A6-1a and 1b represent different individuals who analyzed the Autosal sample.

Anomalous Autosal data were discounted by eliminating differences that were more than .003 PPT (parts per thousand) from the group of points in each cast. If no data for a particular cast were grouped closely (within .006 PPT) then all the data for that cast were discounted. Further data reduction was done by eliminating casts in which the difference between the sensor and the Autosal was displaced from those nearby when the difference between the two sensors (Figure A6-1c) did not show a similar displacement. For casts 60 and 62 two bottles were triggered at a very shallow depth. These data were also eliminated. Figure A6-1 shows the result after discarding these data.

The mean difference between the Autosal salinity and the CTD salinity was calculated for each cast and for each salinity pair, dS1 and dS2 (Figure A6-2). The data in Figure A6-2b for casts 1 through 72 are considered steady enough to use the mean of the values as a constant correction to the salinities calculated using the second sensor pair. That constant is $\Delta S2(1:72) = .0036$ PPT and is plotted as a line on Figure A6-2b. The data in Figure A6-2b for casts 73 through 82 were taken using the replacement secondary conductivity sensor. The calibration factor for these data is a mean of the data, $\Delta S2(73:82) = .0120$ PPT, and is plotted as the short line on Figure A6-2b.

Figure A6-2c shows the difference between the corrected values for the second sensor and the uncorrected values for the first sensor. The salinity correction for the first sensor pair was estimated using this relationship. For casts 4 through 17, a quadratic fit to the data points in Figure A6-2c was used. For casts 1 through 3 the first value of this curve was used. For casts 18 through 72 the mean of the difference was used as a constant correction factor. This value is $\Delta S1(18:72) = -.0033$ PPT. For casts 73 through 82 (where the replacement for the second sensor was used) the mean of the difference was $\Delta S1(73:82) = -.0008$ PPT. The correction for the first sensor is plotted as a line in Figure A6-2c. There is no reason for the shift of 0.0021 at cast 72; this shift appears to be due to an over correction of S2. Systematic errors of +/- 0.003 therefore seem likely throughout the cruise, even after calibration.

Post-cruise calibrations were performed on the conductivity sensors. The most conservative estimate of sensor offset yields a $\Delta S1 = -.0098$ PPT. S2 (Sensor 763) was broken after cast 72 so no post calibration was possible. Corrections were not made using these data.

The final values for the corrections are given in the file sal_cor.dat
The columns are:
Cast number
Sensor 1 correction
Sensor 2 correction

These numbers should be added to the values for salinity in the data files.

Figure A6-3 shows the difference between the corrected salinity values, which reflects residual noise.

The following table shows the correction constants for each cast along with the number of points used to determine the correction and the root mean square deviation of the smoothed ΔS1,2 from original ds1,2.

Cast #'s	**ΔS1 (ppm)**	**n**	**S.D. (ppm)**	**ΔS2 (ppm)**	**n**	**S.D. (ppm)**
1-3	5.1	3	1.5	3.6	40	1.4
4-17	fit	14	0.2	3.6	40	1.4
18-72	-3.3	55	0.30	3.6	40	1.4
73-82	-0.8	10	0.1	12.0	10	0.4

