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Woods Hole Oceanographic Institution

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Approved for Distribution:

James Luyten

James Luyten, Chairman
Department of Physical Oceanography

Abstract

Neutrally buoyant SOFAR floats at nominal depths of 800, 1800, and 3300 m were tracked for 21 months in the vicinity of western boundary currents near 6N and at several sites in the Atlantic near 11N and along the equator. Trajectories at 1800 m show a swift (> 50 cm/sec), narrow (100 km wide) southward-flowing deep western boundary current (DWBC) extending from 7N to the equator. At times (February–March 1989) DWBC water turned eastward and flowed along the equator and at other times (August–September 1990) the DWBC crossed the equator and continued southward. The mean velocity near the equator was eastward from February 1989 to February 1990 and westward from March 1990 to November 1990. Thus the cross-equatorial flow in the DWBC appeared to be linked to the direction of equatorial currents which varied over periods of more than a year. No obvious DWBC nor swift equatorial current was observed by 3300 m floats.

Eight-hundred-meter floats revealed a northwestward intermediate level western boundary current although flow patterns were complicated. Three floats that significantly contributed to the northwestward flow looped in anticyclonic eddies that translated up the coast at 8 cm/sec. Six 800 m floats drifted eastward along the equator between 5S and 6N at a mean velocity of 11 cm/sec; one reached 5W in the Gulf of Guinea, suggesting that the equatorial current extended at least 35–40° along the equator. Three of these floats reversed direction near the end of the tracking period, implying low frequency fluctuations.

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1 Introduction

This report describes SOFAR float trajectories in the equatorial Atlantic at depths of 800 m in the Antarctic Intermediate Water and at 1800 m and 3300 m in the North Atlantic Deep Water. The fundamental issue investigated is the exchange of water between the North and South Atlantic Oceans. Water mass properties including freon imply that deep western boundary current (DWBC) water splits near the equator, with part flowing eastward along the equator and part continuing southward along the western boundary. It was not known to what extent the tongue of freon lying along the equator near 1700 m is due to advection or to enhanced mixing. Thus a secondary issue investigated is the nature of the connection between the DWBC and flow along the equator.

The DWBC is the major pathway by which cold deep water flows southward into the South Atlantic and, eventually, into the Pacific and Indian Oceans. The warm upper layer in the Atlantic, including the intermediate water, is thought to flow northward in compensation for the deep water. Schmitz and Richardson (1991) have identified 13×10^6 m^3/s of upper level water from the South Atlantic flowing northward across the equator into the Gulf Stream. Neither flow had previously been directly measured crossing the equator. This large-scale thermohaline circulation results in a northward heat flux through the Atlantic which is important for world climate. An improved understanding of the thermohaline circulation and its variability is required in order to design a scheme to measure variations in the meridional flux of heat in the oceans and variations in climate.

The results described here are the first subsurface float trajectories in this region. They reveal new information concerning the thermohaline circulation, including a swift, $\sim$ 50 cm/sec, southward-flowing DWBC at 1800 m that at times feeds into an eastward equatorial current and at other times crosses the equator directly. These data provide a first direct measurement of the cross-equatorial flow of deep water and its complex patterns. Some floats at 800 m and 1800 m drifted long distances along the equator, up to 38° of longitude, and give a first Lagrangian view of these equatorial currents and their connections to the currents along the western boundary.

The report is divided into two main parts. The first follows this introduction and summarizes the whole experiment. The second part consists of two appendices that show some summary composites of trajectories (Appendix A) and plots of individual floats (Appendix B).

2 Methods

During January and February 1989, 48 SOFAR floats were launched in the tropical Atlantic, 14 at 800 m in the intermediate water, 15 at 1800 m and 15 at 3300 m in the deep water, and 4 by J. Price as engineering tests of a Bobber float, at depths near 300 and 650 db (Figure 1, Tables I and II). The floats were tracked acoustically from January 1989 to November 1990 by means of an array of six moored autonomous listening stations. See Table I for the dates during which each float was tracked. Float tracking is continuing for an additional two years. Thirty-one of the floats were launched along a line spanning the Atlantic between 6N and 11N, with closest spacing between floats near the western boundary off French Guiana, where the velocity is swiftest. Seventeen floats were launched along the equator in the west, where meridional flow is thought to cross the equator and eastward flow along the equator originates. Thus the whole width of the Atlantic between French Guiana and West Africa was instrumented with floats, although sparsely in the eastern region.

