WHOI-85-31
Copy 2

Woods Hole Oceanographic Institution

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930

Surface Drifter Measurements in the Atlantic North Equatorial Countercurrent 1983 — 1985

by

Philip L. Richardson
Christine M. Wooding

September 1985

Technical Report

Funding provided by the National Science Foundation
under grant No. OCE 82-08744.

Approved for public release; distribution unlimited.

WHOI-85-31

Surface Drifter Measurements in the Atlantic North Equatorial Countercurrent 1983-1985

by

Philip L. Richardson
Christine M. Wooding

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

September 1985

Technical Report

Funding was provided by the National Science Foundation under grant Number OCE 82-08744.

Approved for Distribution:

Robert C Beardsley

Robert C. Beardsley, Chairman
Department of Physical Oceanography

Abstract

Thirty freely drifting drogued surface buoys were tracked by satellite in the vicinity of the Atlantic North Equatorial Countercurrent from February 1983 to February 1985 as part of the SEQUAL (Seasonal Equatorial Atlantic) Experiment. Buoys were launched at several different times of the year in order to sample the Countercurrent in different seasons. The purpose was to measure the seasonal variation of the Countercurrent in relation to wind forcing.

The basic data set consists of buoy trajectories, and sea surface temperature, velocity, and wind speed along the trajectories. A comparison is made between the data from the buoys and from a current meter mooring near 6N, 28W. The main results presented here consist of the collection of figures which show trajectories and time series data along the Countercurrent, and in the North and South Equatorial Currents, Guinea Current and North Brazil Current.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Introduction

This report describes results from freely-drifting drogued buoys that were tracked by satellite in the Atlantic North Equatorial Countercurrent (NECC), over a two-year period from February 1983 to February 1985. The purpose of the experiment was to directly measure the seasonal variation of the NECC and to relate this to variations in wind forcing. The drifters program is one element of a larger scale experiment called SEQUAL (Seasonal Equatorial Atlantic Experiment) which is related to a similar French experiment called FOCAL (Français Ocean Climat l'Atlantique EquatoriaL). During FOCAL, French drifters were tracked in the South Equatorial Current; some of these moved northward across the equator and merged with SEQUAL drifters in the vicinity of the NECC.

The SEQUAL buoys plus a single current meter mooring near 6N, 28W are noteworthy because they gave two years of data, the longest velocity series ever obtained in the NECC. The data provide (1) a visualization of the flow field, (2) a measure of where the water goes, (3) a direct measure of the seasonal variation in velocity during a two-year period, and (4) information about higher frequency oscillations including inertial gravity and synoptic scale waves.

The preliminary results from the SEQUAL drifters and current meter mooring in the NECC were published along with other papers about SEQUAL and FOCAL in a single issue of Geophysical Research Letters (see Richardson, 1984a; 1984b; and Appendix 1). Reports describing the current meter mooring data in the NECC have been published by Levy and Richardson (1984a; 1984b; 1985) and FOCAL drifters by Reverdin and Kartavtseff (1984).

Buoys

The buoys were made by Polar Research Laboratory (PRL). Twenty were TIROS Oceanographic Drifters (TOD), 3.0 m in length and 102 kg in weight. Six buoys were mini TODs, 1.5 m in length and 33 kg in weight. One additional buoy was a CML 80 satellite beacon made by CEIS ESPACE in Toulouse, France. The beacon was originally used to monitor the position of a current meter mooring, but the beacon was knocked from the mooring when an unknown ship collided with it.

All PRL buoys measured sea surface temperature at a depth of 1.2 m for TODs and 0.6 m for mini TODs. Thirteen TODs (57-69) and one mini TOD (70) measured wind speed by means of a Savonious rotor located on top of the antenna housing, a height of 1.0 m above the sea surface (.6 m for the mini).

All the TOD buoys and one mini (70) were drogued with a PRL window shade drogue 1.8 m by 11.6 m centered at a depth of 20 m. The tethers, designed by Bob Walden at WHOI and built by the WHOI Buoy Group, were configured to decouple the motion of the buoy from the drogue and to eliminate loss due to fishbite. Each tether consisted of a 50 m section of buoyant wire rope which lay near the sea surface and a 15 m section of wire rope that descended to the drogue (Figures 1, 2). Mini TODs 58B, and 71-74 had a smaller drogue 0.6 x 3.7 m hung directly below the buoys and centered at a depth of 5.0 m.

The limited information that we have about the drogues and tethers suggests that they worked well and stayed attached for a long time (at least the floating ones). TOD buoys 53A and 56A were found and retrieved at sea in the Gulf of Guinea on one of the SEQUAL cruises thanks to the efforts of Eli Katz. These two buoys, their tethers and drogues, which had been at sea for 217 days were in excellent condition and were subsequently relaunched (53B, 56B) on a later cruise. Buoy 62A was stolen by a fishing vessel off the mouth of the Amazon after 302 days at sea, and the evidence is that the drogue and tether were retrieved when it was stolen. This buoy was subsequently traced and recovered by our agent in Belem and relaunched as 62B without a drogue after the final SEQUAL cruise. Buoy 59A went aground in Martinique (or was picked up by a fisherman); it was eventually shipped to WHOI and relaunched in vicinity of the Countercurrent as buoy 59B. No information about drogue or tether was available, but the tether attachment point was shiny, slightly worn, and in good condition implying that the tether had stayed attached until the buoy grounded. This buoy (59B) was subsequently picked up by a fisherman near Saba Island on its second pass by the Antilles, and there was at least part of the drogue attached but the information is scanty; the electronics were recovered thanks to Tom Boynton. Buoy 60 was found on the beach on Long Island in the Bahamas after it had been at sea for 350 days. The tether attachment point on the buoy was worn or cut through and no drogue or tether was found. The electronics were recovered thanks to Pat O'Malley.

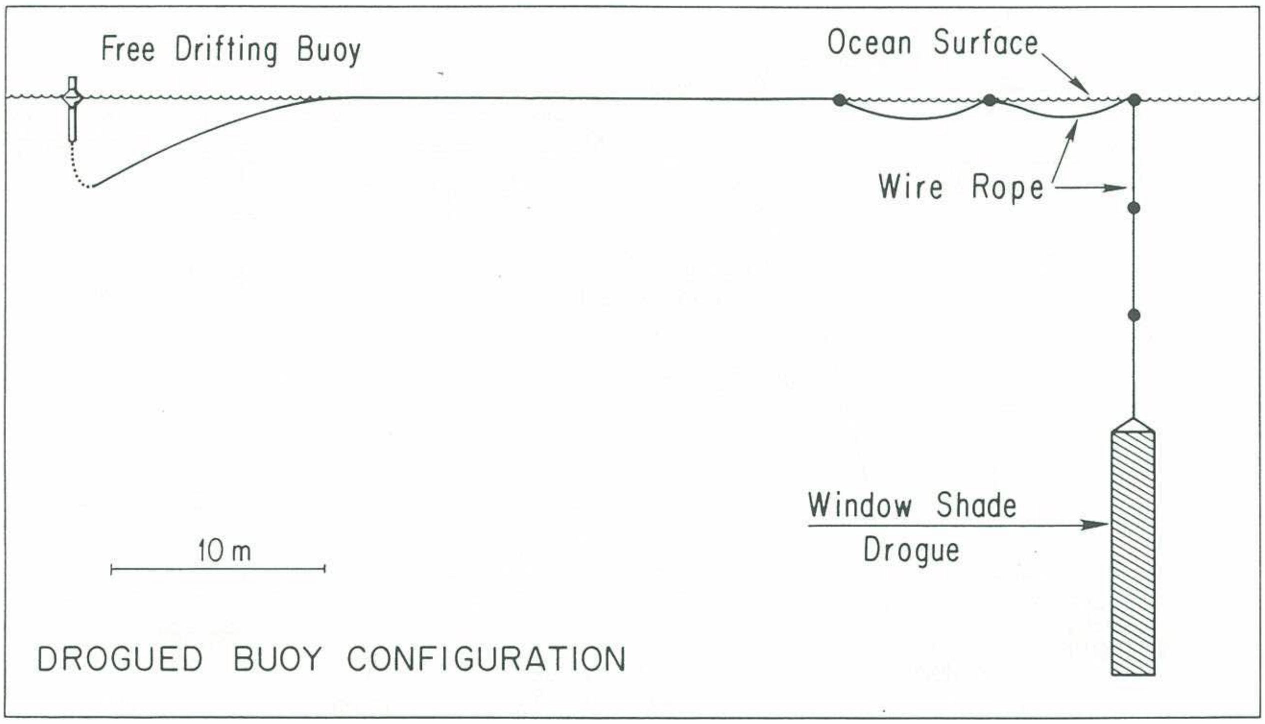


Figure 1: Schematic diagram of the drogued buoy configuration approximately to scale.

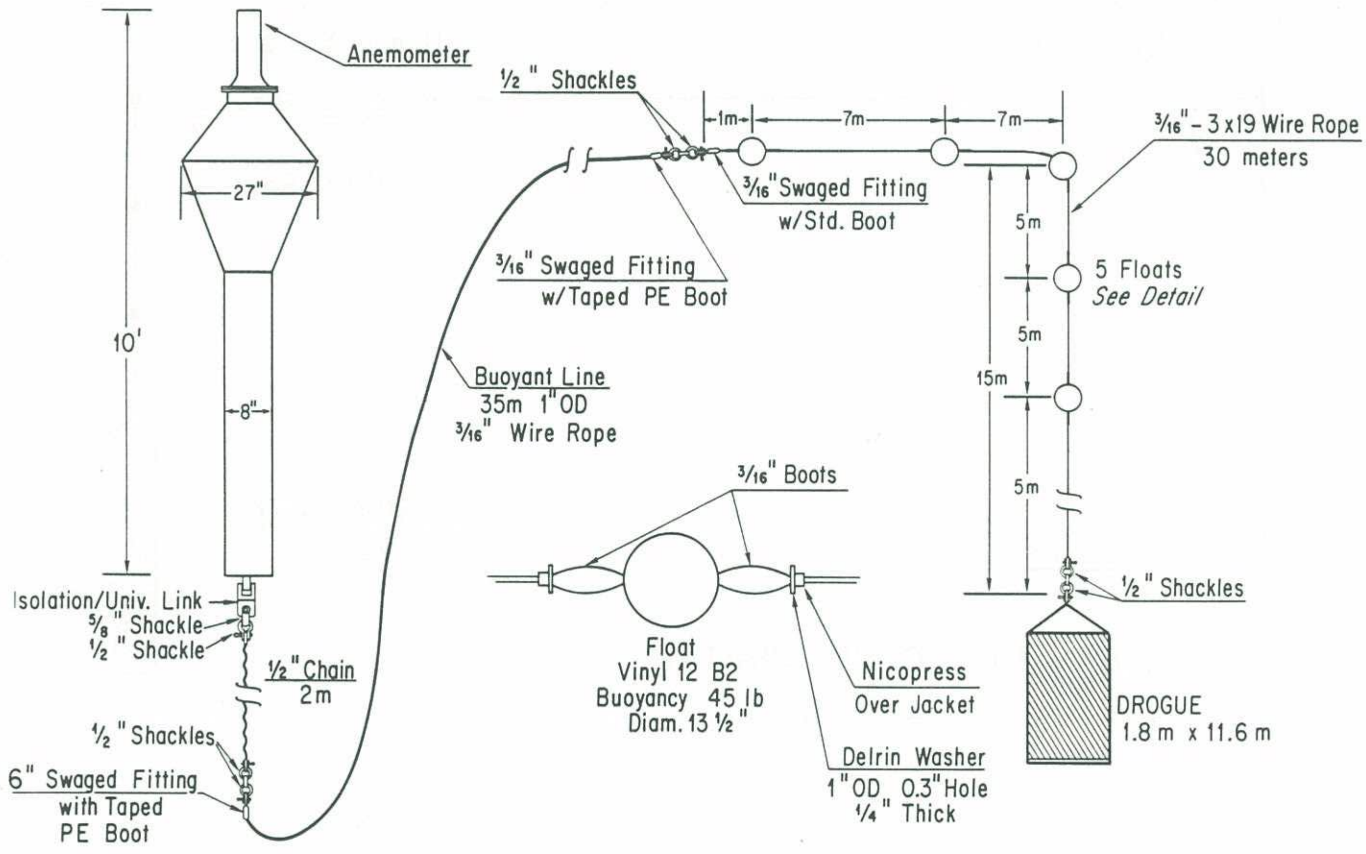


Figure 2: Details of the tether and connections.

The positions of launch and end of trajectories and lifetimes are given in Tables 1 and 2. The average lifetime for SEQUAL drifters up to August 1, 1985, is 291 days (Figure 3). Eight buoys were still working on March 1, 1985, and four on August 1, 1985. Buoys stopped transmitting for several reasons: (1) the electronics failed, (2) they were damaged at sea (run down or shot), (3) they ran aground and were damaged or turned off, (4) they were stolen and turned off. Since the battery life was two years, battery exhaustion was probably not a problem. Fourteen buoys went aground (or were stolen close to shore), two on the Bahamas, three on the Antilles, one in Nicaragua and eight on the coast of Africa, two in Liberia, two in Ghana, two in the Ivory Coast, one in Nigeria, and one in Guinea. One of these, 54, had stopped transmitting at sea but started up again when it went aground. Three buoys, 59B, 62A, 68, were clearly stolen and we tracked two of the pirate vessels, one near Africa, the other near Brazil. Another, 67, was very probably stolen as its last transmitted temperature and position fluctuated from normal as if the buoy were out of the water and being transported by boat. Six buoys stopped transmitting off the coast of Africa where fishing is heavy.

Data

The buoys transmitted a 401.65 mHz signal every 55 seconds. Position was calculated from the Doppler shift of the signal as it was received by a passing TIROS-N/NOAA series satellite. These satellites have an orbit which is near-polar and sunsynchronous and is at a nominal altitude of 870 km and a period of 102 minutes. The buoys were tracked by Service ARGOS at the Centre National d'Etudes Spatiale in Toulouse, France. On average about 6 fixes were received per buoy per day. The precision of a fix was determined from 106 fixes of a buoy lying on its side on the dock in Woods Hole and is about $\pm$ 0.4 km NS and $\pm$ 1.1 km EW. The apparent eddy kinetic energy for this buoy after smoothing was 2.1 cm^2/sec^2 which represents noise. The precision of a fix of a satellite beacon on the roof of a building at WHOI was $\pm$ 0.3 km NS and $\pm$ 0.4 km EW (C. Collins, personal communications)

Data was received once a month from Service ARGOS on magnetic tape. Processing the data consisted of the following steps:

1) Positions, temperatures, and wind speeds averaged over 30 minutes were plotted and edited for obviously erroneous values.

Table 1: SEQUAL Drifting Buoy Summary by Launch Date

Buoy ID	Launch Information Day	Lat°N	Lon°W	Last Day of Data Day	Lat°N	Lon°W	Life (days)	Comments
CONRAD	February 1983							
50	830301	7.00	21.00	830410	5.08	20.44	40	
51	830226	10.00	28.00	840801	15.43	61.25	522	Grounded, Dominica
52	830224	4.50	28.00	831208	9.09	16.89	287	
53A	830225	6.08	27.86	830930	3.40	0.66	217	Retrieved by KNORR
54	830301	5.02	20.98	830404	3.60	21.57	34	Died, grounded Liberia
55	830226	8.50	27.96	840421	5.10	5.39	420	Grounded, Ivory Coast
56A	830226	7.26	28.00	830930	3.77	2.08	216	Retrieved by KNORR
CAPRICORNE	April 1983							
58A W	830414	5.50	34.75	830624	10.87	39.13	71	
59A W	830414	6.00	34.75	830915	14.62	60.90	154	Grounded, Martinique
CAPRICORNE	July 1983							
61 W	830722	5.49	34.88	841230	4.85	1.75	162	Grounded, Ghana
62A W	830722	4.98	34.87	840519	0.09	45.56	302	Stolen, found, Brazil
68 W	830722	5.99	34.86	840221	6.60	12.33	215	Stolen
KNORR	September 1983							
57 W	830910	8.02	28.03	831208	3.95	13.35	89	
63 W	830912	7.00	27.95	840724	5.26	9.42	316	Grounded, Liberia
64 W	830913	3.99	27.96	840304	5.89	4.98E	173	Grounded, Nigeria
67 W	830913	4.99	27.88	840215	3.84	5.02	156	Stolen
70 WM	830913	6.00	27.85	840111	4.84	2.31	120	Grounded, Ghana
60 W	830908	5.99	38.55	840823	22.90	75.86	350	Grounded, Bahamas
65 W	830908	7.00	38.62	840922	23.18	74.83	380	Grounded, Bahamas
66 W	830907	5.00	38.55	841023	9.62	18.11	412	
69 W	830908	8.00	38.58	830923	7.54	38.84	15	
KNORR	March 1984							
53B	840324	5.00	27.89	850327	5.23	3.86	369	Grounded, Ivory Coast
56B	840326	7.00	27.94	841006	3.46	0.40	194	
59B W	840326	6.00	27.78	850416	17.64	63.22	387	Stolen, Saba
CAPRICORNE	August 1984							
58B M	840805	0.00	34.87	850530	12.16	83.68	300	Grounded, Nicaragua
71 M	840804	1.25	34.89	still going			363+	
72 M	840804	2.48	34.90	still going			363+	
73 M	840803	3.76	34.88	still going			364+	
74 M	840803	5.00	34.87	still going			364+	
Special category								
47	840427	3.03	28.00	840913	9.56	13.82	139	Grounded, Guinea
62B W	841102	7.50	47.50	850530	12.29	61.57	211	Grounded, Granada

W = windspeed, M = mini TOD buoy; A = first use of buoy or ID,
B = second use of buoy or ID; + = still going as of 1 August 1985.
Buoy 47 was a mooring beacon that was set adrift; it had neither drogue nor sensors.
Buoy 62B was launched without a drogue. All buoys except 47 gave at least position and temperature. Some buoys that are listed as grounded could have been stolen close to shore.