1 ppm = 0.001 PSU = 0.001 part per thousand

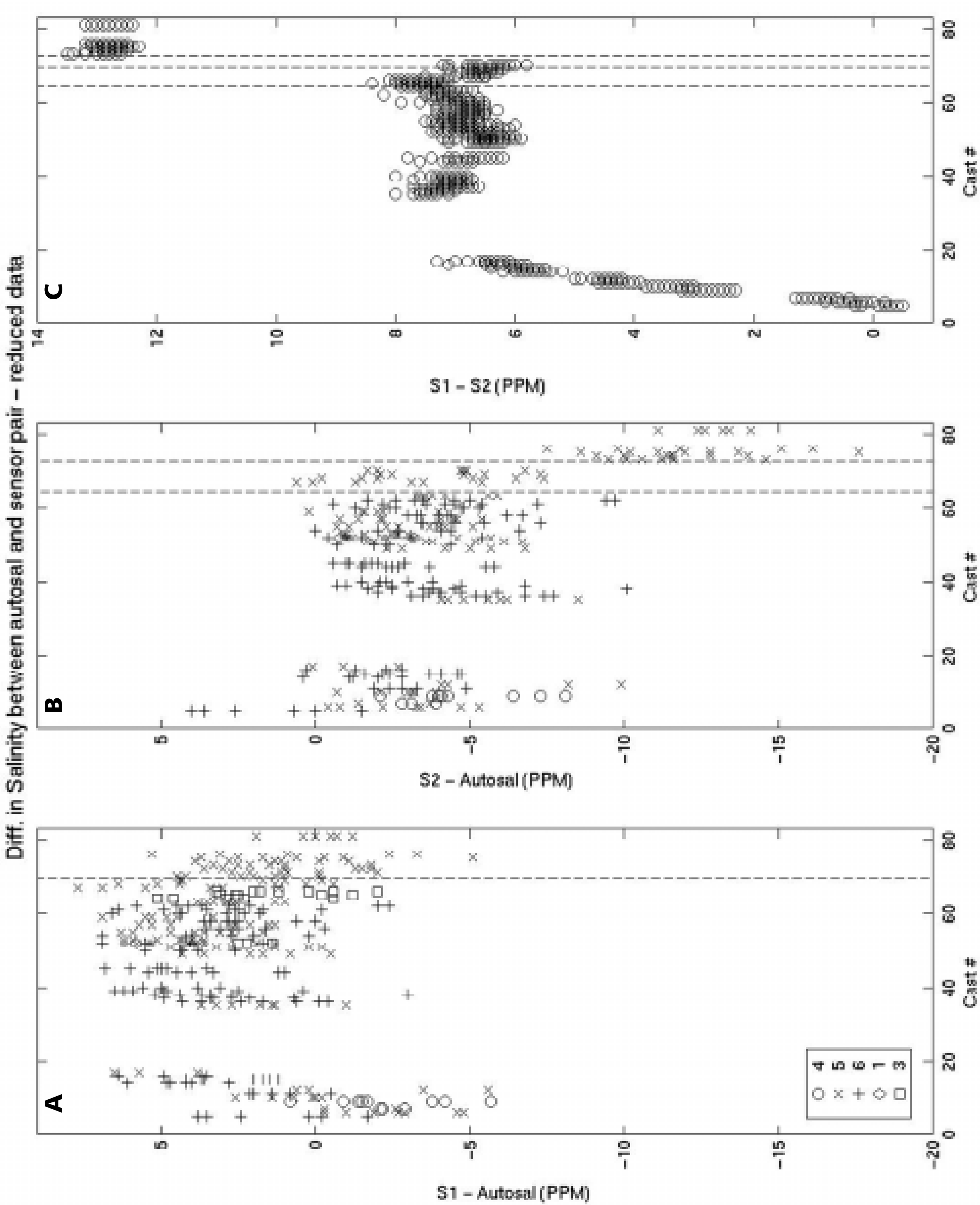


Figure A6-1. Salinity bottle calibration data. (a) The difference between CTD salinity S1 and the bottle salinity for all individual samples. Different plot symbols represent different Autosal analysts. (b) The same for CTD salinity S2. The dashed lines indicate where the sensors were cleaned; the solid line indicates where the conductivity sensor for S2 was changed. (c) The difference S1-S2 at the locations where bottle samples were taken.