All but two of the 800 m and 1800 m floats were tracked for the full 21 months and were heard out to ranges of 3000 km (Table I). One float (28) entered the Caribbean and another (34) faded after six months. Six of the 3300 m floats were never heard, two due to a reduced range of around 1000 km there, four due to unexplained failures. The mean trackable lifetime of 3300 m floats was around a year due to their gradually sinking toward the lower limit of the sound channel. Most of the deep floats that were tracked could be heard by at least one listening station up to October 1990.

a) Temperature and pressure

All floats except the four Bobbers failed to transmit correct temperature and pressure data after they had equilibrated, and they also failed to activate their buoyancy control which keeps them at constant pressure. In order to estimate equilibrium depths at sea, two floats at each level were followed acoustically from the ship as they sank. The floats at the 800 db level equilibrated at 795 db and 800 db; those at the 1800 db level equilibrated at 1825 db and 1770 db. Two deep floats were followed down to 2570 db and 2860 db where their telemetry stopped. An extrapolation of their data to equilibrium pressure showed that the floats reached 3255 db and 3250 db. In the following, the three equilibrium pressures will be referred to as 800 m, 1800 m, and 3300 m, but individual floats could have differed from these nominal depths.

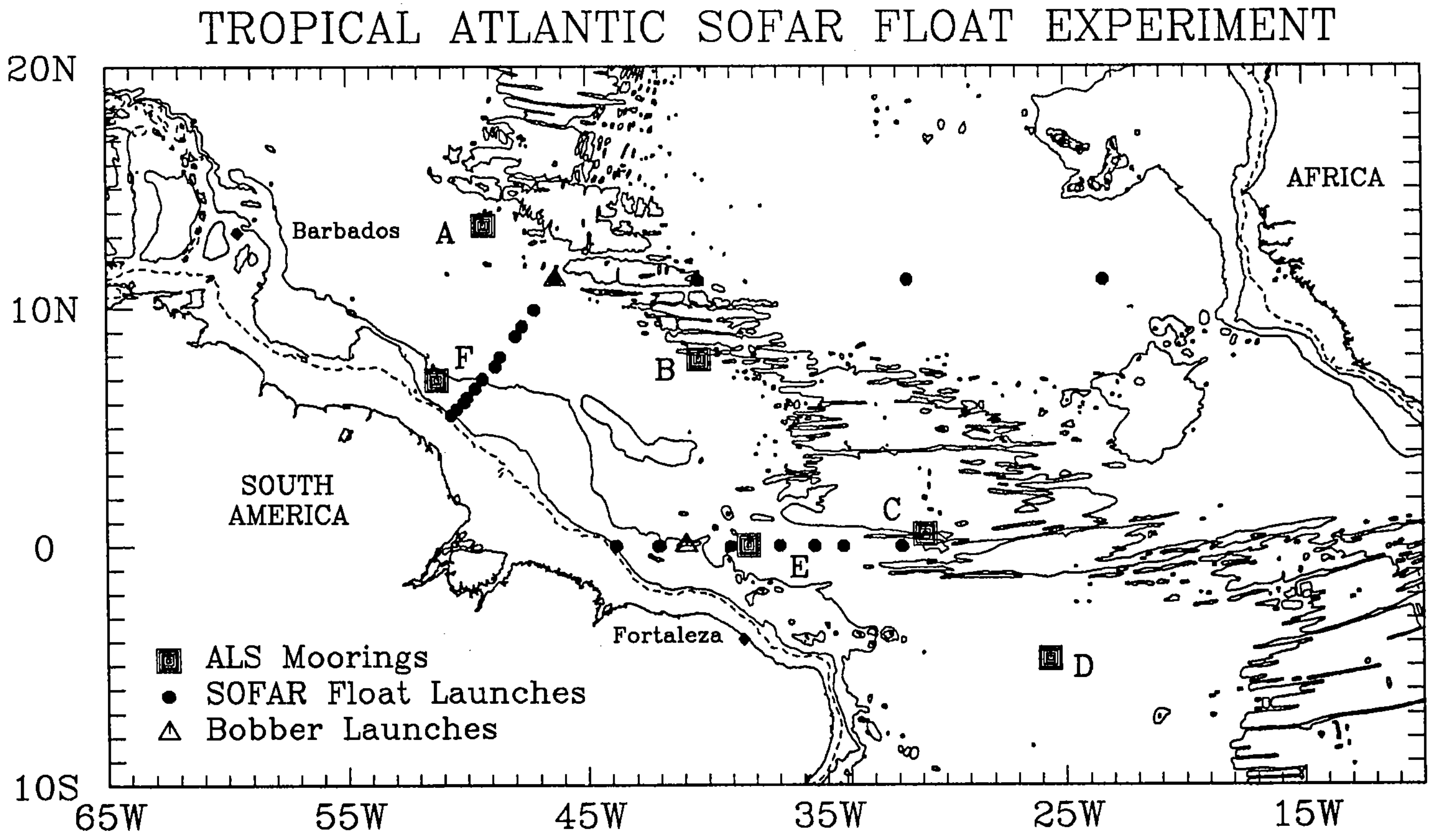

Figure 1: Launch locations of SOFAR floats and Autonomous Listening Stations (ALS) during January–February 1989. Depth contours are from Uchupi (1971): 200 m is dashed, 2000 m and 4000 m are solid lines.

Table I: Summary of SOFAR Float Data[a]