Table 2: SEQUAL Drifting Buoy Summary by Buoy Number

Buoy ID	Launch Information Day	Lat°N	Lon°W	Last Day of Data Day	Lat°N	Lon°W	Life (days)	Comments
47	840427	3.03	28.00	840913	9.56	13.82	139	Grounded, Guinea
50	830301	7.00	21.00	830410	5.08	20.44	40	
51	830226	10.00	28.00	840801	15.43	61.25	522	Grounded, Dominica
52	830224	4.50	28.00	831208	9.09	16.89	287	
53A	830225	6.08	27.86	830930	3.40	0.66	217	Retrieved by KNORR
53B	840324	5.00	27.89	850327	5.23	3.86	369	Grounded, Ivory Coast
54	830301	5.02	20.98	830404	3.60	21.57	34	Died, grounded Liberia
55	830226	8.50	27.96	840421	5.10	5.39	420	Grounded, Ivory Coast
56A	830226	7.26	28.00	830930	3.77	2.08	216	Retrieved by KNORR
56B	840326	7.00	27.94	841006	3.46	0.40	194	
57 W	830910	8.02	28.03	831208	3.95	13.35	89	
58A W	830414	5.50	34.75	830624	10.87	39.13	71	
58B M	840805	0.00	34.87	850530	12.16	83.68	300	Grounded, Nicaragua
59A W	830414	6.00	34.75	830915	14.62	60.90	154	Grounded, Martinique
59B W	840326	6.00	27.78	850416	17.64	63.22	387	Stolen, Saba
60 W	830908	5.99	38.55	840823	22.90	75.86	350	Grounded, Bahamas
61 W	830722	5.49	34.88	841230	4.85	1.75	162	Grounded, Ghana
62A W	830722	4.98	34.87	840519	0.09	45.56	302	Stolen, found, Brazil
62B W	841102	7.50	47.50	850530	12.29	61.57	211	Grounded, Granada
63 W	830912	7.00	27.95	840724	5.26	9.42	316	Grounded, Liberia
64 W	830913	3.99	27.96	840304	5.89	4.98E	173	Grounded, Nigeria
65 W	830908	7.00	38.62	840922	23.18	74.83	380	Grounded, Bahamas
66 W	830907	5.00	38.55	841023	9.62	18.11	412	
67 W	830913	4.99	27.88	840215	3.84	5.02	156	Stolen
68 W	830722	5.99	34.86	840221	6.60	12.33	215	Stolen
69 W	830908	8.00	38.58	830923	7.54	38.84	15	
70 WM	830913	6.00	27.85	840111	4.84	2.31	120	Grounded, Ghana
71 M	840804	1.25	34.89	still going			363+	
72 M	840804	2.48	34.90	still going			363+	
73 M	840803	3.76	34.88	still going			364+	
74 M	840803	5.00	34.87	still going			364+	

W = windspeed, M = mini TOD buoy; A = first use of buoy or ID,
B = second use of buoy or ID; + = still going as of 1 August 1985.
Buoy 47 was a mooring beacon that was set adrift; it had neither drogue nor sensors. Buoy 62B was launched without a drogue. All buoys except for 47 gave at least position and temperature. Some buoys that are listed as grounded could have been stolen close to shore.

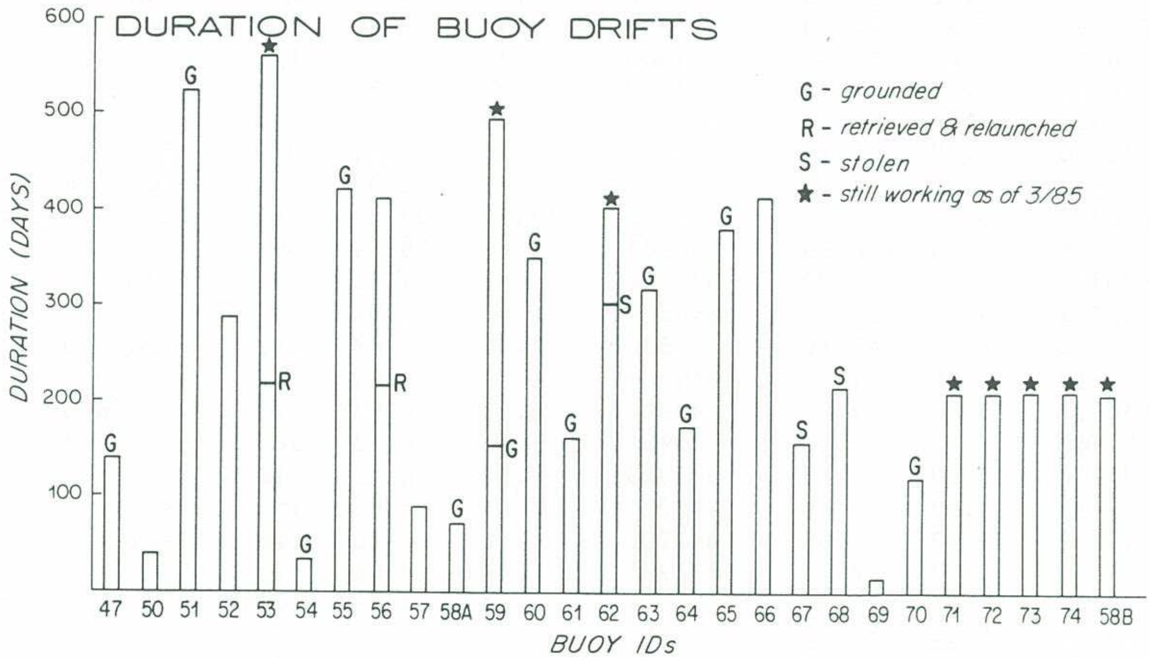


Figure 3a: Duration of the buoys at sea as of March 1, 1985. Four buoys 53, 56, 59, 62 were retrieved and relaunched. One new buoy 58B used a previously used number.

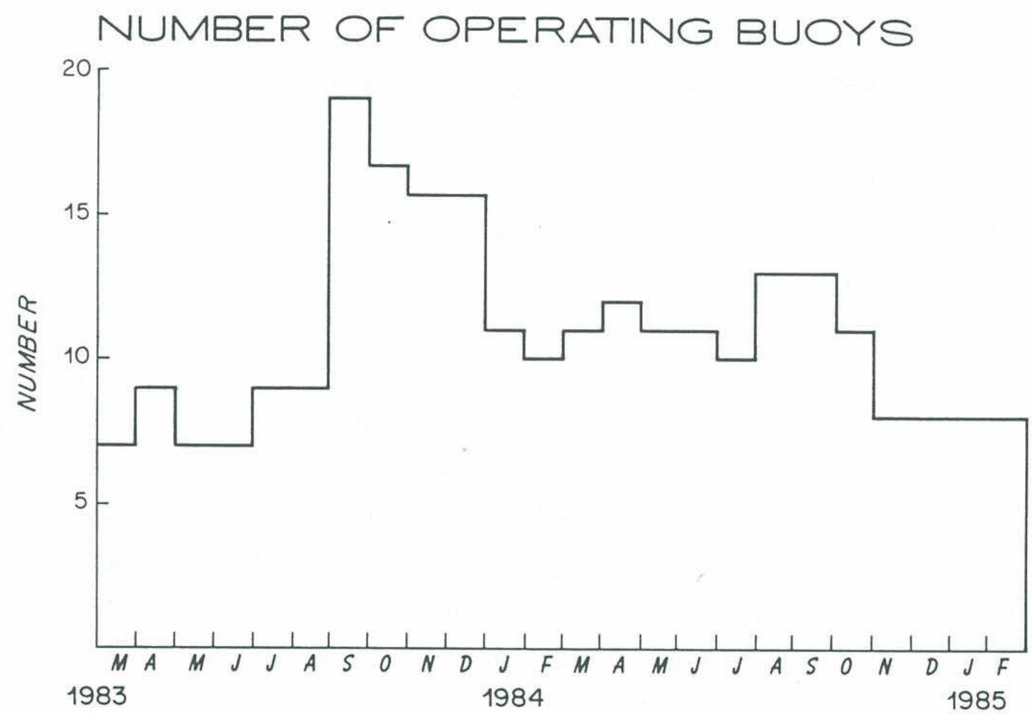


Figure 3b: Number of operating SEQUAL drifters as a function of time.

2) Four values per day of positions, temperatures, and wind speed were linearly interpolated in time at a 6-hour spacing.
3) Values were smoothed with a two-day Gaussian shaped filter (σ = 0.5 days) to reduce tidal and high frequency oscillations and noise due to measurement errors.
4) A cubic spline function was used to calculate velocity at the final positions.
5) Trajectories and time series of wind speed, temperature, u and v velocity components were plotted for each buoy.

On several occasions buoys made close passes to the SEQUAL current meter mooring near 6N, 28W (Figure 4). The following is a comparison of temperature, wind speed and velocity from buoy and mooring data.

a) Temperature

Temperature was measured at a depth of 0.6 m on the surface mooring. The average difference of buoy and mooring temperatures for four close passes was 0.1°C. The unsmoothed temperature series from the buoys showed a diurnal cycle with higher temperature during the afternoon and lower temperature in the early morning. The amplitude of the daily cycle was about 1.0°C for low wind speeds. Although the smoothed temperature series do not show the daily cycle, they do show an increase in temperature corresponding to times of low wind speed due to the daily warming of the sea surface layer (Figure 5). The daily temperature cycle should be considered when merging in situ and satellite infrared sea surface measurements.

b) Wind Speed

Two buoys with anemometers, 59B and 64, drifted past the mooring during the time wind speed was being measured there with a Vector Averaging Wind Recorder (VAWR) at a height of 3 m above the sea surface (see Levy and Richardson 1984a; 1984b; 1985). The agreement between buoy and mooring wind speeds from these is remarkably good (Figures 6, 7). The evidence suggests that the drifter wind speed is about 11 percent less than the VAWR speed. The agreement is surprising considering all the possible problems in trying to measure wind speed on such a low platform as a TOD buoy.

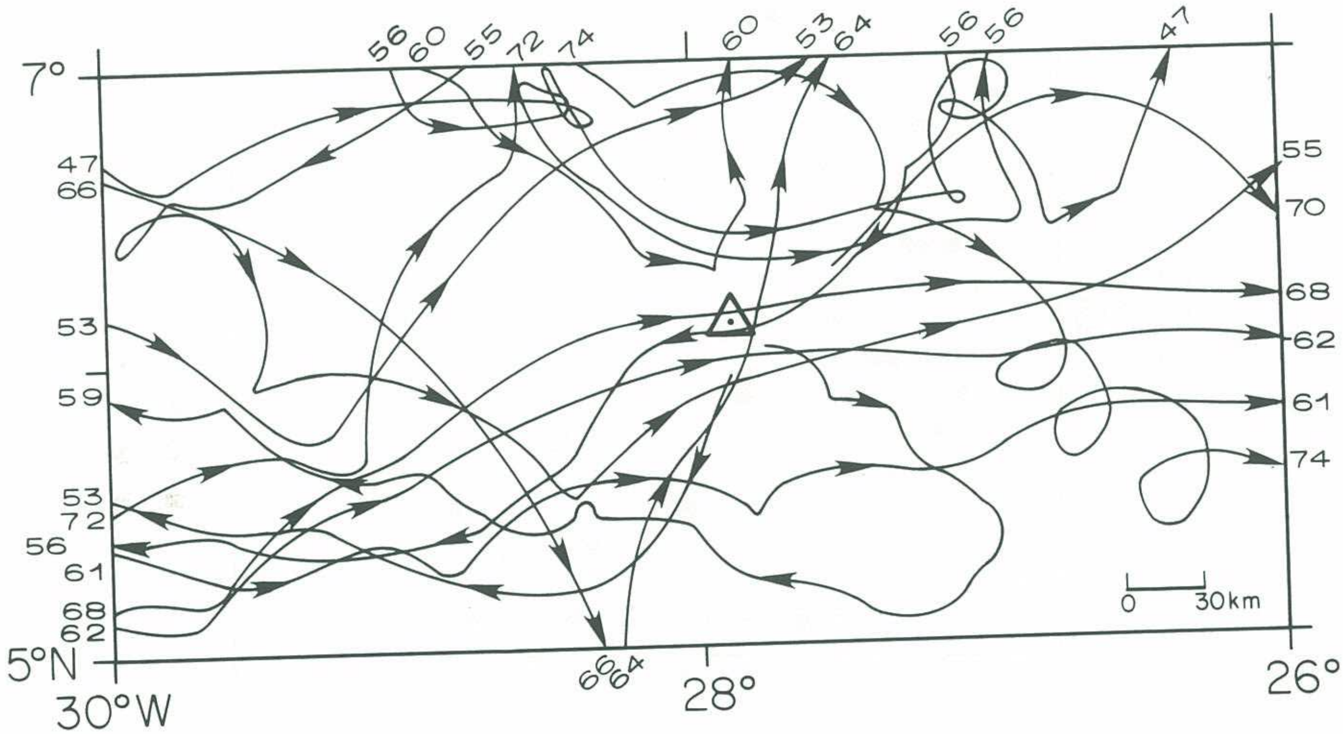


Figure 4: Plot of all buoys passing near to the SEQUAL current meter mooring near 6N, 28W.

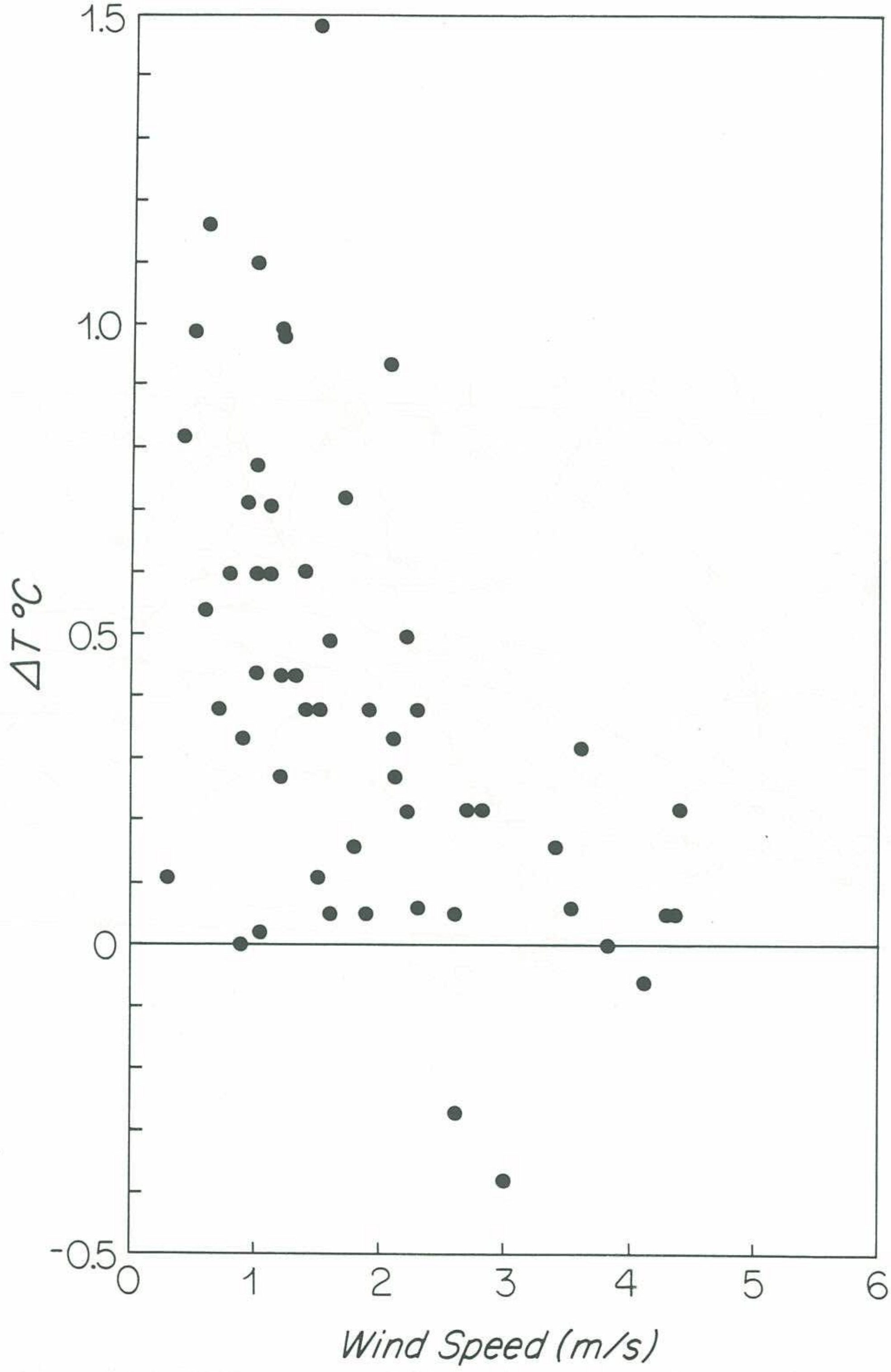


Figure 5: Temperature difference between 1800 and 0600 GMT each day plotted versus wind speed at 1800 GMT. Data are from buoy 64 in October and December 1983 and are unsmoothed.