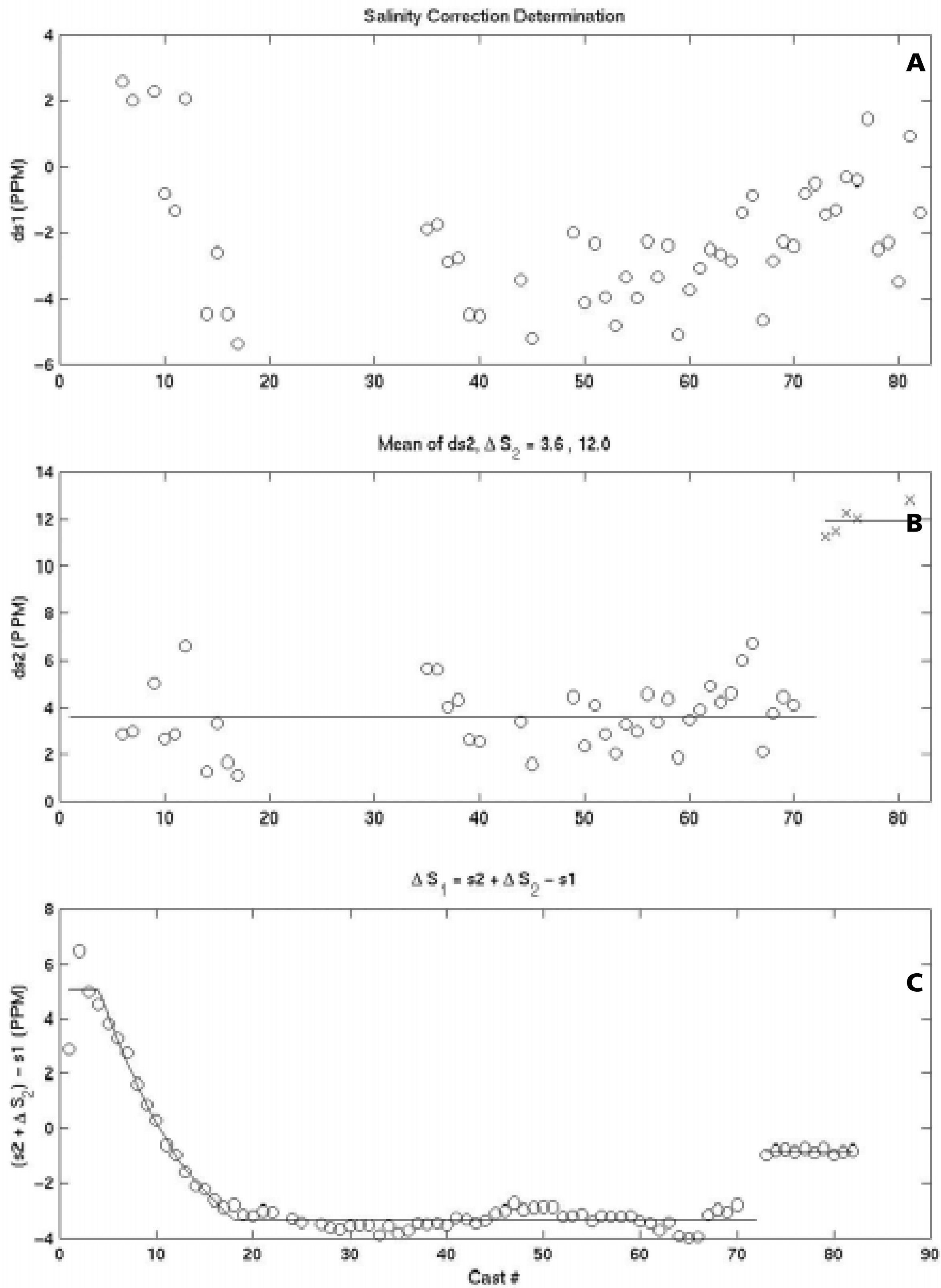


Figure A6-2. Average salinity differences by cast. (a) dS1 is the average Autosal salinity minus S1 (primary pair); (b) dS2 is the average Autosal salinity minus S2 (secondary pair), both excluding anomalies. (c) S2 + ΔS2 – S1 is the average difference between corrected S2 and uncorrected S1 for each cast.