	Float ID	Pressure (db)[b]	Launch			End			Number of Days Tracked	Mean Velocity (cm/sec)	
			Date yymmdd	Lat. deg. N	Long. deg. W	Date yymmdd	Lat. deg. N	Long. deg. W		$\overline{u}$	$\overline{v}$
1) 800 m Floats a) Equatorial	16	(800)	890125	00.01	43.83	901107	−06.10	28.96	650	2.95	−1.16
	31	800	890125	00.01	42.01	901102	00.94	36.32	646	1.13	0.17
	B63	450–850	890124	00.05	40.94	901030	09.97	49.93	643	−1.83	1.98
	B62	200–500	890124	00.04	40.86	890827	01.42	42.58	214	−1.11	0.72
	28	795	890123	00.00	39.00	900422	12.19	61.19	453	−6.24	3.42
	34	(800)	890122	00.00	35.50	890725	−03.67	19.41	182	11.45	−2.45
	24	1125[c]	890121	00.00	31.81	901030	−01.93	09.92	644	4.31	−0.39
b) IWBC/Line	25	(800)	890205	05.52	50.62	901102	03.74	45.34	634	1.10	−0.48
	21	(800)	890205	05.78	50.40	900928	05.74	48.96	598	0.32	0.00
	23	(800)	890206	06.04	50.09	901102	11.55	56.60	634	−1.30	1.13
	22	(800)	890206	06.62	49.61	901102	15.37	58.72	633	−1.84	1.79
	20	(800)	890207	07.54	48.78	901030	07.54	44.09	630	0.95	0.00
	26	(800)	890207	09.23	47.67	901107	03.32	14.46	637	6.74	−1.20
	B12	250–350	890208	11.20	46.29	890714	07.30	44.82	156	1.21	−3.09
	B81	550–700	890208	11.21	46.29	891230	09.94	59.60	325	−5.23	−0.46
	19	(800)	890209	11.15	40.36	901024	05.43	25.83	621	3.03	−1.18
	18	(800)	890213	11.17	31.57	901111	11.37	34.73	634	−0.62	0.07
	17	(800)	890215	11.18	23.40	901107	11.40	18.79	629	0.90	−0.01
2) 1800 m Floats a) Equatorial	9	(1800)	890125	00.01	43.82	901108	−00.35	31.32	651	2.48	0.07
	6	1775	890125	00.01	42.08	901012	−02.77	38.79	624	0.61	−0.57
	1	1825	890123	00.00	39.03	901103	00.70	17.73	646	4.18	0.25
	3[d]	(1800)	890122	00.01	35.51	—	—	—	—	—	—
	15	(1800)	890121	00.01	31.84	901101	00.14	39.60	648	−1.55	0.03