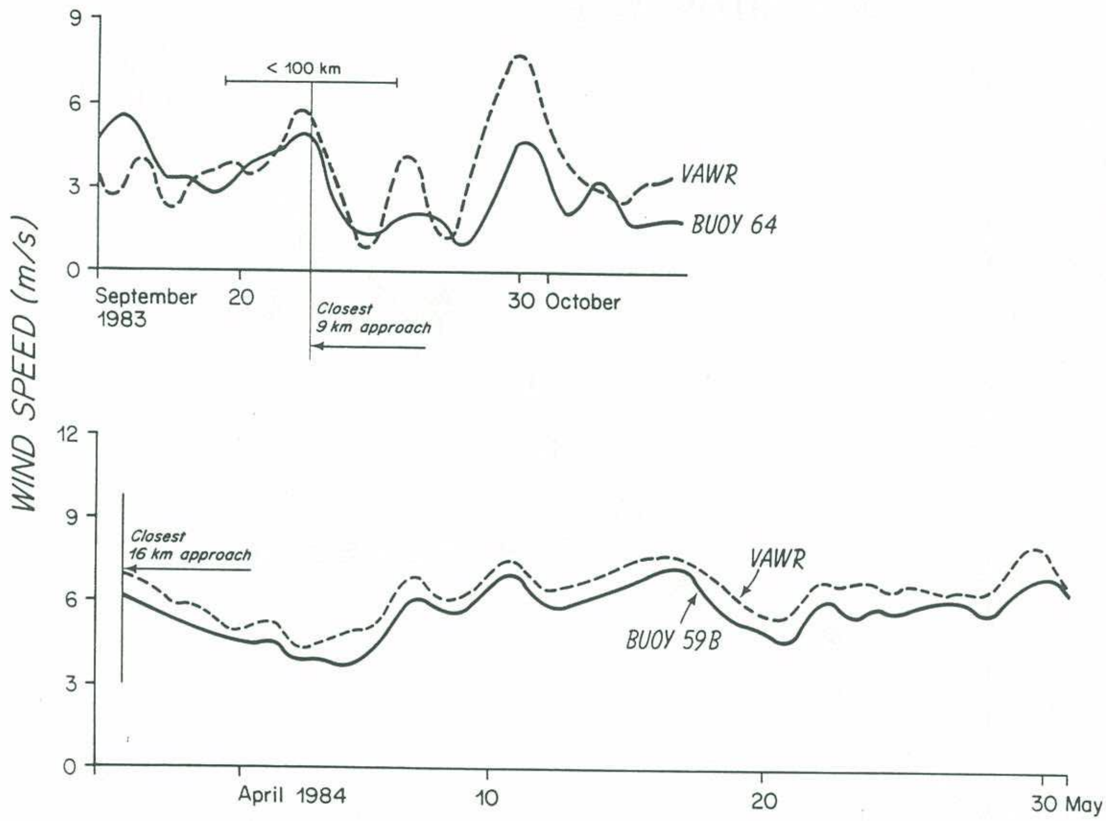


Figure 6: Time series of wind speed from buoys 59B and 64 and from the moored VAWR for times that the buoys made close passes to the mooring. Wind speed values were smoothed with a two-day Gaussian filter to reduce high frequency fluctuations.

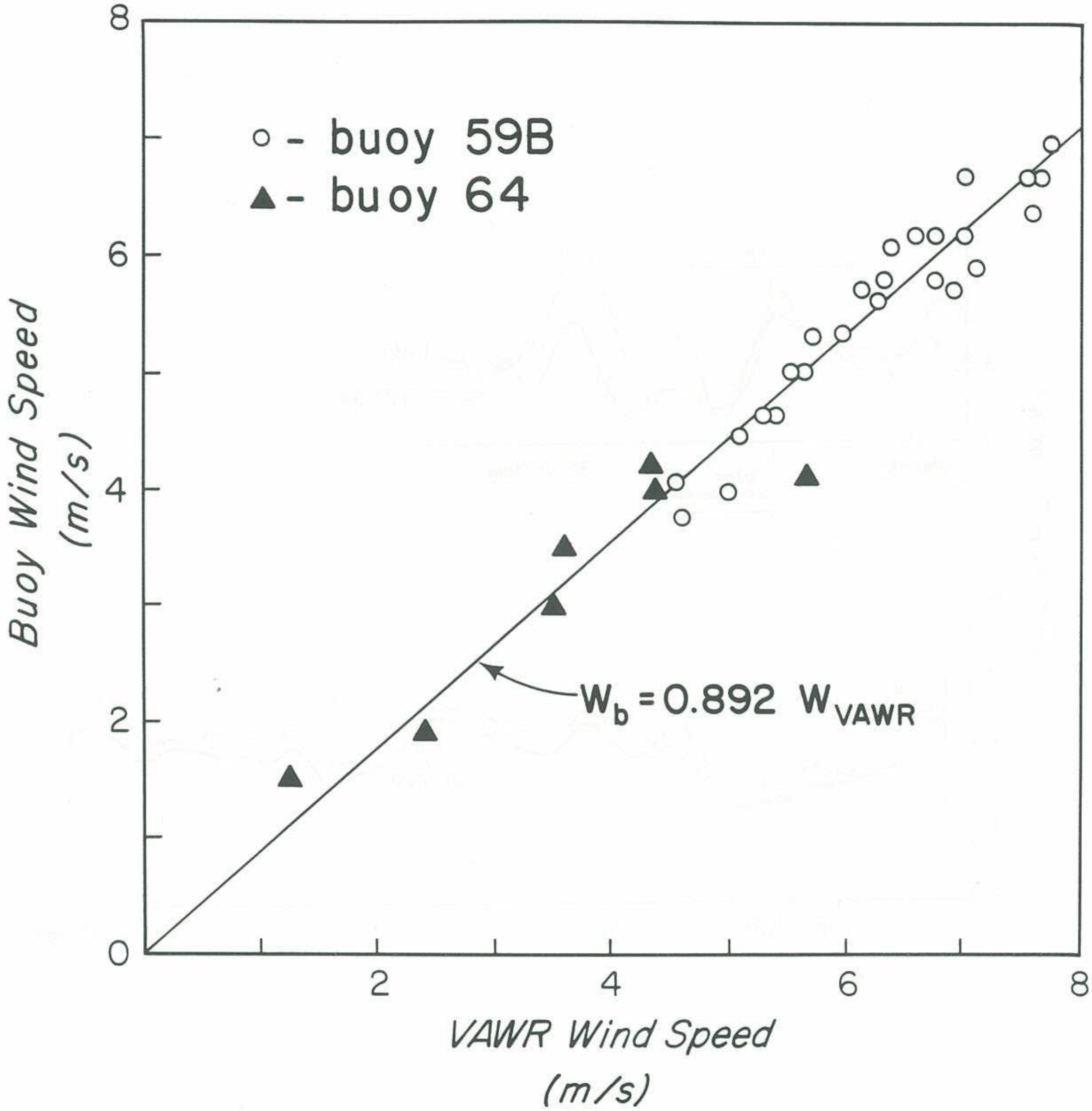


Figure 7: Daily values of smoothed wind speed for buoys 59B and 64 plotted against the simultaneous wind speed from the moored VAWR for separations less than 100 km. The line through the origin and average values of wind speed is $W_b = 0.892\ W_m$ where W_b is the buoy wind speed and W_m is the mooring wind speed. The regression line through the data is given by $W_b = 0.38\ (\pm\ 0.05) + 0.824\ (\pm\ 0.034)\ W_m$. The values in parentheses are estimates of the standard error.

The possible influence of buoy velocity on the buoy wind speed was investigated by subtracting the buoy velocity from the VAWR wind velocity. This was to simulate the wind measured at the mooring if it had been drifting at the same velocity as the buoy. The result was a slightly lower average mooring wind speed because the average buoy velocity had a net downwind component. The equation of the line through the origin and mean wind speeds is $W_b = 0.911 W^*_M$ where W_b is the buoy wind speed and W^*_M is the mooring wind speed after subtracting the buoy velocity from the mooring wind velocity. The "corrections" for buoy velocity are small; the effect is to make the buoy and mooring average wind speeds agree slightly better than before the "correction" was applied (see Figure 7).

Two problems were noted in the buoy wind series. The first concerns buoy 62A that had been at sea for 200 days. Its wind speed was much lower than nearby wind speeds on St. Peter and St. Paul Rock (Garzoli, personal communication), and there were intervals when the buoy anemometer was stalled despite wind speeds of several m/s on the Rock. When the anemometer was stalled, a wind speed of about 1.1 m/s was recorded due to the calibration constant B in Table 3. However, no other wind series seemed to decrease and stall as 62A did. When this buoy was relaunched as 62B, the wind speed looked correct and no stalled periods were seen.

The second problem was noticed in one of three buoys (61, 62A, 68) that drifted close together for three months (Figure 8). The wind speed of 68 was about 1.6 m/s lower than that of the other two despite a clear visual coherence among the three time series. This problem could be due to a calibration mistake, or damage to the anemometer at launch time.

c) Velocity

In general the velocities from the buoys and mooring current meter at a depth of 20 m agree well, and the agreement is best for the closest passes. The difference in buoy and current meter velocity is about the same size as the difference in velocity from two buoys for equivalently close passes -- typically several cm/sec for passes within 10 km. The differences in velocity are due to the spatial gradients in velocity inherent in this region. Thus no difference in velocity is detected solely due to the two different techniques of measuring velocity -- drogued drifting buoys and a moored current meter.

Table 3: Wind speed calibration constants provided by Polar Research Laboratory

Buoy I.D.	Anemometer S/N	A	B	Threshold (m/s)
57	82-026	.1567	.619	1.51
58	82-027	.1537	.557	1.51
59A	82-029	.1521	1.057	1.79
59B	83-022	.1462	.7620	.83
60	82-030	.1518	1.145	1.66
61	82-031	.1528	.807	1.36
62	82-033	.1514	1.113	1.97
63	82-034	.1605	1.132	2.14
64	82-006	.1526	.382	.67
65	83-011	.1559	-.153	.48
66	83-004	.1575	-.136	.48
67	82-038	.1554	1.113	2.03
68	83-009	.1488	.058	.67
69	83-012	.1548	-.054	.48
70*	83-018	.1564	-.195	.34

* mini TOD

The equation for wind speed is $W = A(\text{count}) + B$, where W is the wind speed in meters per second, A and B are coefficients, and count is the decimal count of the wind speed bits telemetered from the buoy. When an anemometer is stalled, the equation gives an apparent wind speed due to the B coefficient. During the data processing, negative wind speeds caused by B coefficients were eliminated and replaced by linearly interpolated values.

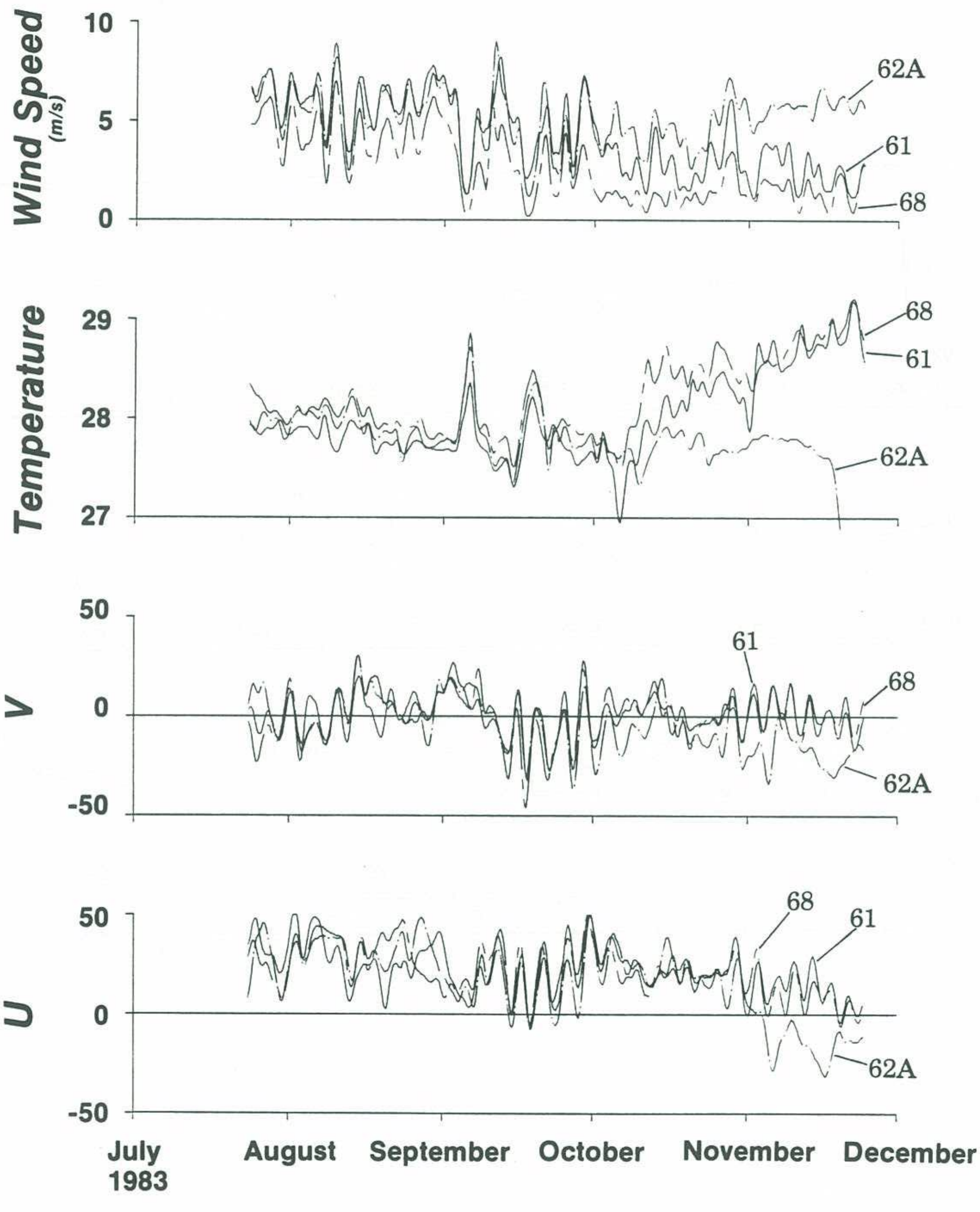


Figure 8a: Time series of buoys 61, 62A, and 68 for four months after their launch. During the first 80 days they remained close to each other. Note (1) strong coherence in velocity components at certain times such as mid-September, (2) an increase of temperature corresponding to a low wind speed in early September, and (3) anomalously low wind speed measured by buoy 68.

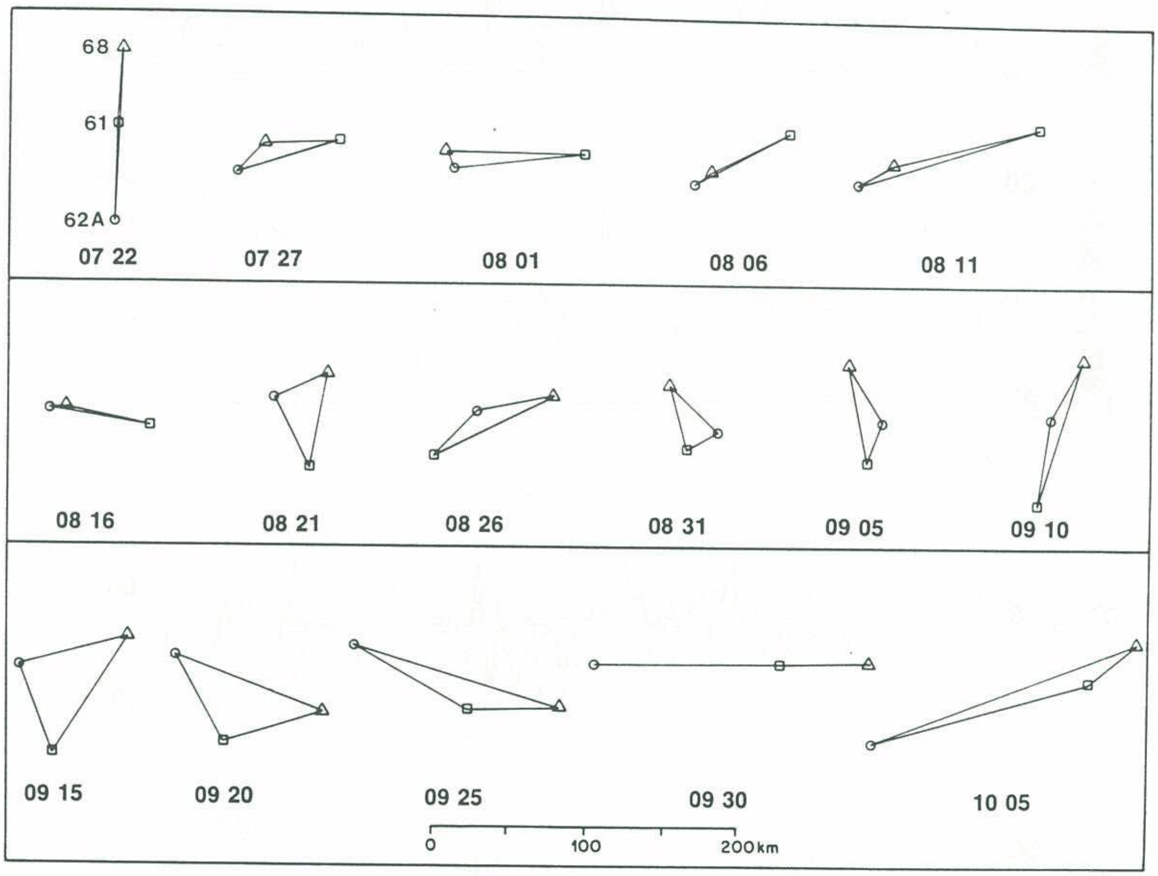


Figure 8b: Relative positions of buoys 61, 62A, and 68 as they drifted together for 80 days. The buoys were launched along 35W at 4.0, 4.5, and 5.0°N in July 1983 by the CAPRICORNE on a FOCAL cruise.