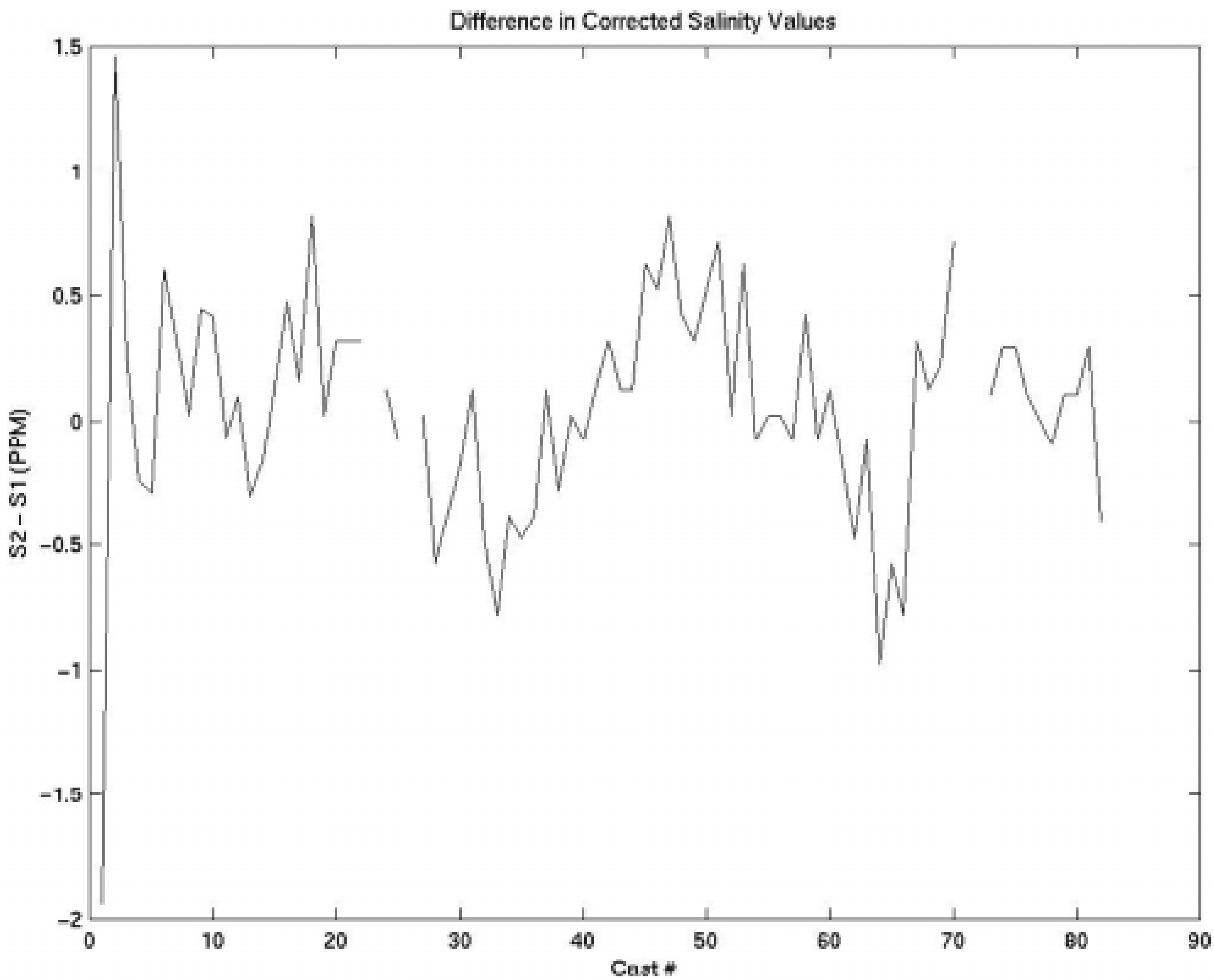


Figure A6-3. Residual salinity difference between sensor pairs, averaged by cast after corrections have been made.