	Float ID	Pressure (db)^b	Launch Date yymmdd	Launch Lat. deg. N	Launch Long. deg. W	End Date yymmdd	End Lat. deg. N	End Long. deg. W	Number of Days Tracked	Mean Velocity (cm/sec) $\overline{u}$	Mean Velocity (cm/sec) $\overline{v}$
2) 1800 m Floats (cont.)											
b) DWBC/Line	10^e	(1800)	890205	05.52	50.62	890329	04.41	48.60	51	4.79	−2.92
	5	(1800)	890205	05.77	50.39	901102	00.71	40.19	634	2.04	−1.01
	14	(1800)	890206	06.04	50.09	901102	05.98	45.70	634	0.91	−0.13
	2	(1800)	890206	06.63	49.61	901112	−03.26	36.43	642	2.60	−1.99
	8	(1800)	890207	07.54	48.78	901106	−03.95	36.37	637	2.53	−2.34
	13	(1800)	890207	09.23	47.67	901030	03.71	45.63	629	0.43	−1.16
	11	(1800)	890208	11.20	46.30	901106	09.43	46.31	635	−0.03	−0.35
	4	(1800)	890209	11.15	40.36	901103	06.93	47.51	631	−1.44	−0.76
	12	(1800)	890213	11.17	31.57	901112	10.65	30.82	636	0.17	−0.09
	7	(1800)	890215	11.18	23.40	901112	11.95	25.08	635	−0.38	0.14
3) 3300 m Floats											
a) Equatorial	41^f	(3300)	890125	00.02	42.01	—	—	—	—	—	—
	30	(3300)	890123	00.00	39.02	900925	−04.59	34.66	605	0.91	−1.00
	45	(3300)	890123	00.03	36.95	891017	−01.13	36.71	267	0.11	−0.62
	35	3250	890122	00.00	34.29	901028	00.32	32.95	623	0.35	−0.17
	38	(3300)	890121	−00.01	31.79	900521	−01.46	34.18	483	−0.64	−0.39
b) DWBC/Line	42	3255	890206	06.25	49.96	891021	07.82	50.93	257	−0.57	0.83
	39	(3300)	890206	06.63	49.62	891205	05.52	46.19	301	1.44	−0.38
	40	(3300)	890206	07.02	49.31	900213	08.81	45.82	371	1.17	0.60
	36	(3300)	890207	07.95	48.59	890930	09.24	51.04	235	−1.27	0.64
	29^f	(3300)	890207	08.82	47.95	—	—	—	—	—	—
	37^f	(3300)	890207	09.92	47.17	—	—	—	—	—	—
	43^f	(3300)	890208	11.20	46.29	—	—	—	—	—	—
	44	(3300)	890209	11.15	40.37	890522	11.15	41.15	99	−0.90	0.39
	33^f	(3300)	890213	11.17	31.57	—	—	—	—	—	—
	32^f	(3300)	890215	11.18	23.40	—	—	—	—	—	—
								total	57.9 years		

a) Floats are sorted by pressure, general location, then by longitude.
b) Initial float pressure was observed for two floats at each level. The range in pressure is given for the four Bobber floats. Target pressures of other floats are shown in parentheses.
c) Ballasted deep to lie in the eastward current jet.
d) Not tracked due to the acoustic signal being overwhelmed by a simultaneous test signal in each listening station.
e) Grounded on continental slope.
f) Never heard by listening stations.

Table II: Autonomous Listening Station (ALS) Moorings

ALS Site	ALS #	ALS Depth (m)	Launch Date yymmdd	Recovery Date yymmdd	Latitude deg. N	Longitude deg. W
A	160A	950	890109	901030	13.453	49.260
B	161A	815	890112	901102	7.845	40.345
C	162A	645	890117	901119	0.519	30.848
D	163A	751	890119	901108	–4.711	25.667
E	164A	751	890123	901112	0.034	38.276
F	159A	756	890108	901028	6.980	51.235

All ALSs functioned normally except for 159A which failed electronically on 890816.