The simultaneous velocities for close passes are shown (a) in time series (Figure 9), (b) by superimposing buoy trajectories and current meter progressive vector plots (Figure 10), and (c) by plotting buoy velocity against current meter velocity (Figure 11). Table 4 lists the six closest passes to the mooring. The closest pass was by buoy 56A which drifted to a minimum separation from the mooring of 1.8 km. The average vector speed of the buoy and current meter (which both were 24 cm/sec) agree within 0.2 cm/sec (Table 4). The trend is that farther passes disagree more. Buoy 68 stands out as having an exceptionally large disagreement. This buoy made a close pass of 4.4 km yet had a vector speed difference of 5.6 cm/sec. However this buoy and buoy 62A which remained relatively close together for three months also disagreed with each other by about the same amount when separated by similar distances (Figures 8, 9). A plot of the velocity of buoys 61, 62A, and 68 shows that at times their velocity components are very similar and clearly coherent and at other times, such as during the close pass to the mooring, they are not similar despite relatively small separations (Figure 8). The dominant variability seen on these series is caused by 4-5 day inertial gravity waves which vary in amplitude and phase with time. If the velocity comparison had been made during one of the coherent events, then the velocities would no doubt have agreed much better than they did during a time of incoherent motion like buoy 68's close pass. Averaging the velocity values over longer periods of time did not decrease the disagreement appreciably. The not-so-close pass of buoy 70 may have occurred during one of those coherent times. The time series of this buoy and mooring show a strong visual coherence despite relatively large separations (Figure 9).

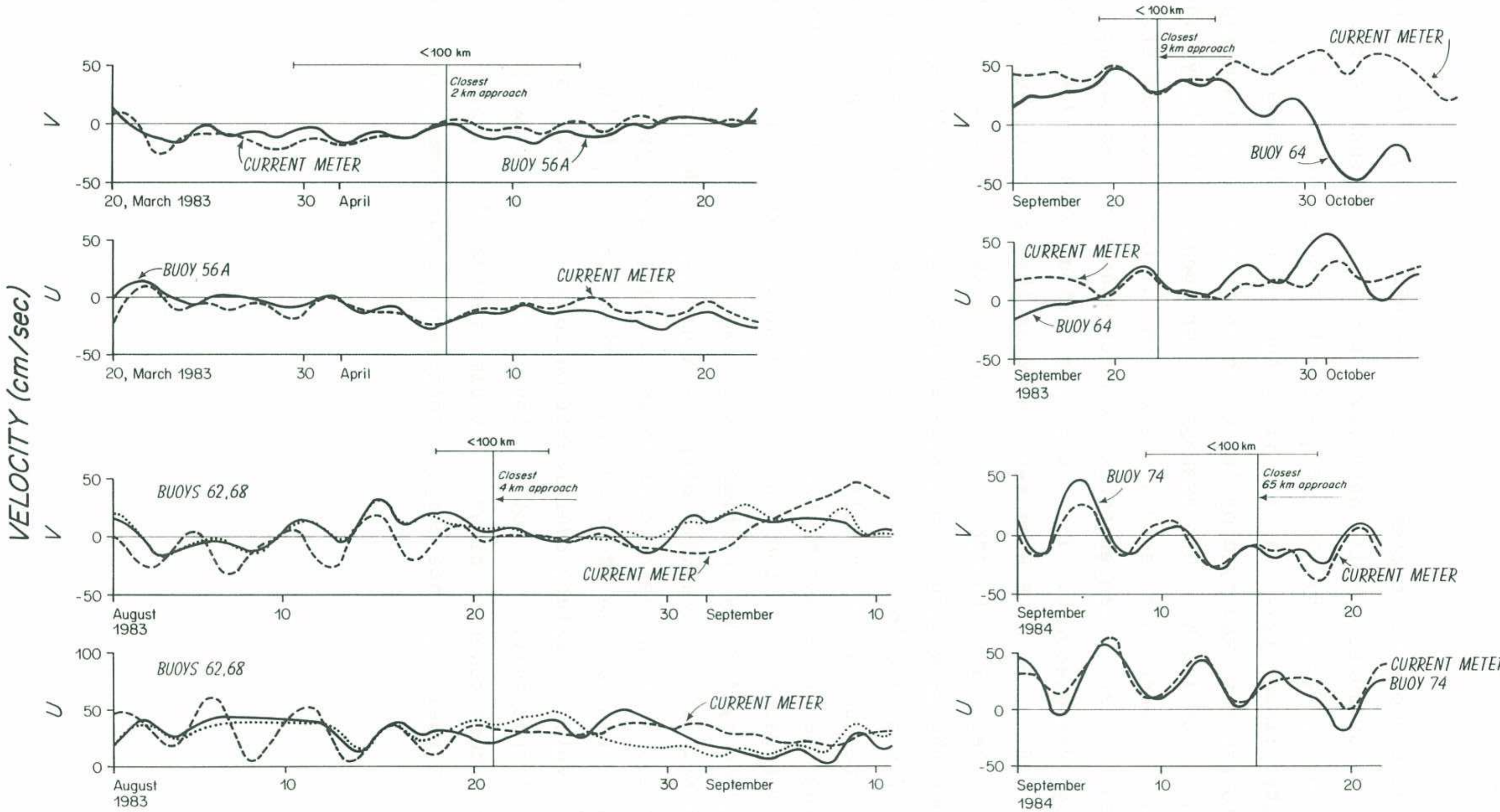


Figure 9: Velocity time series from drifters and current meter (at 20 m) for five drifters that passed close to the mooring. Series were smoothed with a two-day Gaussian filter.

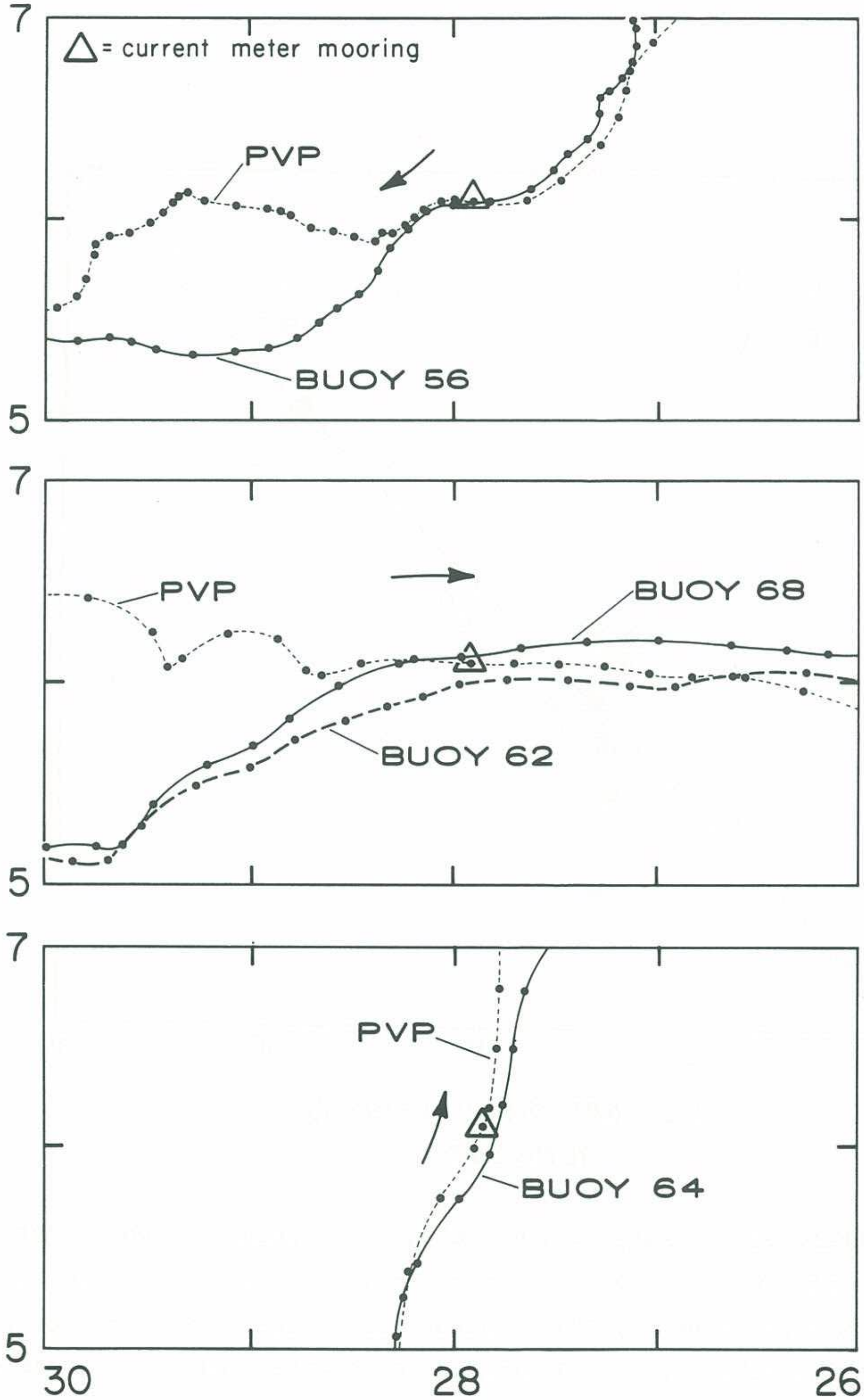


Figure 10: Superposition of buoy trajectories and current meter (20 m depth) progressive vector plots (PVP) for four buoys that made close passes to the mooring.

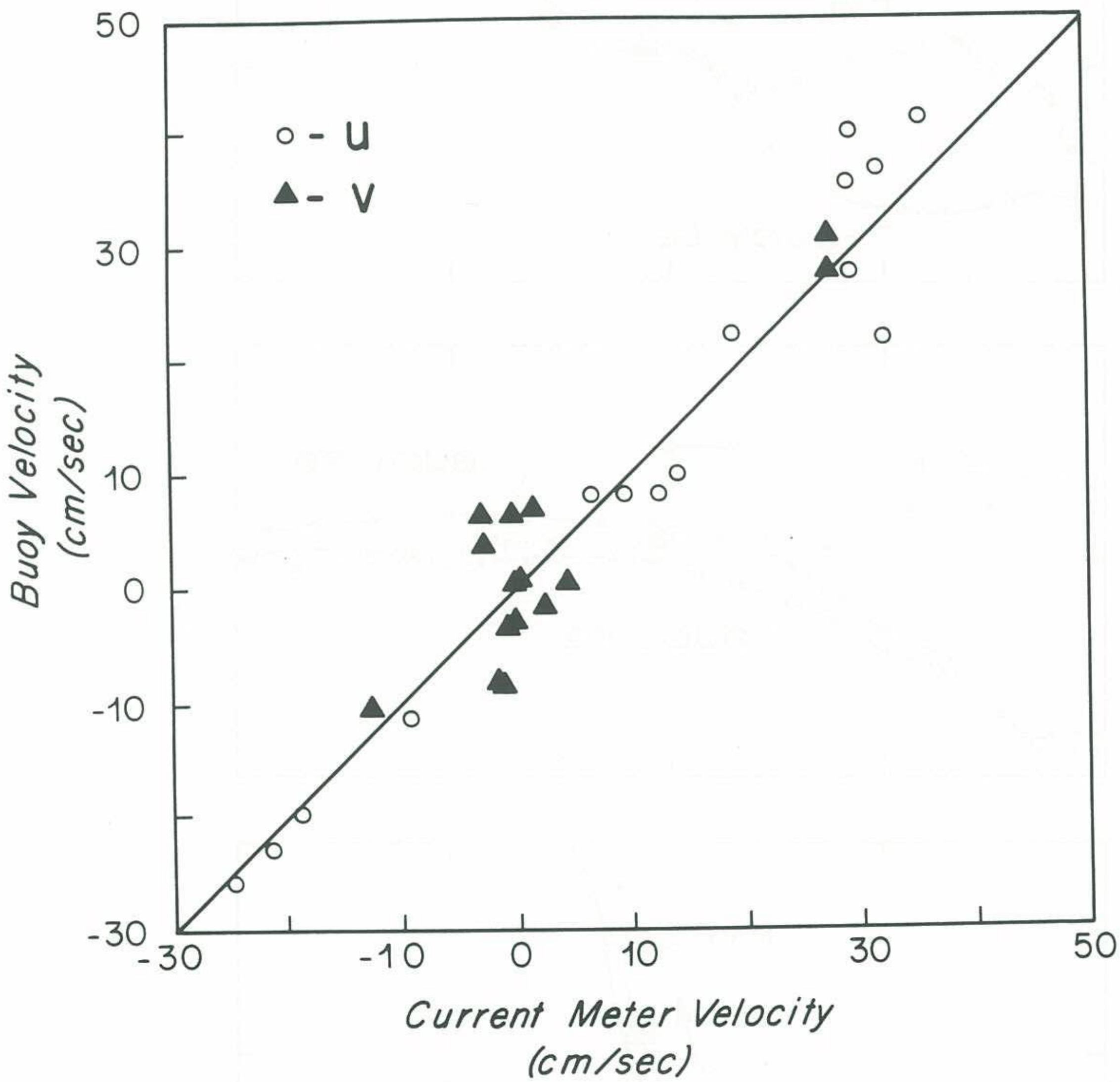


Figure 11: Scatterplot of daily buoy velocity V_b versus current meter velocity V_{cm} at 20 m for drifters that passed within 30 km of the mooring near 6N, 28W. Values were smoothed with a two-day Gaussian filter ($\sigma = 0.5$ days). The equation of the regression line is $V_b = 0.9(\pm 1.1) + 0.97(\pm 0.06)\ V_{cm}$, which is not significantly different from a one to one relationship. The values in parentheses are estimates of the standard errors of the regression coefficients.

Table 4: Drifter-current, meter mooring comparisons for close passes.

Drifter	Distance	Drifter Velocity		Current Meter Velocity		Difference		Drifter		Mooring	
	(km)	Speed cm/sec	Direction	Speed cm/sec	Direction	Speed cm/sec	Direction	Temp °C	Wind Speed m/s	Temp °C	Wind Speed m/s
56A	1.8	24.3	265.4	24.2	273.5	0.2	-8.1	27.9	--	27.6	8.3
68	4.4	37.2	82.9	31.6	92.8	5.6	-9.9	27.9	4.8	--	--
64	8.8	34.2	13.0	32.9	11.1	1.3	1.9	27.5	3.7	27.7	3.6
62A	10.1	31.8	86.3	28.5	90.8	3.4	-4.5	27.9	5.0	--	--
59B	15.6	7.5	84.4	12.0	61.7	-4.5	22.7	26.8	6.3	26.5	7.0
70	43.0	36.2	47.3	41.4	28.4	-5.1	18.9	28.0	3.5	27.9	4.6

Note: The distance is the closest pass of each buoy to the mooring which was located near 6N, 28W. The current meter was at a depth of 20 m, wind speed was measured by a VAWR at a height of 3 m, and mooring temperature was at a depth of 0.6 m. All values were low passed with a two-day filter to suppress high frequency oscillations and noise. Buoy 70 was a mini TOD.

Acknowledgements

Funds were provided by the National Science Foundation Grant OCE82-08744. Many SEQUAL and FOCAL participants helped to launch the buoys from the N/O CAPRICORNE, R/V CONRAD, R/V GYRE and R/V KNORR. Chief scientists were E. Katz, C. Henin and C. Hisard. G. Reverdin generously provided FOCAL buoy data which were used in several figures. M. A. Lucas typed the manuscript.

References

Levy, E. and P. L. Richardson, 1984a. Moored current meter data from the Atlantic North Equatorial Countercurrent near 6°N, 28°W (February-September 1983) Vol. XXXIV. Woods Hole Oceanographic Institution Technical Report, WHOI-84-16, 42 pp.

Levy, E. and P. L. Richardson, 1984b. Moored current meter data from the Atlantic North Equatorial Countercurrent near 6°N, 28°W (September 1983-March 1984) Vol. XXXVI. Woods Hole Oceanographic Institution Technical Report, WHOI-84-37, 42 pp.

Levy, E. and P. L. Richardson, 1985. Moored current meter data from the Atlantic North Equatorial Countercurrent near 6°N, 28°W (March-October 1984) Vol. XXXVII. Woods Hole Oceanographic Institution Technical Report, WHOI-85-7, 50 pp.

Reverdin, G. and A. Kartavtseff, 1984. Bouées FOCAL, Mai 1983-October 1984, Recueil des trajectoires et séries temporelles. Laboratoire d'Océanographie Physique, Muséum National d'Histoire Naturelle, Paris, 120 pp.

Richardson, P. L., 1984a. Moored current meter measurements in the Atlantic North Equatorial Countercurrent during 1983. Geophysical Research Letters, 11, 749-752.

Richardson, P. L., 1984b. Drifting buoy trajectories in the Atlantic North Equatorial Countercurrent during 1983. Geophysical Research Letters, 11, 745-748 (reprinted here as Appendix 1).

Summary of the Figures

A summary of the SEQUAL drifting buoy data is shown in a series of figures which follow this brief description. The first set of figures (Figures 12-31) shows trajectories grouped in different ways. The next set (Figures 32-93) shows individual trajectories and time series of velocity, temperature, and wind speed. A third set (Figures 94-103) show details of a few interesting trajectories. The figures are briefly described below.

Figure 12, page 26, shows the total displacement and average velocity vector of the buoys from their launch to final position (or position on March 1, 1985). The launch position is shown by a small black square, the final position by an arrowhead.

Figure 13, page 27, is a summary of all SEQUAL buoy trajectories superimposed.

Figures 14-17, pages 28-31, show summaries of trajectories during year 1, year 2, July-December when the Countercurrent runs eastward, and January-June when the Countercurrent disappears. Arrowheads are spaced at 10 days.

Figures 18-19, pages 32-33, show the launch locations and trajectories during the first few months of the buoys that were launched together on individual cruises. Some additional buoys that passed near to the launch locations and times are included. Arrowheads are spaced at 10 days. Trajectories were smoothed with a 10-day Gaussian filter to remove the high frequency oscillations. The smoothing cuts off the first and last five days of the records.

Figures 20-23, pages 34-37, are 4 figures which show the trajectories in each month from March 1983 to February 1985. Trajectories were smoothed with a 10-day filter. Data from FOCAL buoys which were launched in the South Equatorial Current were kindly provided by Gilles Reverdin (see Reverdin and Kartavtseff, 1984).