APPENDIX 7. CURRENT METER MOORING RECOVERY

In 1998 a mooring was deployed near the tracer injection site, and during *Knorr* Cruise 161-6 this mooring was recovered. It consisted of 8 VACMs, 1 FSI acoustic current meter, 1 tandem release and a 3-ball float with a strobe light and VHF radio beacon. On May 3rd at 0500 Z, we arrived at the mooring area with less than ideal weather. Winds were approaching 30 knots and seas were building. I gave the bridge 3 positions, all 1.5 miles from the best known location of the mooring. At the first of these positions I enabled one of the acoustic releases and ranged on it. The same was done at the next two locations as well. The first two ranges agreed with the launch position but the third ranging did not. I added one more point to range from but this proved to be inconclusive. The amount of error was less than .5 miles so I decided on a safe location for the ship to be and at 0730 Z from that spot I sent the release command and the release confirmed it had released. The first balls were spotted on the surface just 30 minutes later. We allowed another 30 minutes for the bottom cluster of balls to make it to the surface.

The ship approached the mooring from upwind so that we could begin the recovery with the top set of flotation. We hooked into the 3-ball float on the first attempt and began the recovery. About half way through the 2000 meter long mooring we encountered a huge mess. During the ascent the mooring had become severally tangled. By attaching the loose ends together with Crosby clamps we were able to continue the recovery process. It was necessary for us to recover some items at unexpected times because lower sections of the mooring were entangled with upper sections. I feel the problem occurred because the amount of the flotation at the bottom of the mooring was enough to enable it to reach the surface at almost the same time as the upper flotation. The flotation in the middle sections was not enough to support the wire and instrumentation, which created a huge catenary hanging beneath the top and bottom flotation. In the future, moorings that are of similar design and duration of operation may benefit from swivels or at least a more balanced floatation scheme.

We had finally reached the last cluster of glass ball flotation and had the balls at the rail the when the wire rope parted. We maneuvered the ship around and attached a snap hook to the cluster of balls using a pickup pole. We then proceed to recover this last section. All equipment was aboard by 1030 Z. One VACM (V-0201) had lost its vane and the rotor, but this probably happened just after the release was fired during its ascent.

APPENDIX 8. SHEARMETER FLOATS

As part of the BBTRE experiment, leg 161-6, 6 shearmeters were deployed near the original injection site. The instruments were shipped to the Azores in March unassembled. Tim Duda and Brian Guest traveled to Ponta Delgada to load them on the R/V *Knorr* and assemble each float. After assembly, each float was checked for proper operation and the clocks set to GMT via the Ashtech GPS receiver.

On April 7, in Recife, the time and status of each float was checked. The status check gives a report on state of initialization (Idle, Active or Control modes), time, vacuum in dBars, voltage of both the controller and Argos PTT batteries, pressure sensor readings and temperature. Approximately 24 hours prior to deployment, each float was checked, including the mission parameters, and put into Active mode. The start date and number of windows were changed as necessary to facilitate the desired mission length. Then two floats at a time were brought on deck and the rotor cups attached with the hardware provided and a small amount of loctite permanent thread lock was applied.

Deployments began on May 6, 2000 at locations near the initial tracer release. The method chosen to deploy the equipment was to lower one float at a time horizontally over the stern using three (3) slip lines that were positioned to support the float in the middle of each section of tubing. The intent was to gently lower it by hand to the water and have the ship produce enough thrust to carry the shearmeter away from the hull. Once the float was at the water, all three slip lines would be released. The first attempt at this failed when the line on the lower, and heavier end of the float (RF03) was lowered too quickly and the instrument slid down through the other two lines. The top end of the float tangled with the lifeline, snapping off two of the cups. An attempt was made to keep the float at the rail in a vertical position in order to replace the broken cups but the pitching of the ship generated enough force that a clamp holding the top and middle sections of the pressure case together failed and fell away. The top section, which contains the electronics, was recovered.