To determine the equilibrium pressure of the deep floats, the linear regression between the square of the float's vertical velocity and the pressure was used to estimate the pressure at the point of zero velocity. Vertical velocity was calculated from the pressure time series telemetered from the floats as they descended. This method assumed that at any instant the drag force on a float, given by $\rho/2(C_D A W^2)$ where C_D is the drag coefficient, A is the area, ρ is the water density, and W is vertical velocity, is balanced by the negative buoyancy force on the float, which is proportional to its height above equilibrium pressure. Calculations using a characteristic CTD profile in the tropical Atlantic show that the negative buoyancy of a deep float is approximately linear from its equilibrium pressure up to a pressure of around 1000 db. The drag coefficient of spheres vs Reynold number is nearly constant over virtually the entire range of vertical velocities experienced by the floats as they descended.

Without active ballasting, SOFAR floats gradually sink due to the slow deformation of their pressure housing, which is aluminum for 800 m and 1800 m floats and glass for 3300 m floats. In order to estimate this sink rate, all available historical float data were examined. Ten aluminum floats and five glass floats were found to give reliable estimates of the long-term sink rate (Table III). The low number is because (1) most floats actively adjusted their buoyancy to maintain a constant pressure, (2) most floats were ballasted too deep and rose toward their target pressure, and (3) many floats were near the Gulf Stream where their pressure varied in time due to the vertical heaving of the water column, which made estimating the sink rate difficult.

The mean sink rate and standard error of aluminum floats was 0.37±0.05 db/d. No obvious relationship was seen between their sink rate and the pressure level, which suggests that the mean sink rate is appropriate for all depths. The mean rate implies that the 800 m and 1800 m floats would have sunk around 230 m over the 21 months discussed here. The mean sink rate of the glass floats was 0.62 ±0.11 db/d, which implies that the 3300 m floats would have sunk around 220 m over their mean lifetime of 12 months. The gradually decreasing acoustic range observed with the 3300 m floats is inferred to be due to their gradual sinking toward the lower limit of the sound channel.

b) Groundings

A few 1800 m floats on the inshore edge of the DWBC drifted into water shallower than their equilibrium depth and probably dragged along the sea floor. One of these (float 10) clearly went aground after 51 days and remained stuck for the rest of the 21 months. The speed of a few of these DWBC floats seemed to decrease as they

Table III: Slow Sinking Rate of SOFAR Floats

Aluminum floats

Float ID	Pressure (db)	Days in water	Sink Rate (db/d)[a]
GU 162	2000	278	0.18
GU 156	2000	260	0.36
LD 62	700	147	0.37
GU 167	2000	120	0.22
LD 86	1300	92	0.41
MO 10	1500	72	0.69
LD 51	1300	69	0.22
MO 5	1500	58	0.48
MO 2	1500	52	0.39
LD 65	700	32	0.42
average			0.37±0.05[b]

Glass floats

Float ID	Pressure (db)	Days in water	Sink Rate (db/d)[c]
MA 24	2500	1320	0.32
MA 25	2500	1240	0.46
MA 22	2500	740	0.74
MA 26	2500	740	0.70
MA 63	2500	320	0.93
average			0.62 ± 0.11[d]

a) Around half of the aluminum floats exhibited a somewhat decreasing sink rate with time. For these, the slower sink rate is given since this would seem to be the best estimate of the long term rate. Only floats that sank longer than 30 days were included because of this variable rate. The wall thickness of the aluminum tubes was 1.59 cm for shallow ones (< 1000 db) and 1.90 cm for deep ones (> 1000) db.

b) The standard deviation of values is 0.15 db/d and the standard error is 0.05 db/d.

c) The glass float's sinking rate deviated in curious ways from a constant rate (Rees and Gould, personal communication).

d) The standard deviation of values is 0.24 db/d and the standard error is 0.11 db/d. The data imply that the longer a float is in the water the slower its sink rate, which results from slower sinking floats taking longer to reach equilibrium pressure than faster sinking ones.

drifted landward, probably due to both friction as the floats dragged on the sea floor and reduced near-bottom water velocity.