Figures 24-31, pages 38-45, show groups of trajectories from various currents and regions including the North Equatorial Current, the Caribbean, the North Equatorial Countercurrent, the North Brazil Current, the Guinea Current, and the South Equatorial Current. Arrowheads are spaced at 10 days. FOCAL buoy data were provided by Gilles Reverdin (see Reverdin and Kartavtseff, 1984).

Figures 32-93, pages 46-107, show individual trajectories and time series of velocity, temperature, and wind speed (when available) from each of the SEQUAL buoys. Arrowheads are spaced at 10 days. Data were smoothed with a 2-day filter.

Figures 94-103, pages 108-117, show some curious trajectories that are not clearly apparent in the other figures. Included are the individual loops of buoy 65, the trajectory of buoy 63 which hovered off the coast of Africa for eight months, the semi-diurnal tidal fluctuations on the continental shelf off Africa of buoy 55, the eastward drift along the equator of buoys 62A and 66B during spring 1984, the trajectory of buoy 59B that stalled near some seamounts, and the trajectory of buoy 68 after it was stolen.

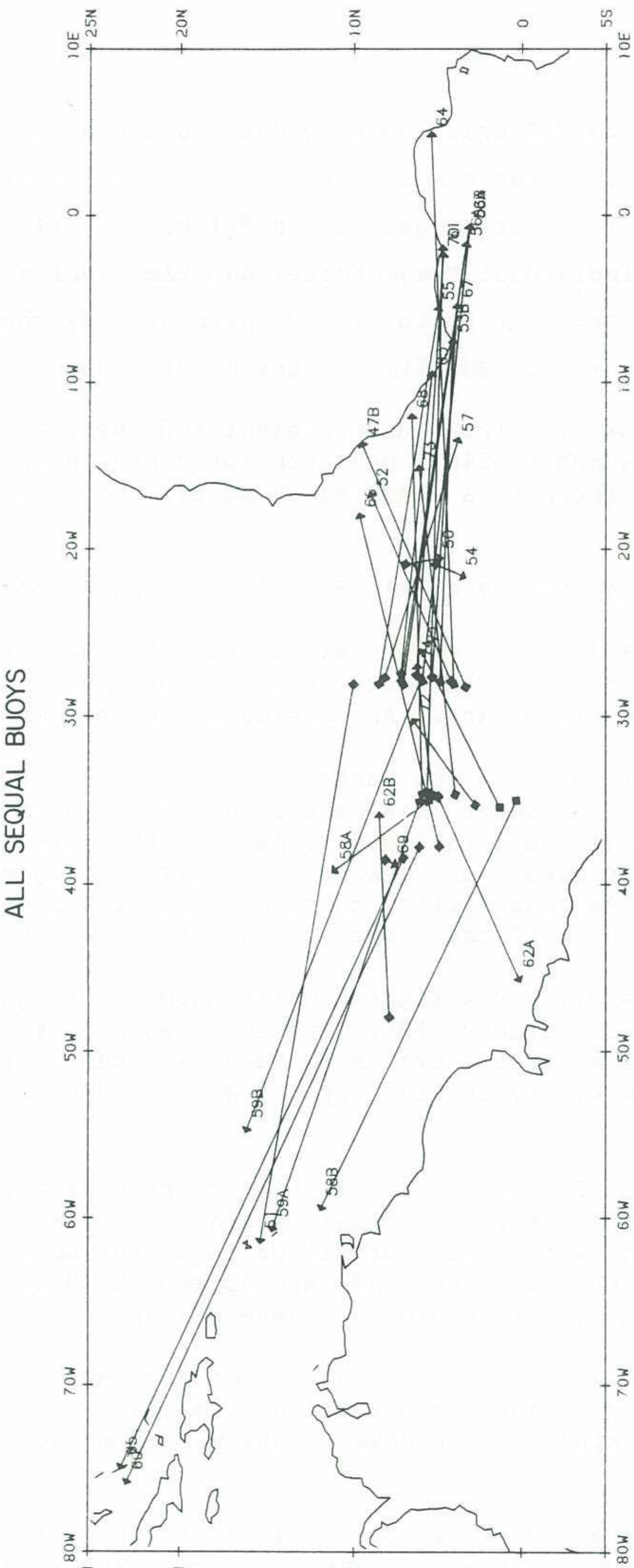

ALL SEQUAL BUOYS
25N
20N
10N
0
5S
80W
70W
60W
50W
40W
30W
20W
10W
0
10E

Figure 12

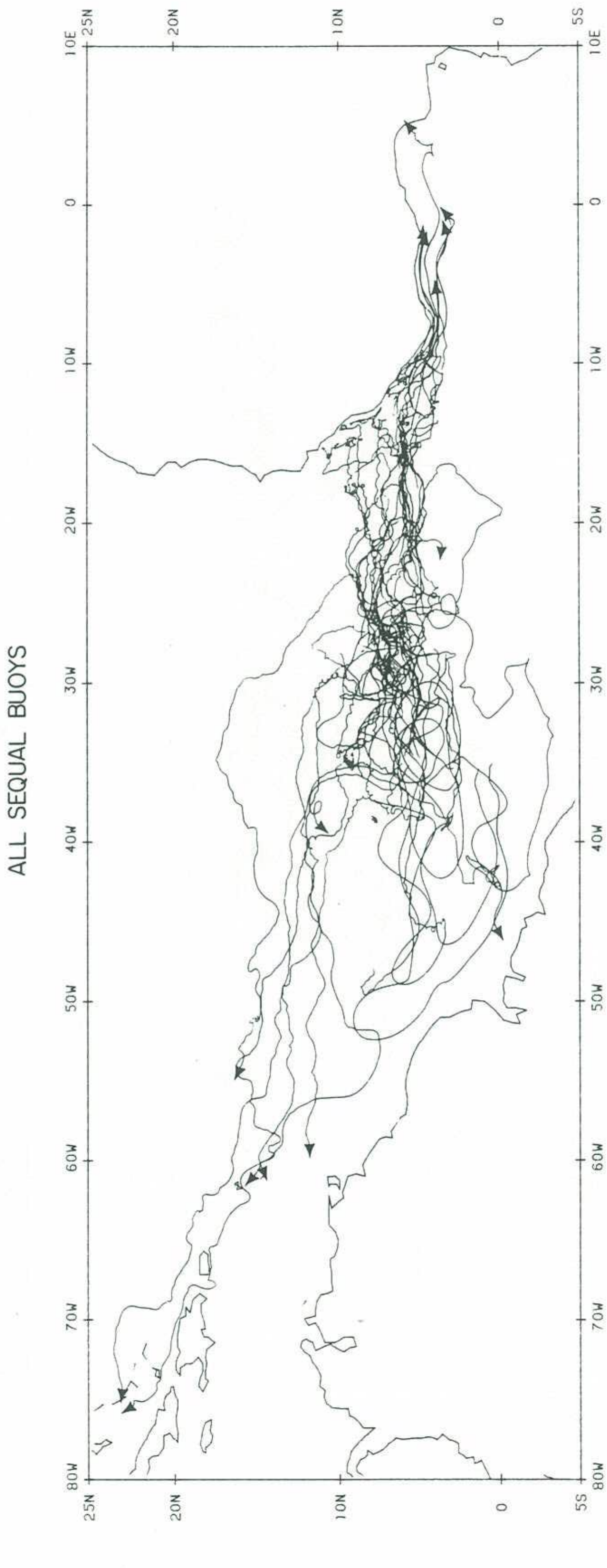

ALL SEQUAL BUOYS
25N
20N
10N
0
5S
10E
0
10W
20W
30W
40W
50W
60W
70W
80W

Figure 13

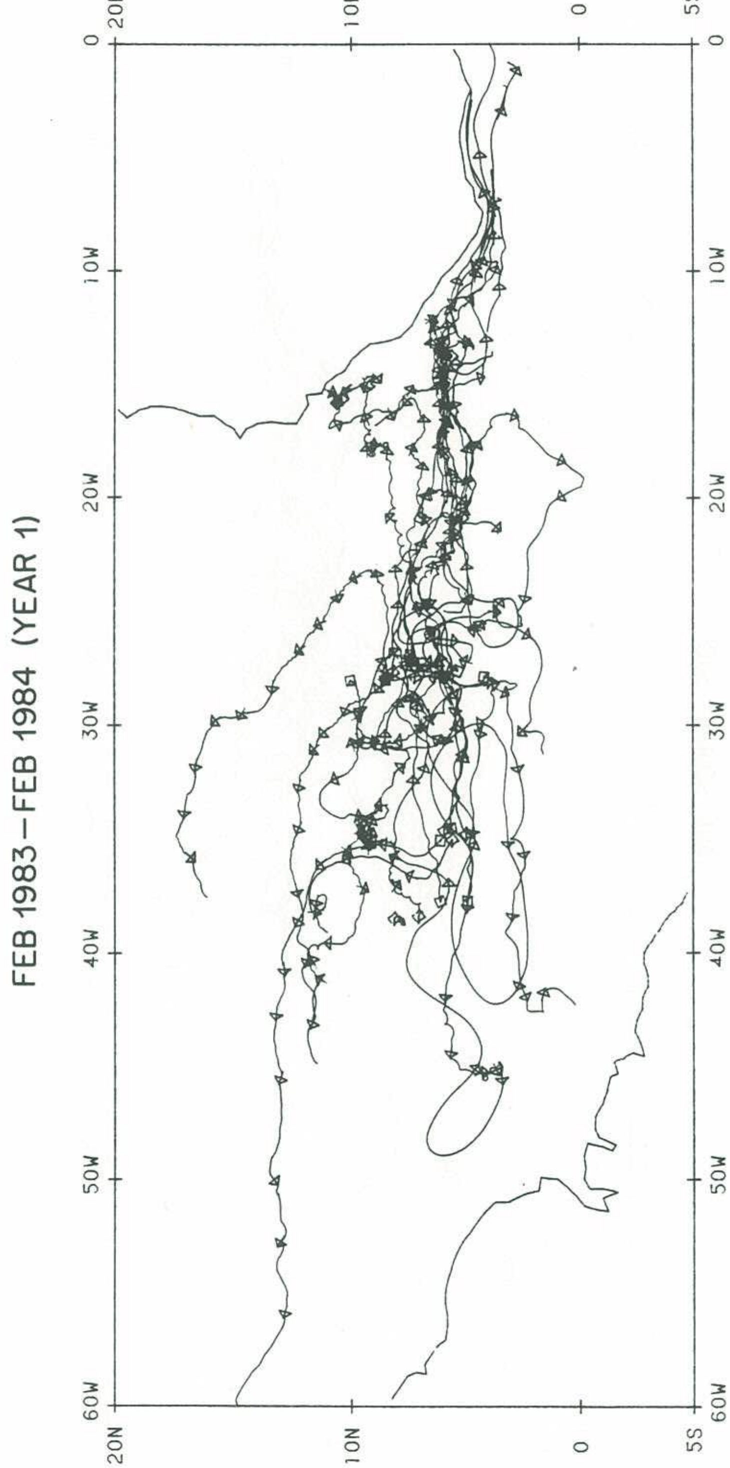


Figure 14

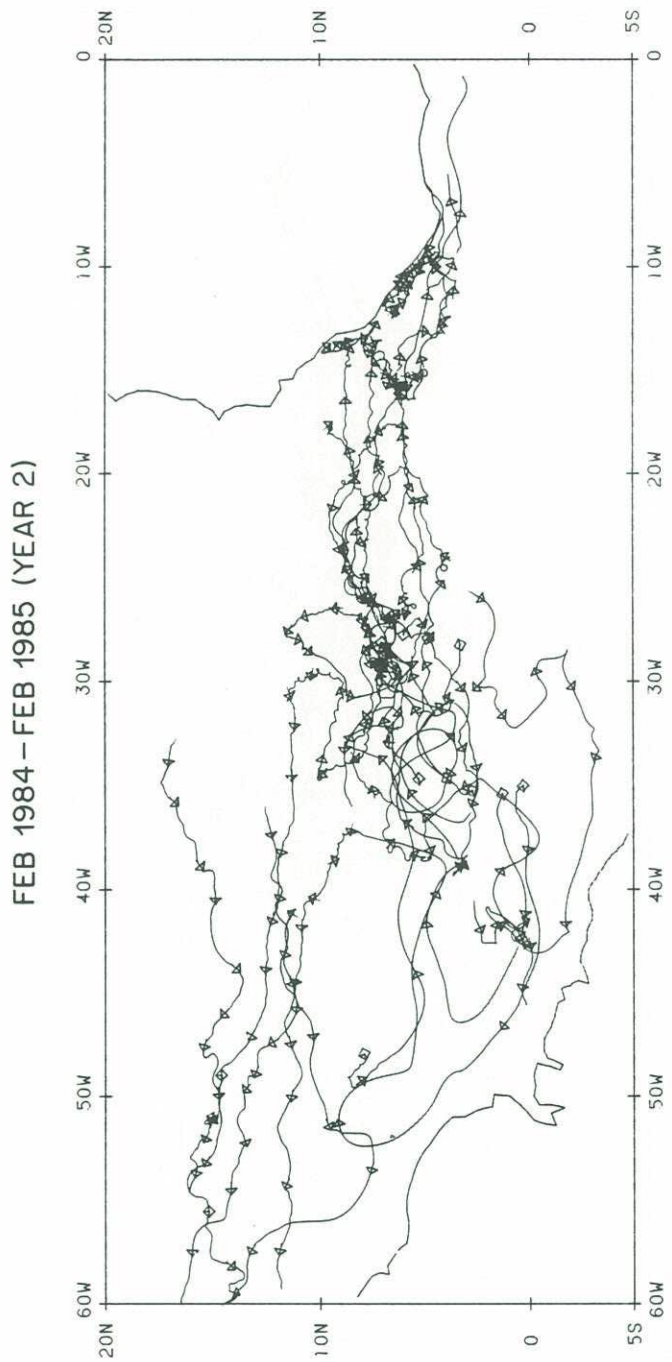


Figure 15

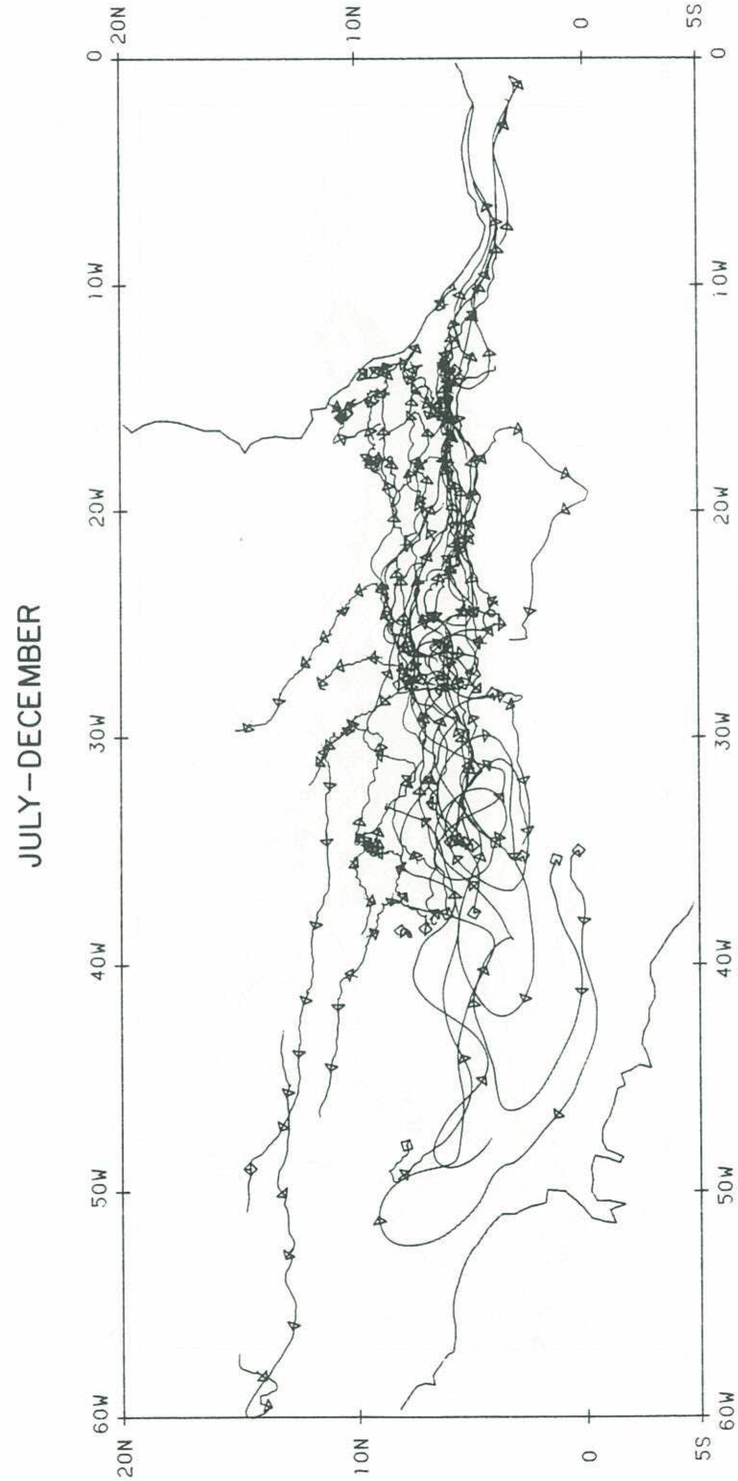


Figure 16

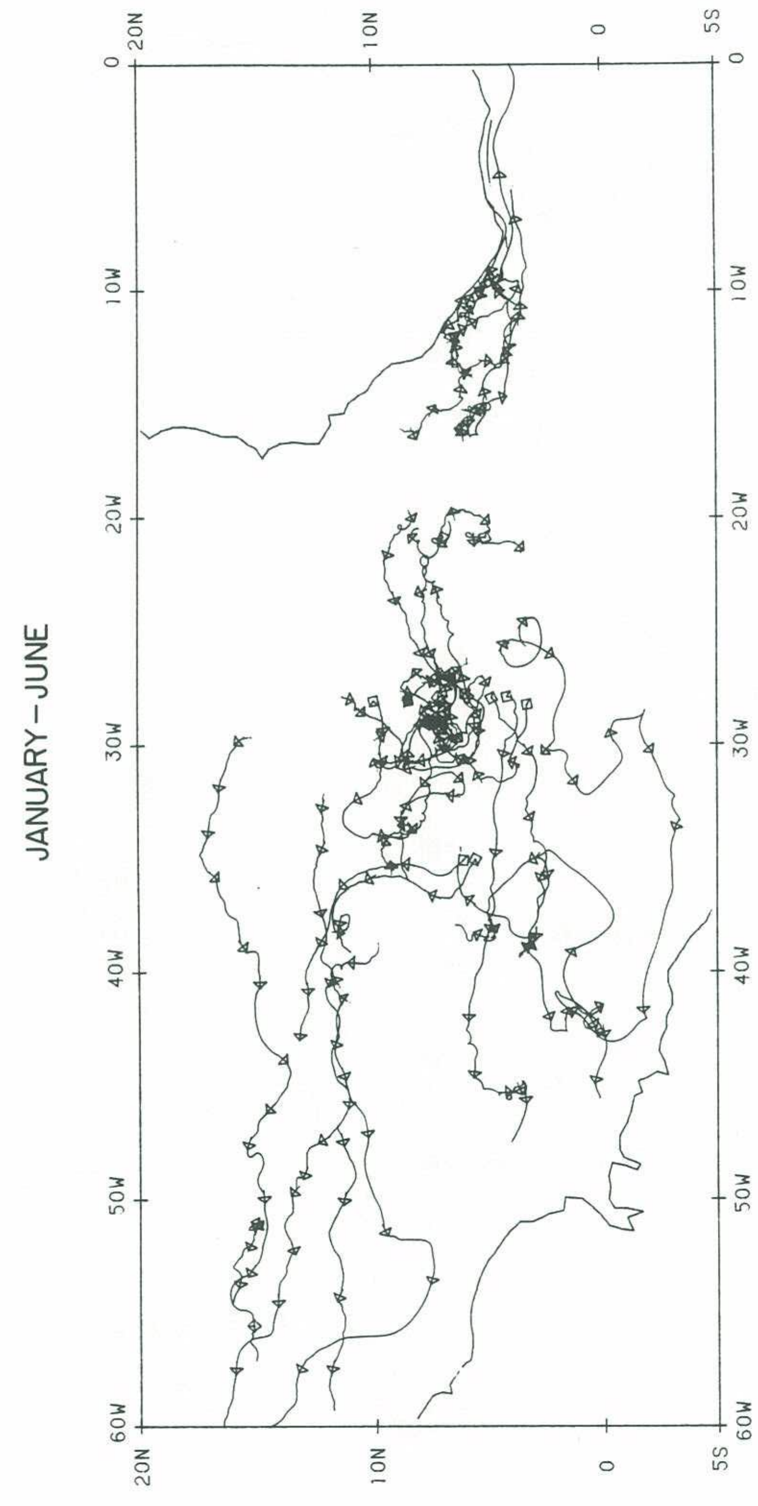


Figure 17

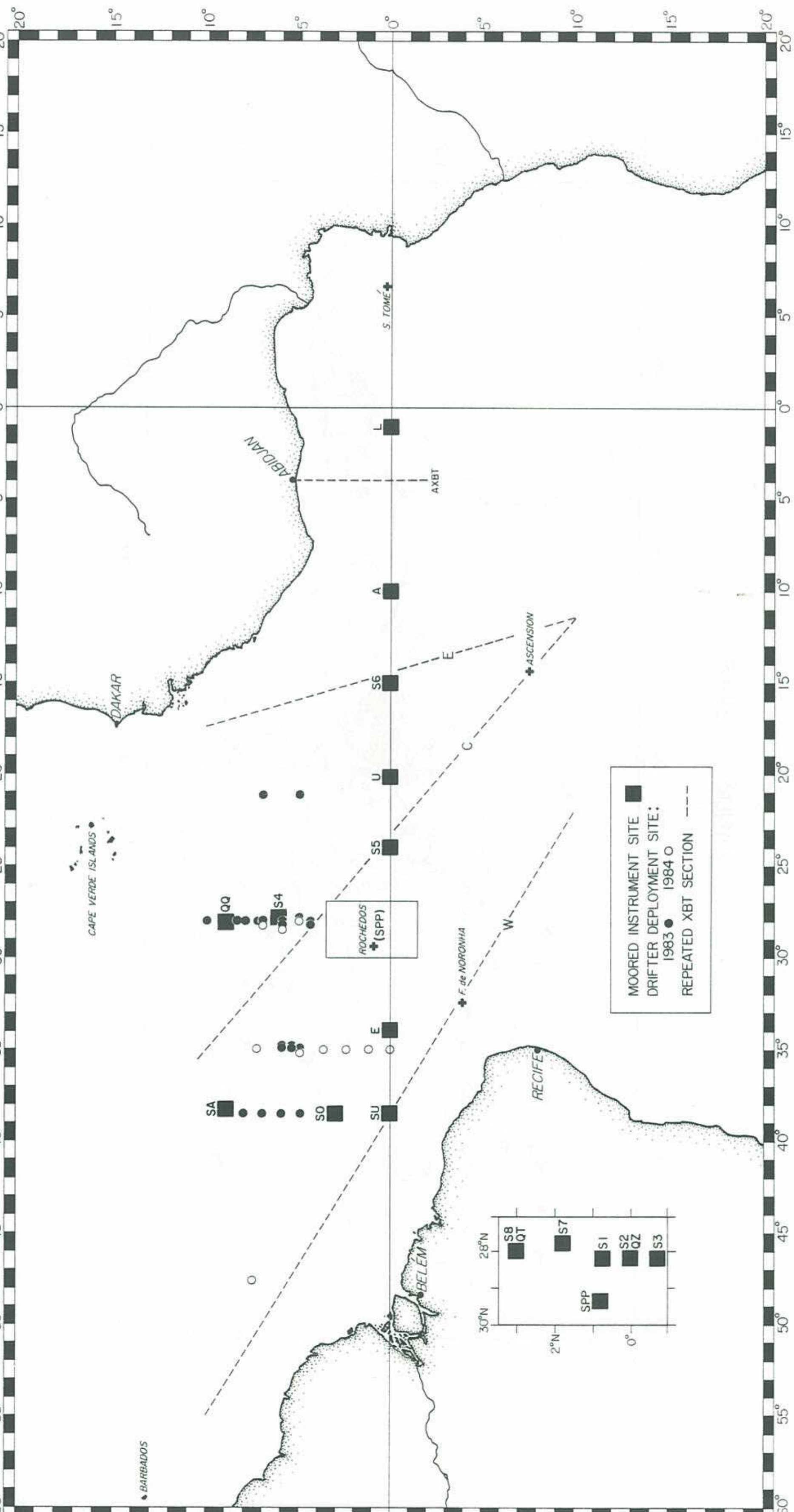

DAKAR
ABIDJAN
S. TOME
AXBT
CAPE VERDE ISLANDS
BARBADOS
ROCHEDOS
(SPP)
F. de NORONHA
ASCENSION
RECIFE
BELEM
L
A
S6
U
S5
S4
QQ
SA
SO
SU
E
C
W
MOORED INSTRUMENT SITE
DRIFTER DEPLOYMENT SITE:
1983 ● 1984 ○
REPEATED XBT SECTION
S8
QT
S7
S1
S2
QZ
S3
SPP
28°N
30°N
2°N
0°