After some debate, it was decided to try this same method of deployment again. No prior means of deployment had been arranged and, considering how fragile this equipment is, we didn't have many options. Shearmeter RF02 was attempted next and entered the water without incident. The remaining four floats were launched in the same manor and entered the water smoothly. If this type of instrumentation is to be used in the future, a more reliable method needs to be developed. One thought is to use a type of stretcher that would support most of the float but could be suspended from a crane and opened with a quick release.

Table of Shearmeter Launch Information

ID	Date	Time	Latitude (deg S)	Longitude (deg W)	Mission Length	Ballast Depth (m)
RF03	5/6/00	Not Deployed				4000
RF02	5/6/00	0755 Z	21 51.360	18 35.220	1 year	3500
RF00	5/6/00	1005 Z	21 50.026	18 18.503	1 year	3000
RF01	5/6/00	1020 Z	21 50.030	18 18.503	till Nov. 1st	3500
RF99	5/7/00	0514 Z	21 42.641	18 37.928	1 year	4000
RF04	5/7/00	0519 Z	21 42.653	18 37.383	1 year	4000

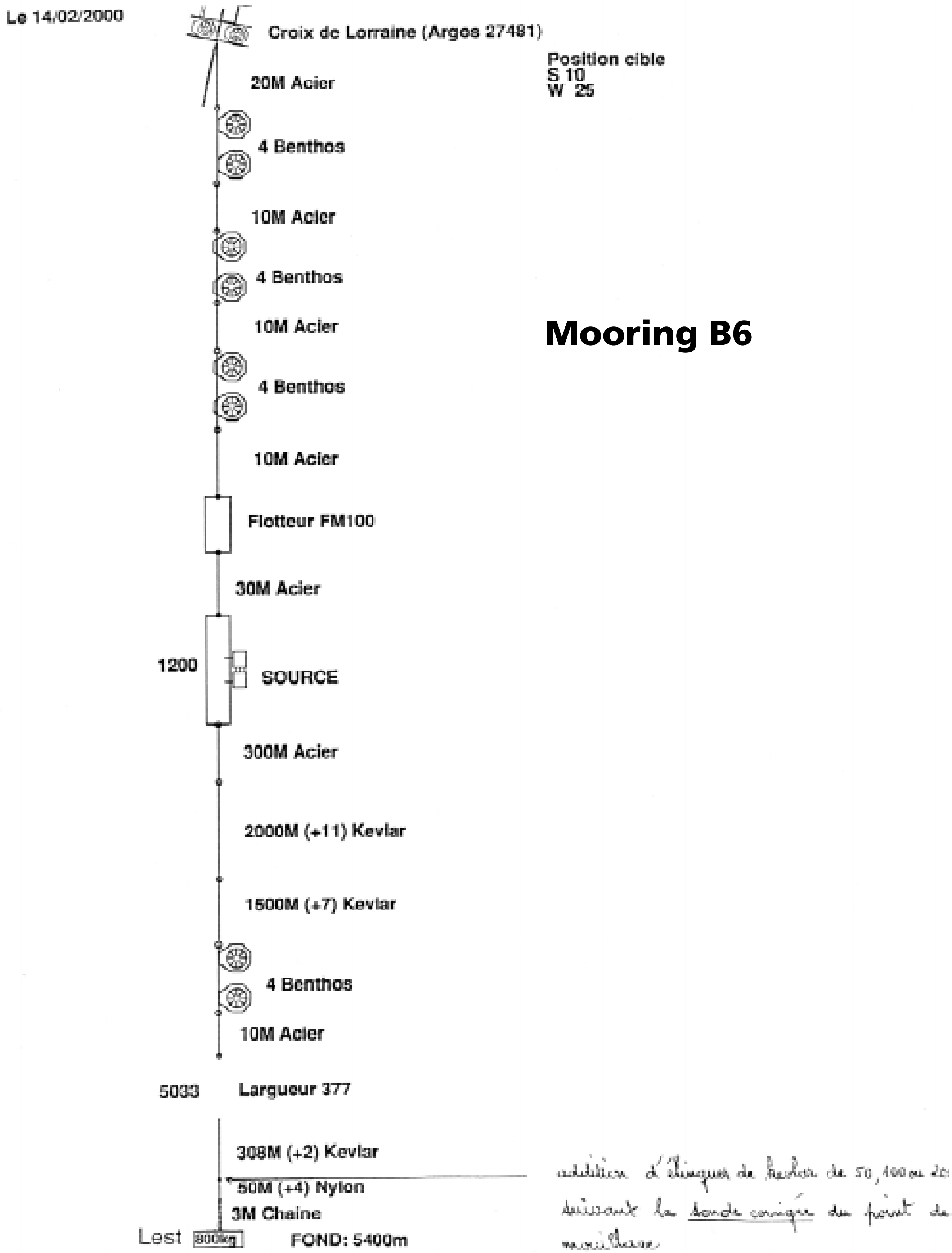
APPENDIX 9. SOUND SOURCE MOORINGS

Within the framework of the Deep Basin Experiment (DBE), IFREMER initiated in 1994 the SAMBA project (Sub-Antarctic Motion in the Brazil BAsin) in order to follow the intermediate Antarctic water by using Lagrangian current measurements. Since 1994 one hundred subsurface MARVOR floats have been deployed at 800 meters depth for five year missions. These floats are freely drifting and are tracked by acoustic transmitters (Webb Research Corp. sound sources) precisely positioned and accurately scheduled.