The ability of a float to drag upslope along the bottom into water shallower than the equilibrium depth can be understood by a simple calculation. Imagine an 1800 m float that is carried upslope along the sea floor to 1300 db where the float is approximately 0.5 kg negatively buoyant. If we assume that the drag of the sea floor on the bottom of a drifting float is equal to this value, that the float remains vertical, and that its drag coefficient is 1.0, then an average water velocity of $\sim$ 7 cm/sec past the float will provide sufficient drag to force it to drift.

c) Float tracking and data processing

The floats transmitted an 80 sec 250 Hz acoustic signal once per day. Float clock corrections and positions were calculated from the times of arrival of signals received at the moored listening stations. Spurious positions were edited manually, gaps less than 10 days long were linearly interpolated, and the resulting time series were smoothed by means of a Gaussian shaped filter (of weights 0.054, 0.245, 0.403, 0.245, and 0.054) to reduce position errors and tidal and inertial fluctuations. Velocity along trajectories was calculated at each final position by means of a cubic spline function. The average accuracy of a fix was estimated to be less than 10 km based on a comparison of float launch locations and first tracked positions (Table IV).

3 1800 m Trajectories

A summary plot (Figure 2) of 1800 m trajectories shows strikingly different kinds of trajectories in different regions. Eight of the fifteen floats drifted southeastward for various lengths of time in a fast (50–60 cm/sec), narrow ($\sim$ 100 km), deep western boundary current (DWBC). Five floats drifted long eastward distances, up to 25° of longitude, within a few degrees of the equator. Compared to these, the two floats in the eastern Atlantic near 11°N barely moved.

a) DWBC trajectories

The best evidence for a narrow, swift DWBC comes from the first two months, February and March 1989, when three floats (10, 14, and 5) drifted southward (Figures 3, 4). Float 10 grounded on the continental slope after 51 days; the two others reached the equator. Float 14 returned northward and ended up near the

Table IV: Differences Between Launch Position And First Tracked Position

	Launch Information				First Tracked Position				Pos.	Est.	Lat.	Long.	Time	Initial
Float	Date yymmdd	Time hhmm	Lat. deg. N	Long. deg. W	Date yymmdd	Time hhmm	Lat. deg. N	Long. deg. W	Diff. km.	Diff. km.	Diff. deg.	Diff. deg.	Diff. hrs.	Clk. Err. secs.
01	890123	2220	0.00	39.03	890126	1	−0.39	38.84	48.7	29.7	0.26	−0.06	49.7	0.0
02	890206	1524	6.63	49.61	890208	21	6.72	49.47	19.2	17.2	−0.01	−0.15	33.0	−4.9
04	890209	2021	11.15	40.36	890210	101	11.13	40.36	2.0	1.5	0.01	0.00	4.7	0.8
05	890205	2015	5.77	50.39	890206	121	5.76	50.39	1.6	3.1	−0.02	0.01	5.1	−5.0
06	890125	907	0.01	42.08	890126	141	0.10	41.98	14.8	8.6	−0.07	−0.03	16.6	−6.7
07	890215	2141	11.18	23.40	890216	201	11.30	23.18	27.4	26.9	−0.11	−0.22	4.3	19.2
08	890207	36	7.54	48.78	890207	221	7.58	48.81	5.2	5.2	−0.03	0.03	1.8	0.5
09	890125	1945	0.01	43.81	890126	241	−0.02	43.67	16.6	8.3	−0.05	−0.06	6.9	−3.5
10	890205	1743	5.52	50.62	890206	301	5.46	50.56	8.6	1.9	−0.01	0.02	9.3	3.0
11	890208	809	11.20	46.30	890209	321	11.25	46.17	14.8	12.9	−0.08	−0.09	19.2	1.3
12	890213	1936	11.17	31.57	890214	341	11.15	31.60	4.4	4.0	0.03	0.03	8.1	−1.1
13	890207	1555	9.23	47.67	890208	401	9.26	47.71	6.0	4.7	−0.01	0.04	12.1	0.2
14	890206	209	6.04	50.09	890206	421	6.05	50.13	4.0	5.0	−0.01	0.04	2.2	−9.4
15	890121	1910	0.01	31.84	890122	441	−0.05	31.89	9.1	12.2	0.09	0.07	9.5	−6.3
16	890125	2005	0.01	43.83	890126	501	0.08	43.91	12.0	14.0	−0.09	0.09	8.9	−3.1
17	890215	2152	11.18	23.40	890216	521	11.23	23.20	22.8	22.3	−0.05	−0.20	7.5	14.5
18	890213	1921	11.17	31.57	890214	541	11.14	31.57	3.8	5.6	0.04	−0.02	10.3	2.4
19	890209	2006	11.15	40.36	890210	601	11.14	40.35	2.4	2.8	0.00	−0.03	9.9	1.8
20	890207	111	7.54	48.78	890207	621	7.55	48.76	2.5	3.0	−0.02	−0.01	5.2	−0.9
21	890205	2145	5.78	50.40	890207	641	5.86	50.47	11.8	16.4	−0.15	−0.02	32.9	−1.5
22	890206	1543	6.62	49.61	890207	701	6.59	49.60	3.6	6.6	−0.05	−0.04	15.3	−0.8
23	890206	223	6.04	50.09	890206	721	6.06	50.17	8.5	6.7	−0.03	0.05	5.0	3.0
24	890121	1655	0.00	31.81	890124	741	0.13	31.42	46.1	28.3	−0.23	−0.10	62.8	−0.8
25	890205	1758	5.52	50.62	890206	801	5.55	50.66	5.4	4.9	−0.04	0.03	14.1	−0.0
26	890207	1537	9.23	47.67	890208	821	9.26	47.75	10.1	7.5	0.02	0.07	16.7	4.0