Figure 18

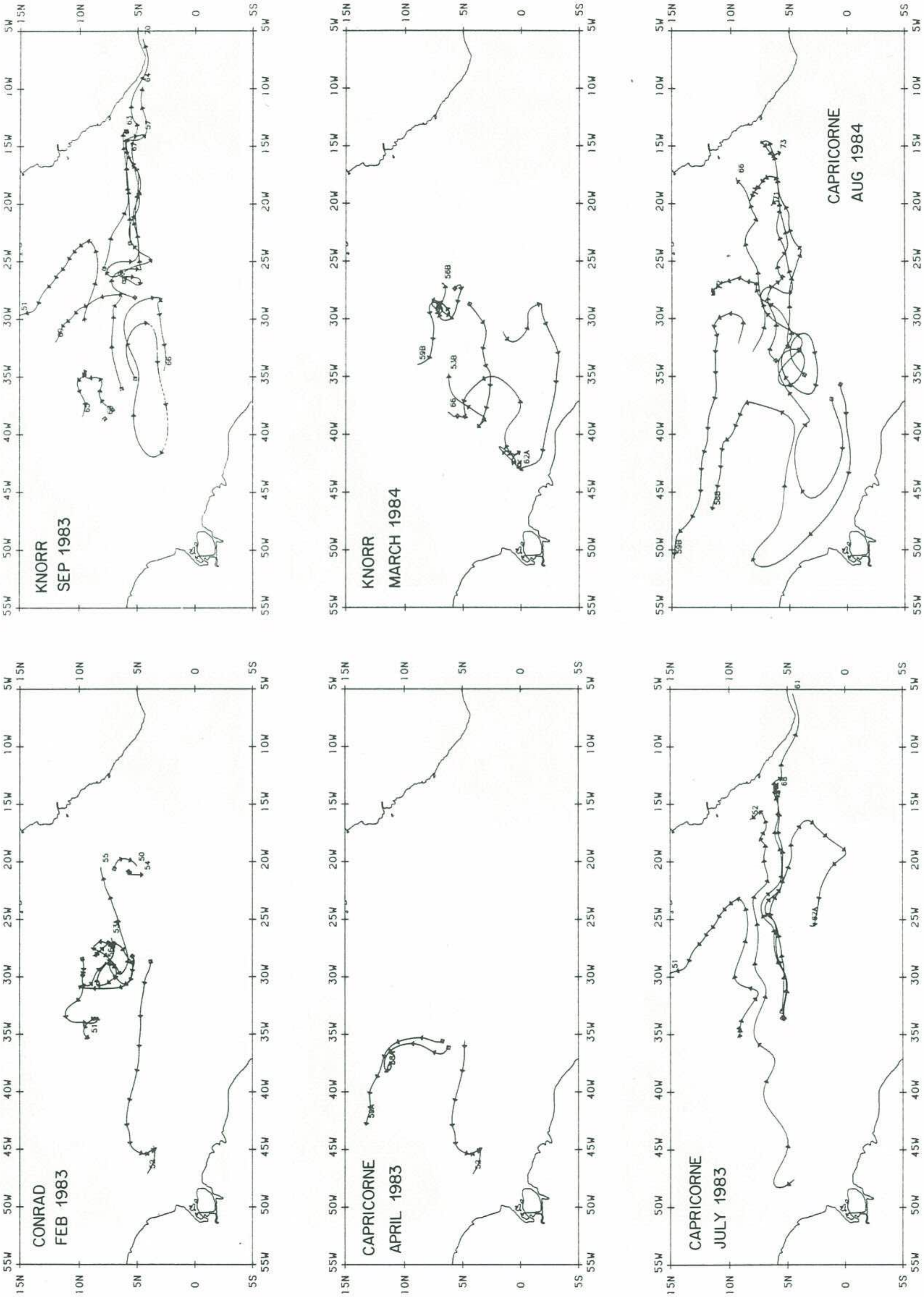

KNORR
SEP 1983
KNORR
MARCH 1984
CAPRICORNE
AUG 1984
CONRAD
FEB 1983
CAPRICORNE
APRIL 1983
CAPRICORNE
JULY 1983

Figure 19

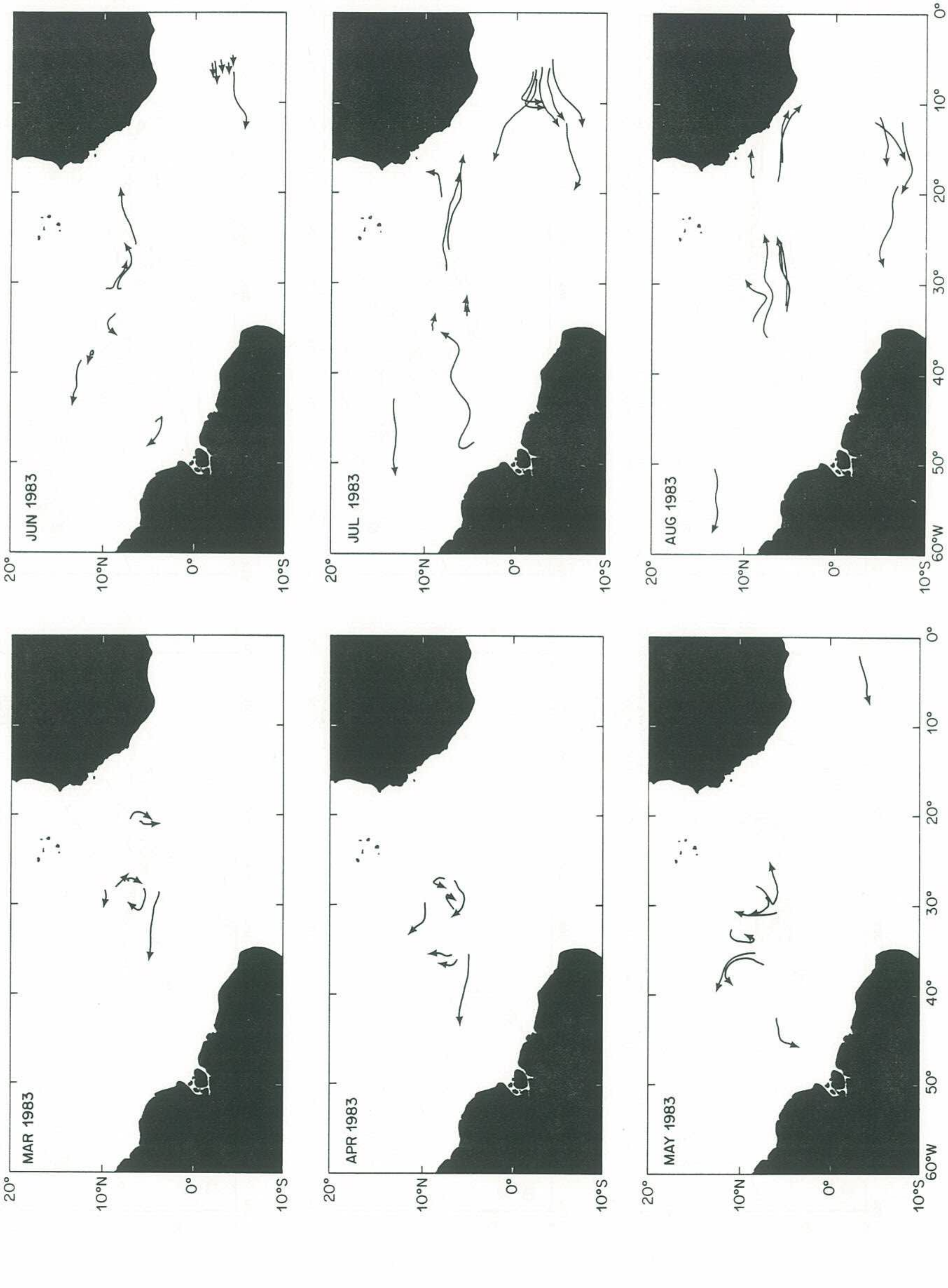

MAR 1983
APR 1983
MAY 1983
JUN 1983
JUL 1983
AUG 1983
20°
10°N
0°
10°S
60°W
50°
40°
30°
20°
10°
0°

Figure 20

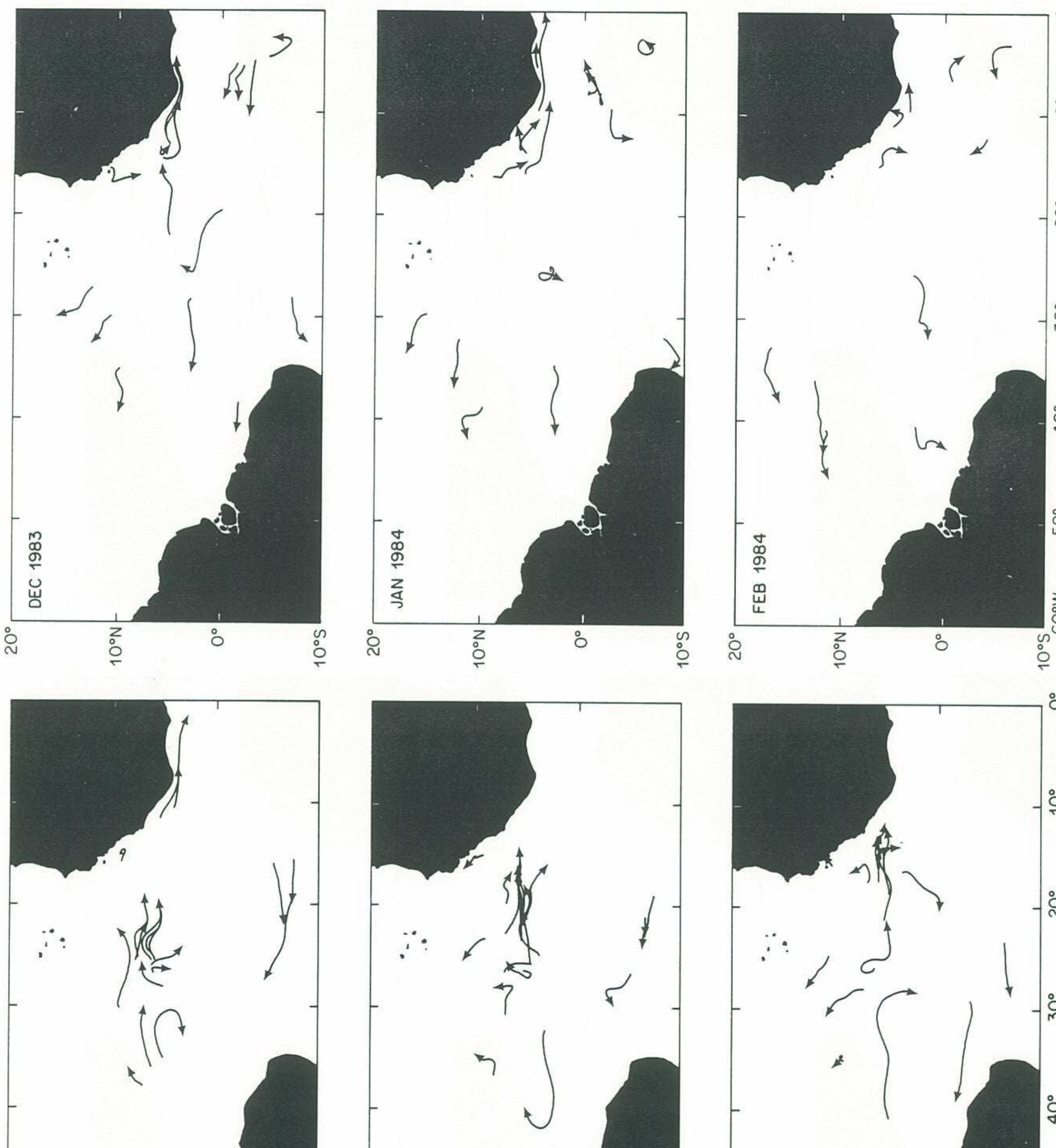

SEP 1983
OCT 1983
NOV 1983
DEC 1983
JAN 1984
FEB 1984
20°
10°N
0°
10°S
60°W
50°
40°
30°
20°
10°
0°

Figure 21

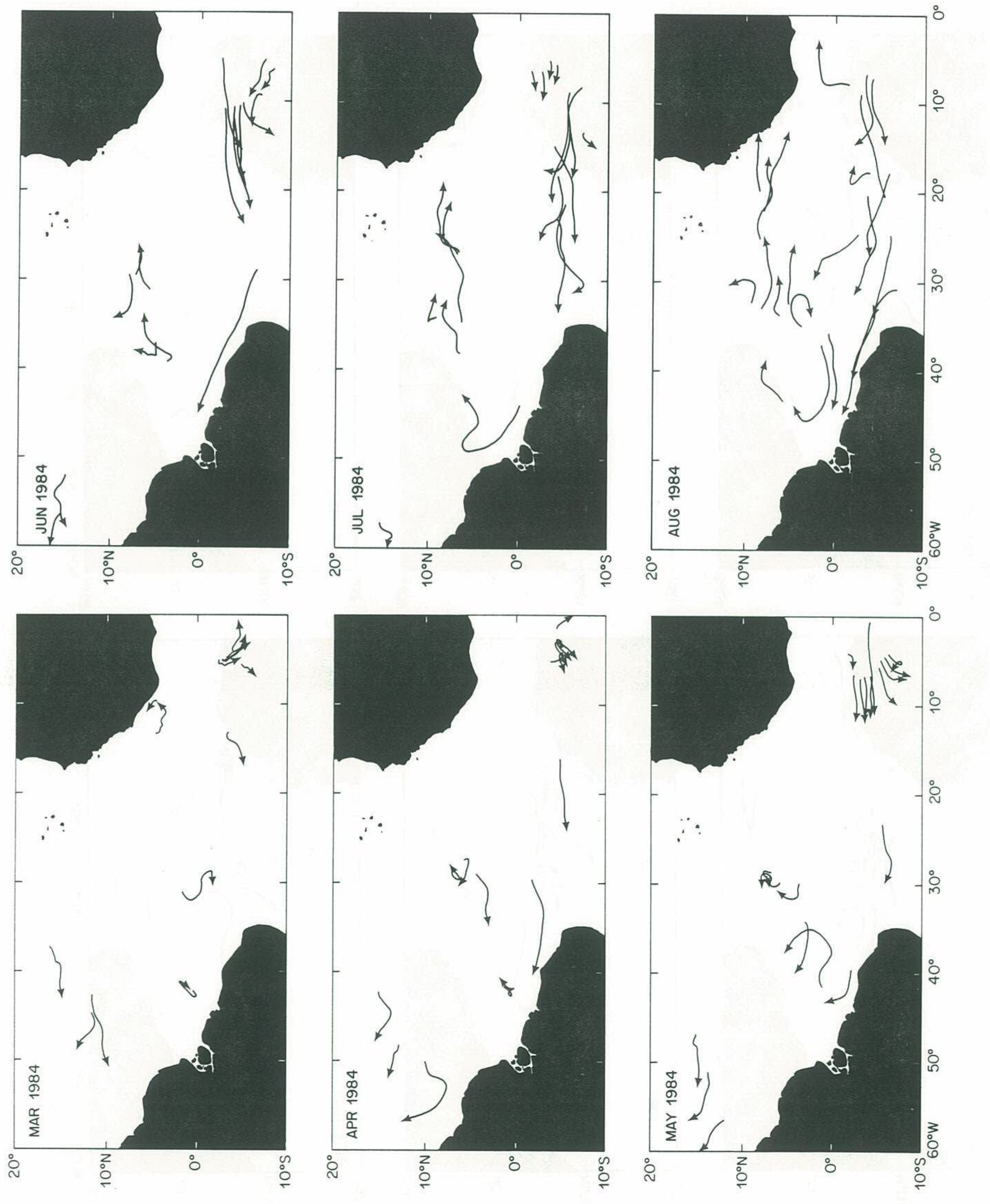

MAR 1984
APR 1984
MAY 1984
JUN 1984