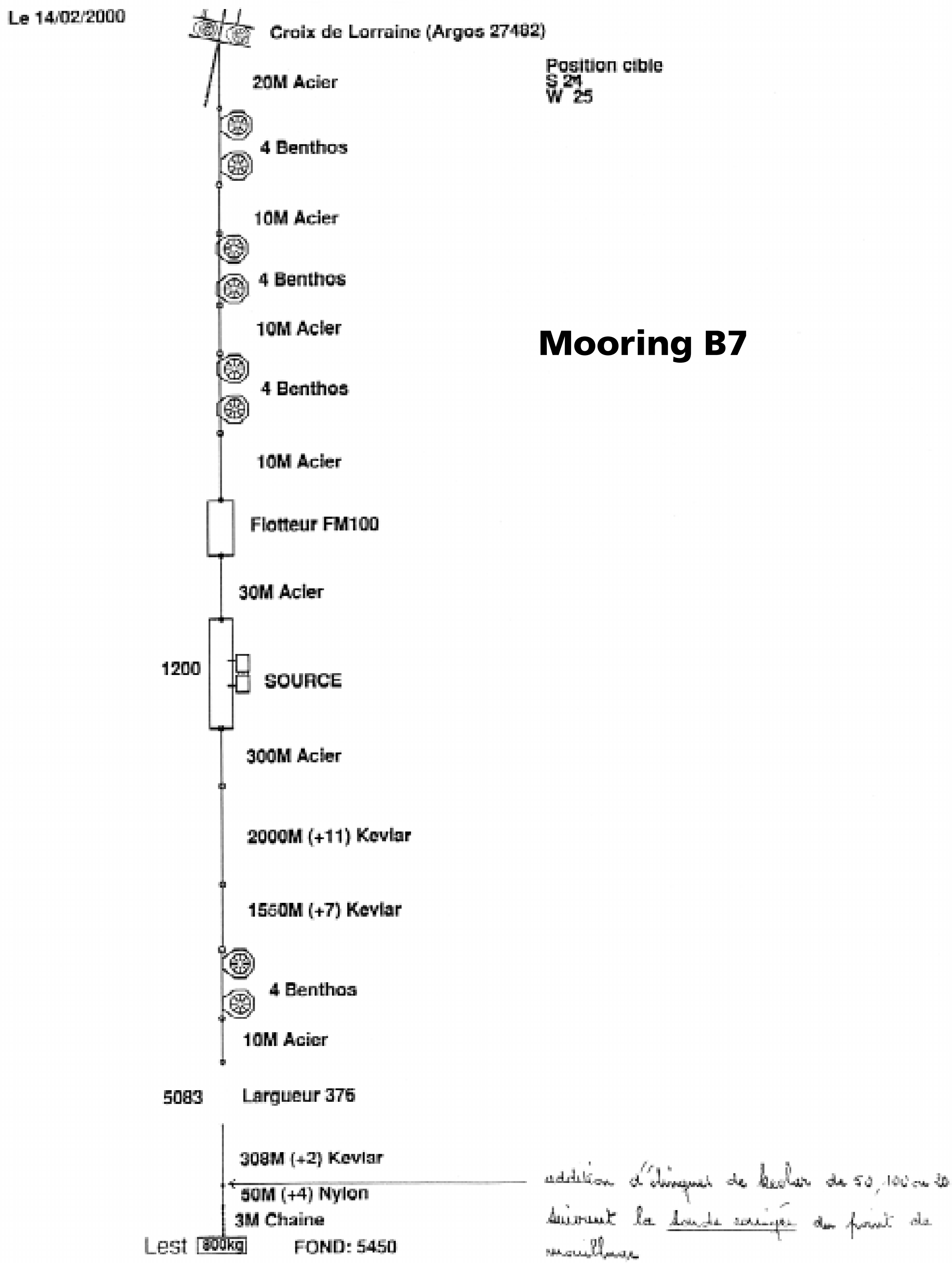
The purpose of the two moorings deployed during the KN161-6 cruise was to improve the sound source network after the recovery of the German and American equipment.

The sound sources have been deployed at 1200 meters depth and have been programmed to transmit a signal once a day at 0130 UTC (Source B6), and 0100 (Source B7) .The last MARVOR deployments occurred in 1997, so these two moorings could probably be recovered in 2002 or 2003 depending of the number of floats still “living.”

The attached figures show the configurations for source mooring B6 at 10 deg, 00.14 min South and 24 deg, 58.88 West and mooring B7 at 23 deg, 53.58 min South and 25 deg, 16.55 West.


Le 14/02/2000
Croix de Lorraine (Argos 27481)
Position cible
S 10
W 25
20M Acier
4 Benthos
10M Acier
4 Benthos
10M Acier
Mooring B6
4 Benthos
10M Acier
Flotteur FM100
30M Acier
1200
SOURCE
300M Acier
2000M (+11) Kevlar
1500M (+7) Kevlar
4 Benthos
10M Acier
5033
Largueur 377
308M (+2) Kevlar
50M (+4) Nylon
3M Chaine
Lest
800kg
FOND: 5400m
addition d'élingues de Kevlar de 50, 100 ou 20
suivant la sonde corrigée du point de
mouillage

Mooring B7



Le 14/02/2000
Croix de Lorraine (Argos 27482)
Position cible
S 24
W 25
20M Acier
4 Benthos
10M Acier
4 Benthos
10M Acier
4 Benthos
10M Acier
Flotteur FM100
30M Acier
1200
SOURCE
300M Acier
2000M (+11) Kevlar
1550M (+7) Kevlar
4 Benthos
10M Acier
5083
Largueur 376
308M (+2) Kevlar
50M (+4) Nylon
3M Chaine
Lest
800kg
FOND: 5450