Table IV: (continued)

	Launch Information				First Tracked Position				Pos.	Est.	Lat.	Long.	Time	Initial
	Date	Time	Lat.	Long.	Date	Time	Lat.	Long.	Diff.	Diff.	Diff.	Diff.	Diff.	Clk. Err.
Float	yymmdd	hhmm	deg. N	deg. W	yymmdd	hhmm	deg. N	deg. W	km.	km.	deg.	deg.	hrs.	secs.
28	890123	2104	0.00	39.00	890124	901	0.05	39.12	14.4	6.2	-0.04	0.04	12.0	1.7
30	890123	2117	0.00	39.02	890128	941	0.25	38.94	28.5	44.9	-0.38	-0.13	108.4	-13.9
31	890125	725	0.01	42.01	890125	1001	0.10	42.01	9.8	10.0	-0.09	0.00	2.6	-2.4
34	890122	2012	0.00	35.50	890124	1101	-0.11	35.42	14.8	2.5	0.00	-0.02	38.8	2.0
35	890122	941	0.00	34.29	890123	1121	-0.05	34.29	5.3	14.2	0.09	0.09	25.7	-0.6
36	890207	439	7.95	48.59	890207	1141	8.00	48.64	7.9	7.3	-0.05	0.05	7.0	-3.3
38	890121	1427	0.01S	31.79	890123	1221	-0.01	31.79	0.6	2.1	-0.02	0.01	45.9	-0.7
39	890206	1457	6.63	49.62	890207	1241	6.69	49.59	6.9	7.3	-0.06	0.03	21.7	-6.0
40	890206	1937	7.02	49.31	890207	1301	7.07	49.28	6.5	6.2	-0.05	-0.02	17.4	8.4
42	890206	610	6.25	49.96	890206	1341	6.28	49.90	6.6	5.2	-0.03	-0.03	7.5	-1.3
44	890209	1941	11.15	40.37	890212	1421	11.27	40.29	15.7	29.7	-0.24	-0.11	66.7	7.2
45	890123	720	0.03	36.95	890123	1441	0.10	36.94	7.6	8.1	-0.07	-0.01	7.4	-0.9
B12	890208	901	11.20	46.29	890208	1501	11.21	46.30	1.1	1.9	-0.02	0.00	6.0	1.8
B62	890124	1046	0.04	40.87	890125	1541	0.15	40.78	15.4	7.3	0.00	-0.07	28.9	-2.1
B63	890124	2004	0.05	40.94	890126	1601	0.19	40.71	30.0	9.8	-0.01	-0.09	44.0	-7.1
B81	890208	824	11.21	46.29	890208	1621	11.19	46.30	2.0	1.5	0.01	0.01	8.0	-2.9
	Average differences								11.8	10.3			20.0	

The average difference between the launch position and the first tracked position for all floats is 11.8 km. The floats with the largest difference in positions often have large differences in time between launch and first tracked position. When we include only those floats whose first position falls within 24 hours of the time of launch, the average difference in position is reduced to 8.3 km. The difference is reduced further to 7.4 km when the position at the time of launch, estimated from the first two tracked positions, is used. Thus a significant part of the mean difference in position for all floats is due to the float drift between launch and first tracked position. An additional part of the average difference is due to the inaccuracy of the estimated launch positions which were based on GPS fixes, satellite navigation fixes, and dead reckoning between satellite fixes.