JUL 1984
AUG 1984
20°
10°N
0°
10°S
60°W
50°
40°
30°
20°
10°
0°

Figure 22

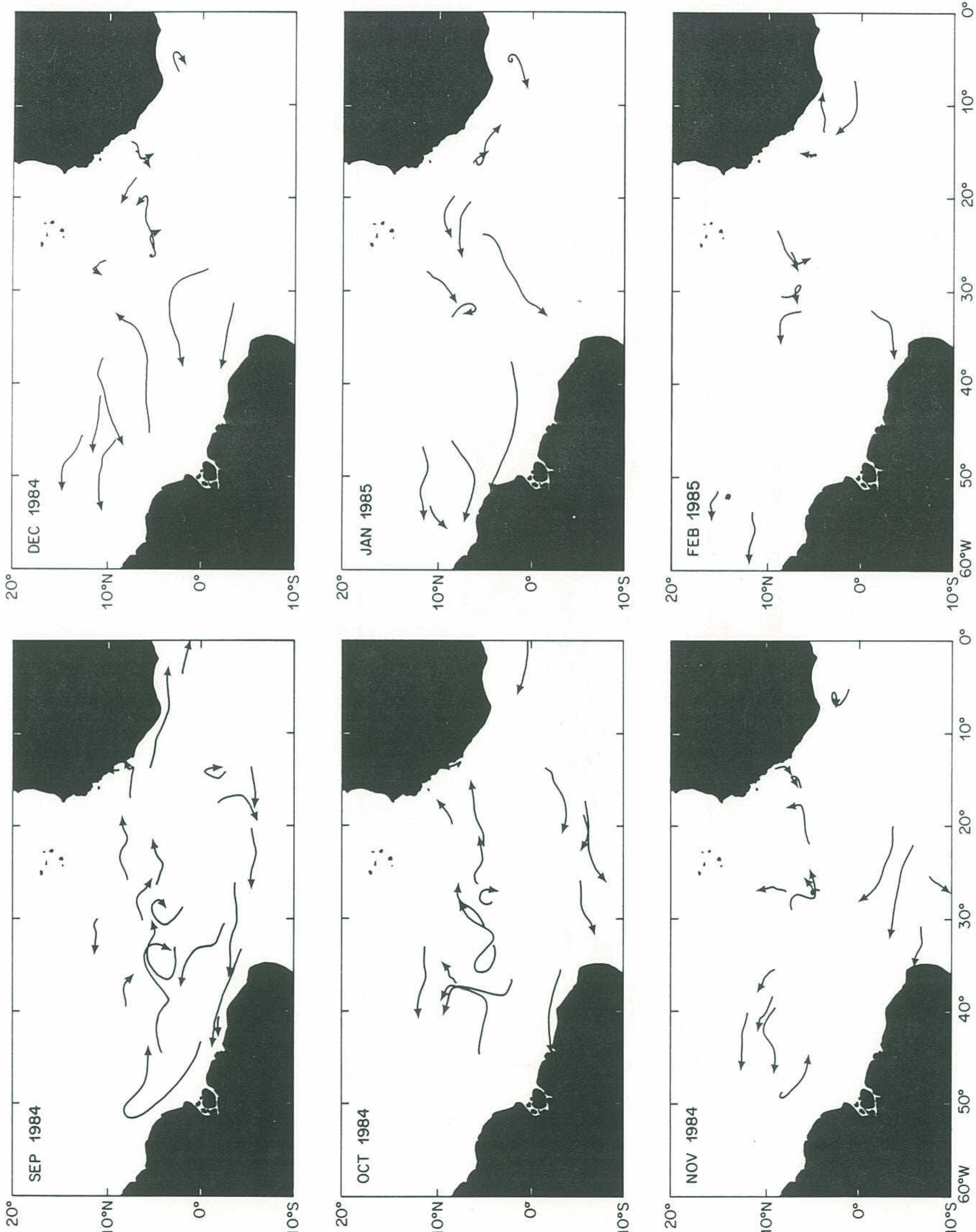

SEP 1984
OCT 1984
NOV 1984
DEC 1984
JAN 1985
FEB 1985
20°
10°N
0°
10°S
60°W
50°
40°
30°
20°
10°
0°

Figure 23

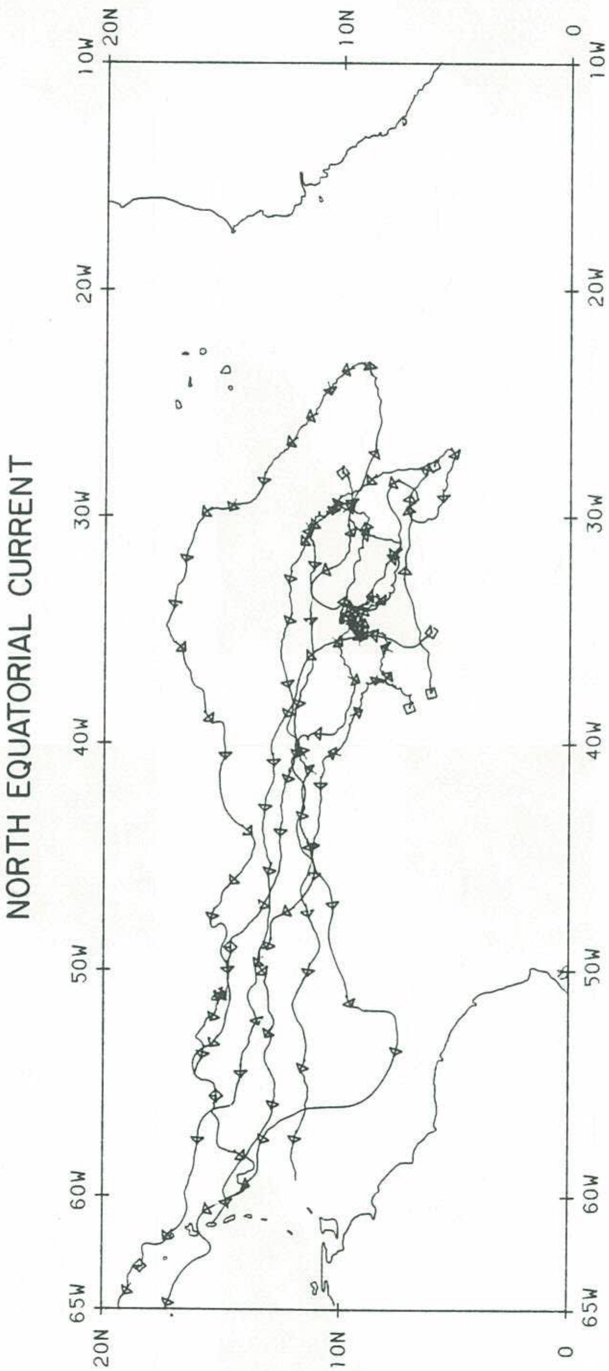

NORTH EQUATORIAL CURRENT
20N
10N
0
65W
60W
50W
40W
30W
20W
10W

Figure 24

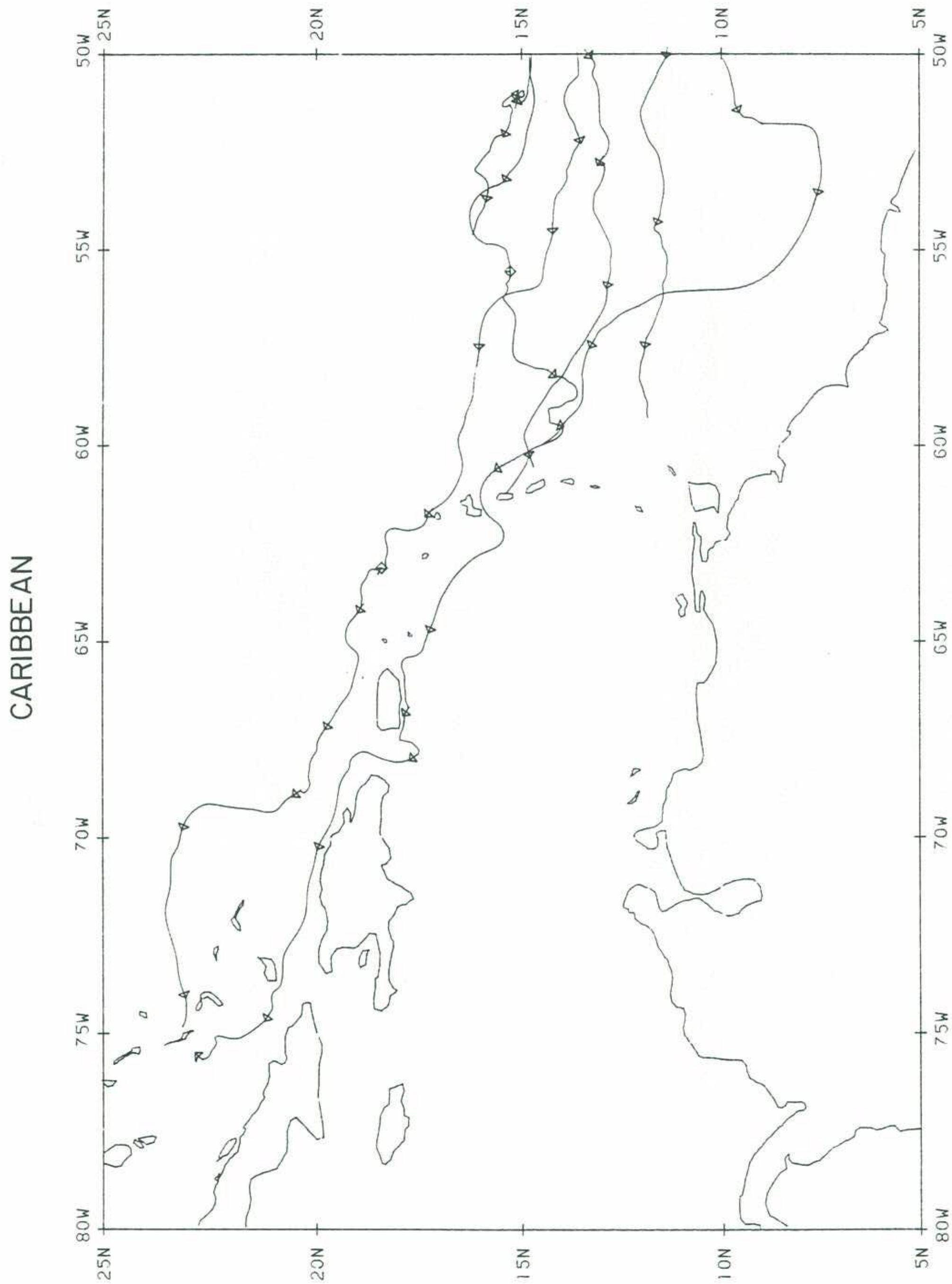


Figure 25

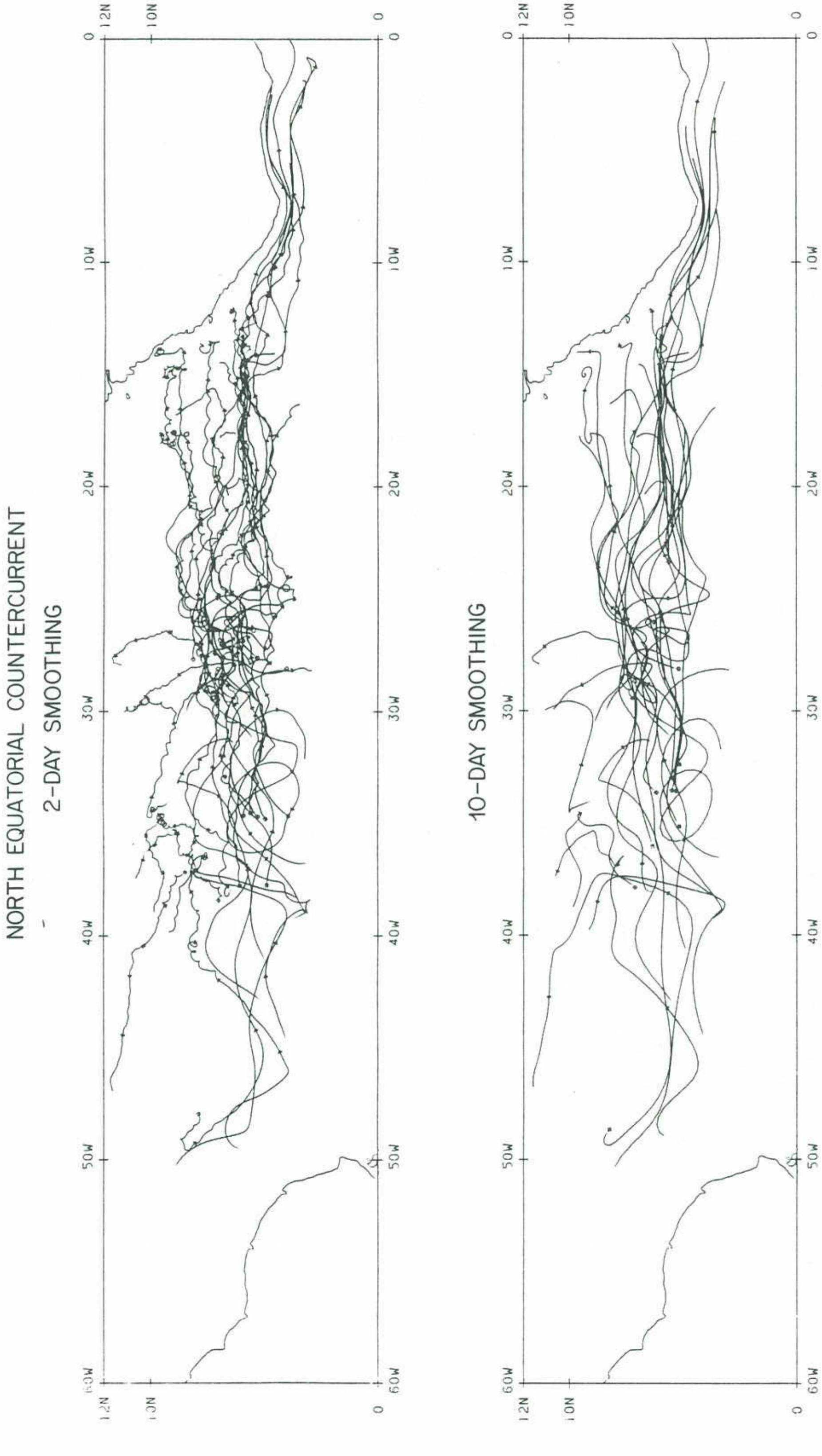

NORTH EQUATORIAL COUNTERCURRENT
2-DAY SMOOTHING
10-DAY SMOOTHING
0
10W
20W
30W
40W
50W
60W
12N
10N
0

Figure 26