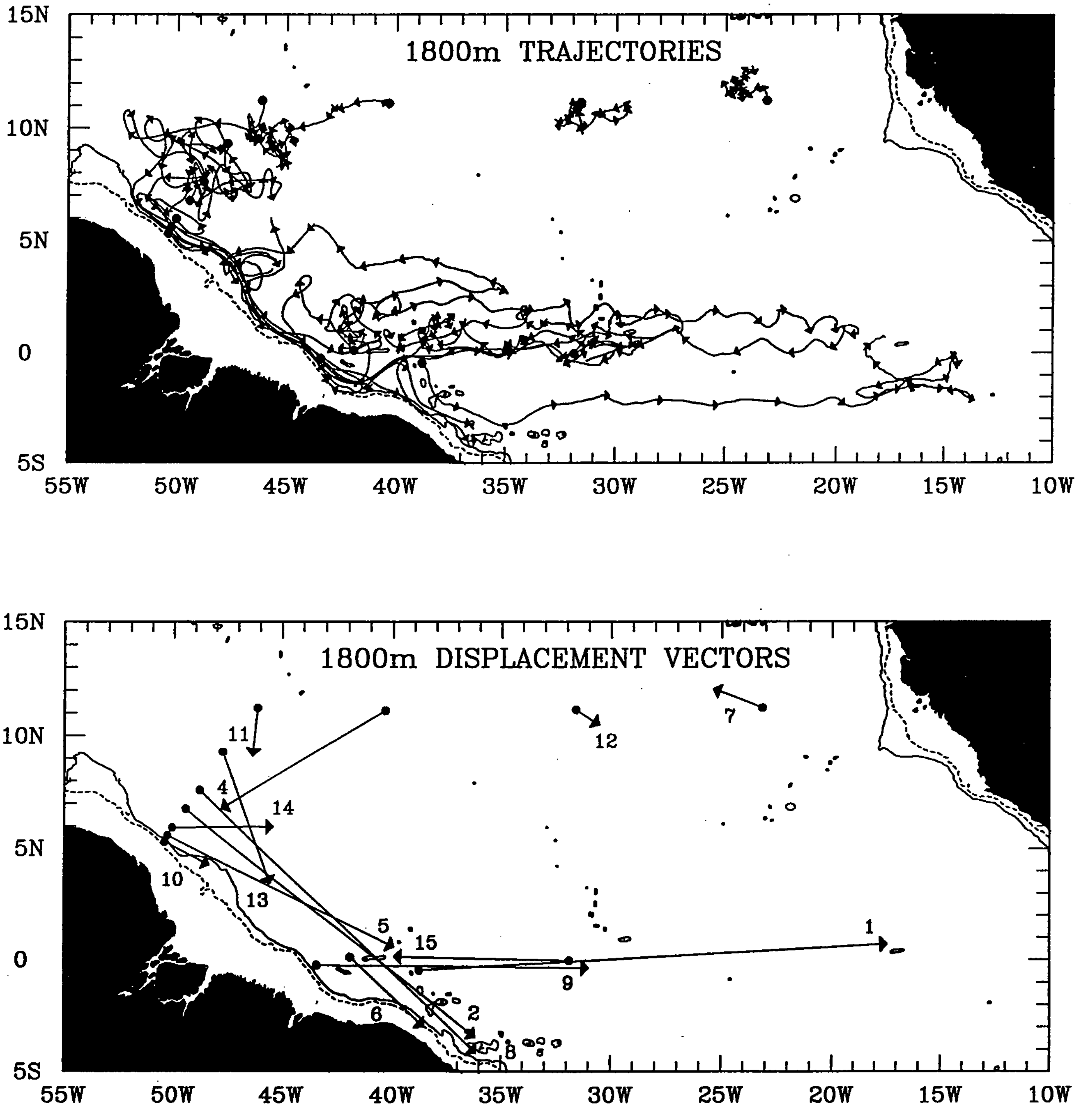

Figure 2: Summary of 1800 m SOFAR float trajectories and overall displacement vectors from January 1989 to November 1990. Arrowheads are spaced at intervals of 30 days along trajectories.