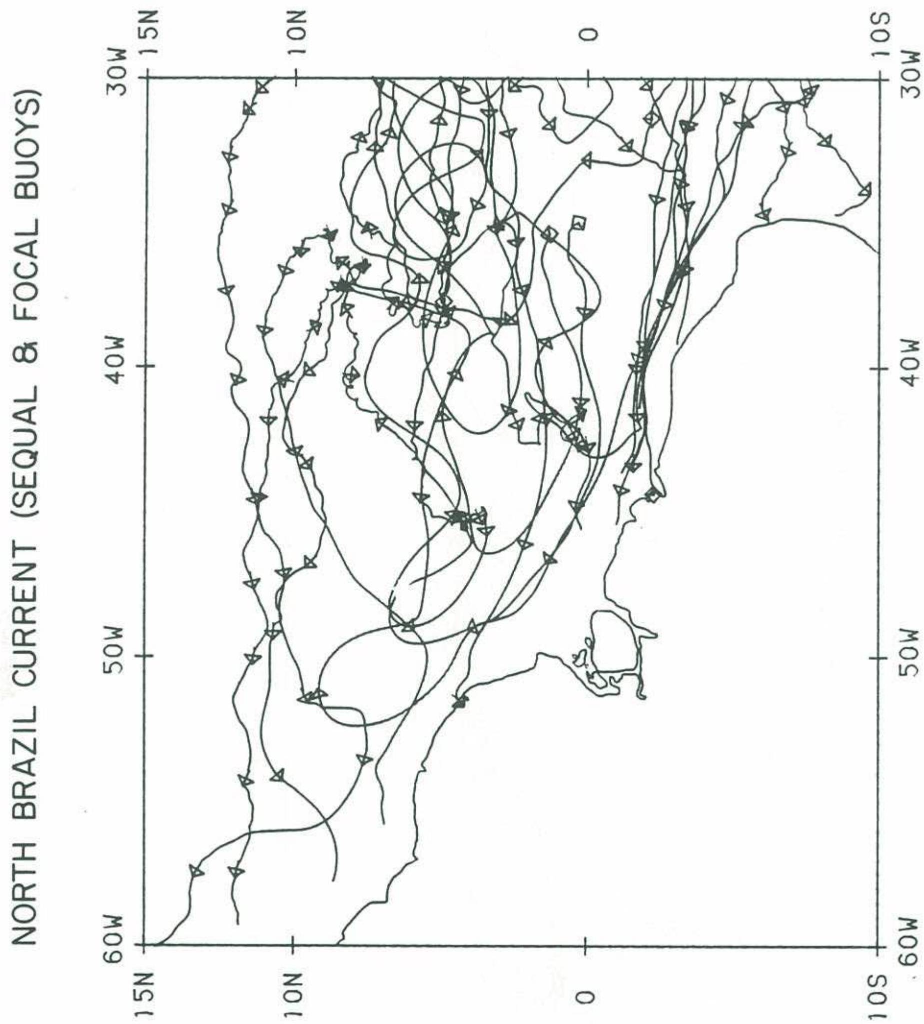

NORTH BRAZIL CURRENT (SEQUAL & FOCAL BUOYS)
60W
50W
40W
30W
15N
10N
0
10S

Figure 27

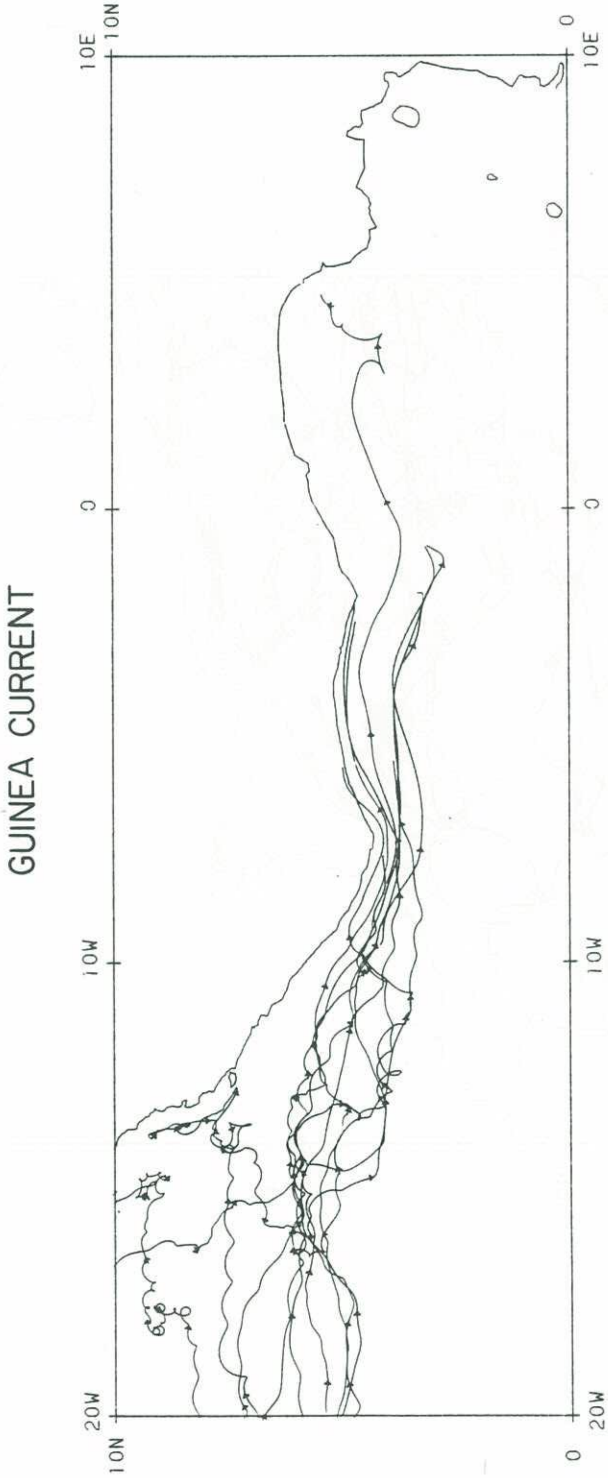


Figure 28

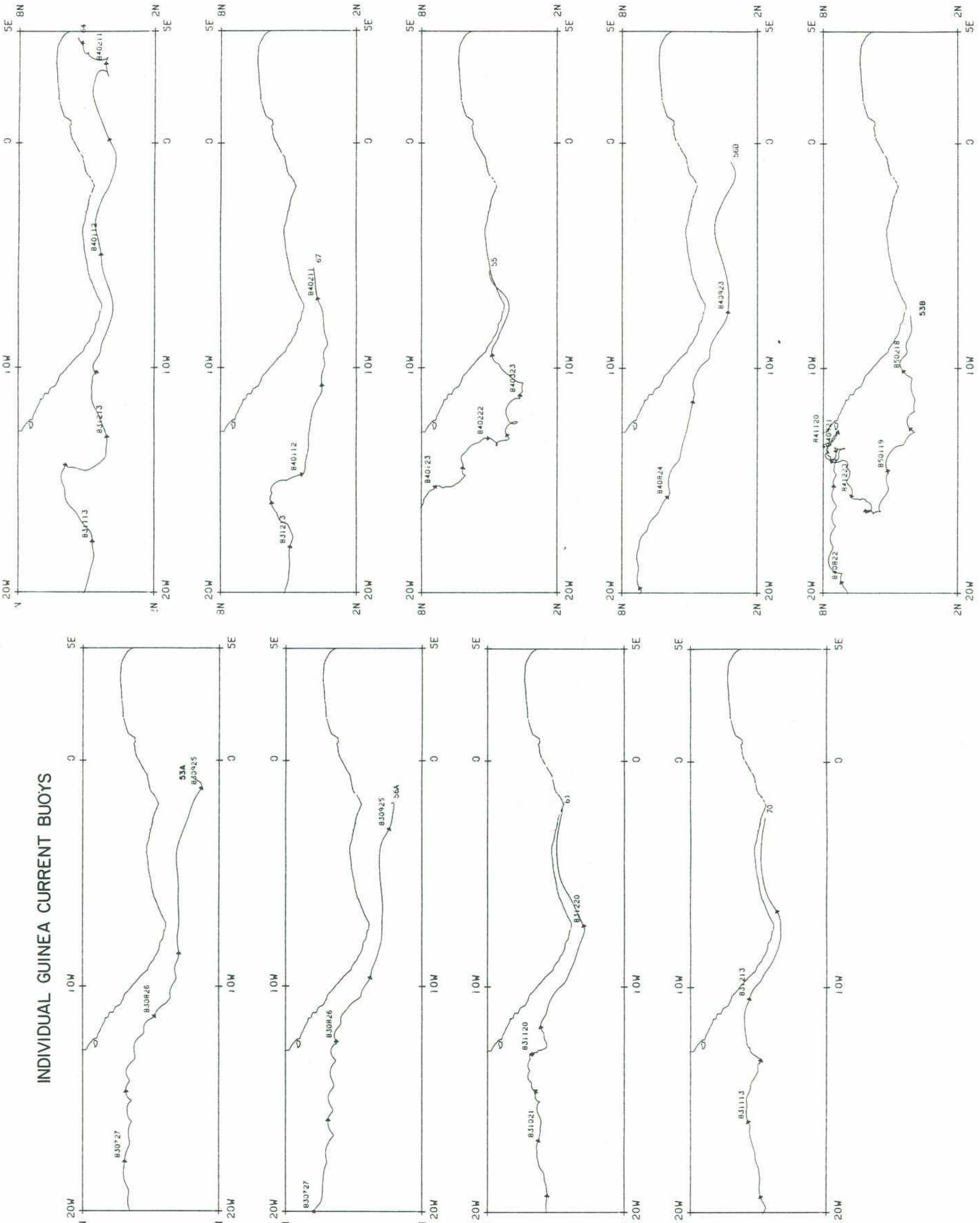

INDIVIDUAL GUINEA CURRENT BUOYS
20W
10W
0
5E
8N
2N
53A
830925
830727
830826
56A
830925
831021
831120
831220
61
70
831113
831213
840112
840211
64
67
831213
840123
840222
840323
55
840824
840923
56B
53B
850218
850119
841120
840821
841220
840822

Figure 29

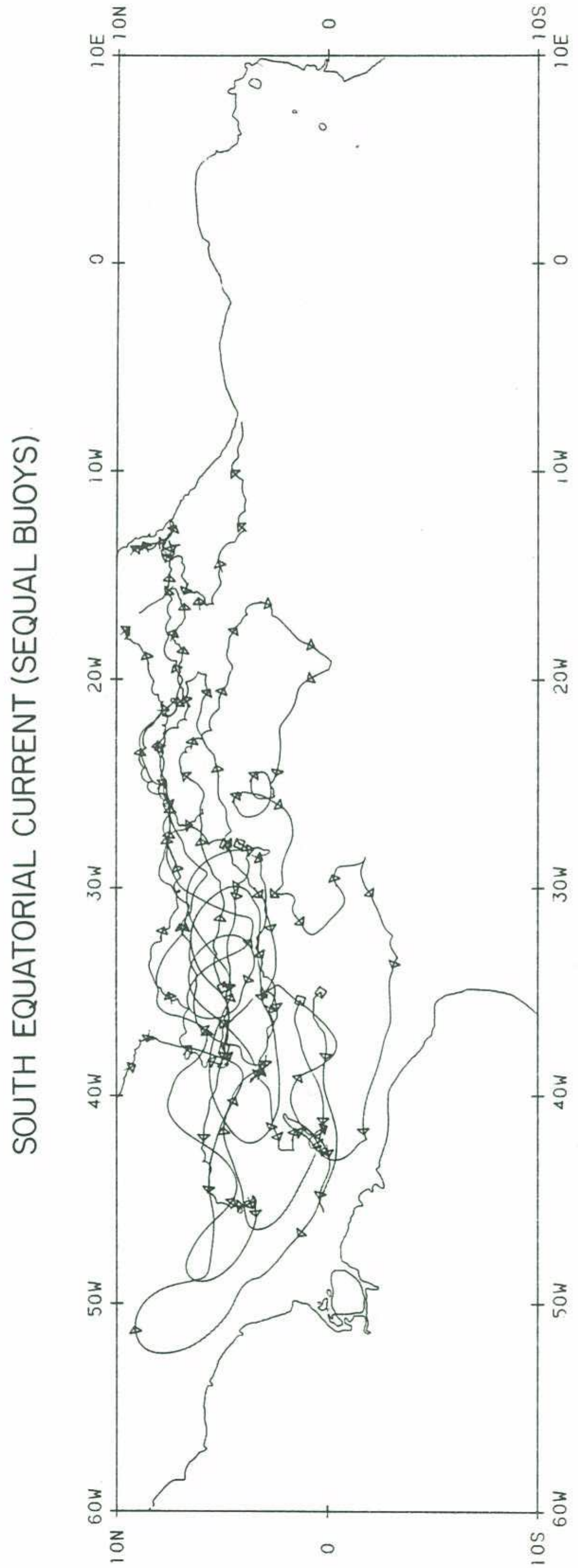
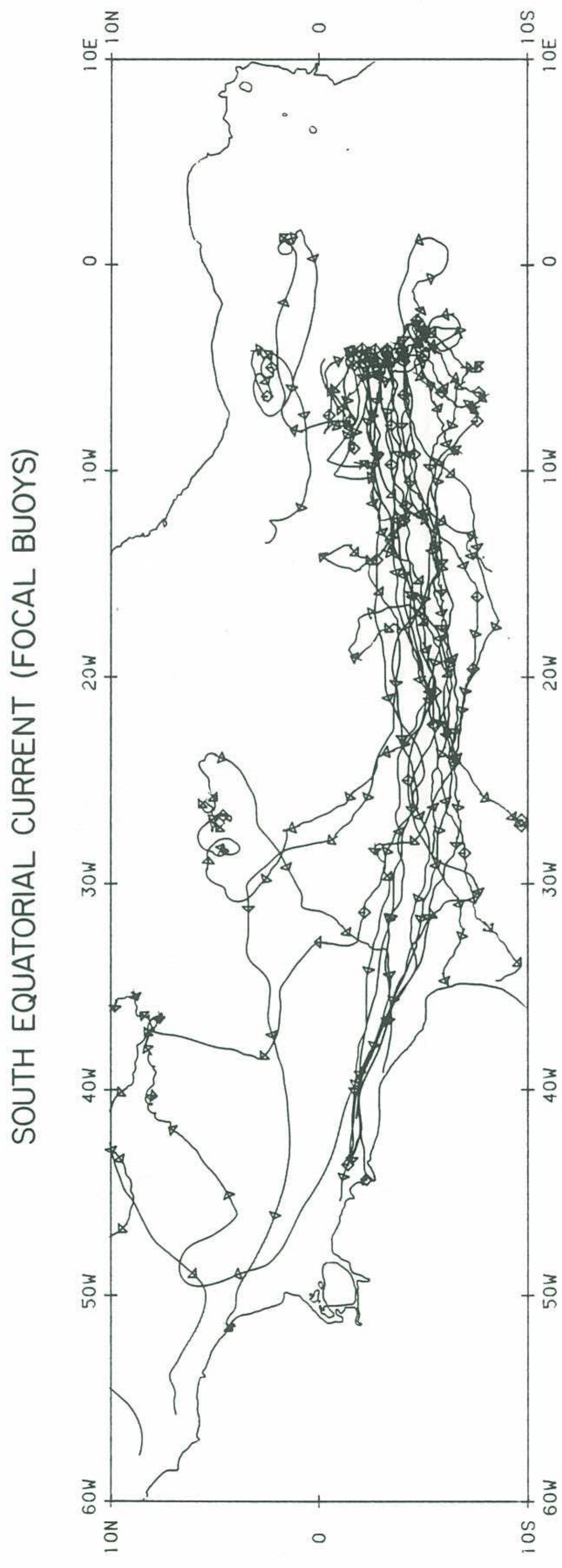
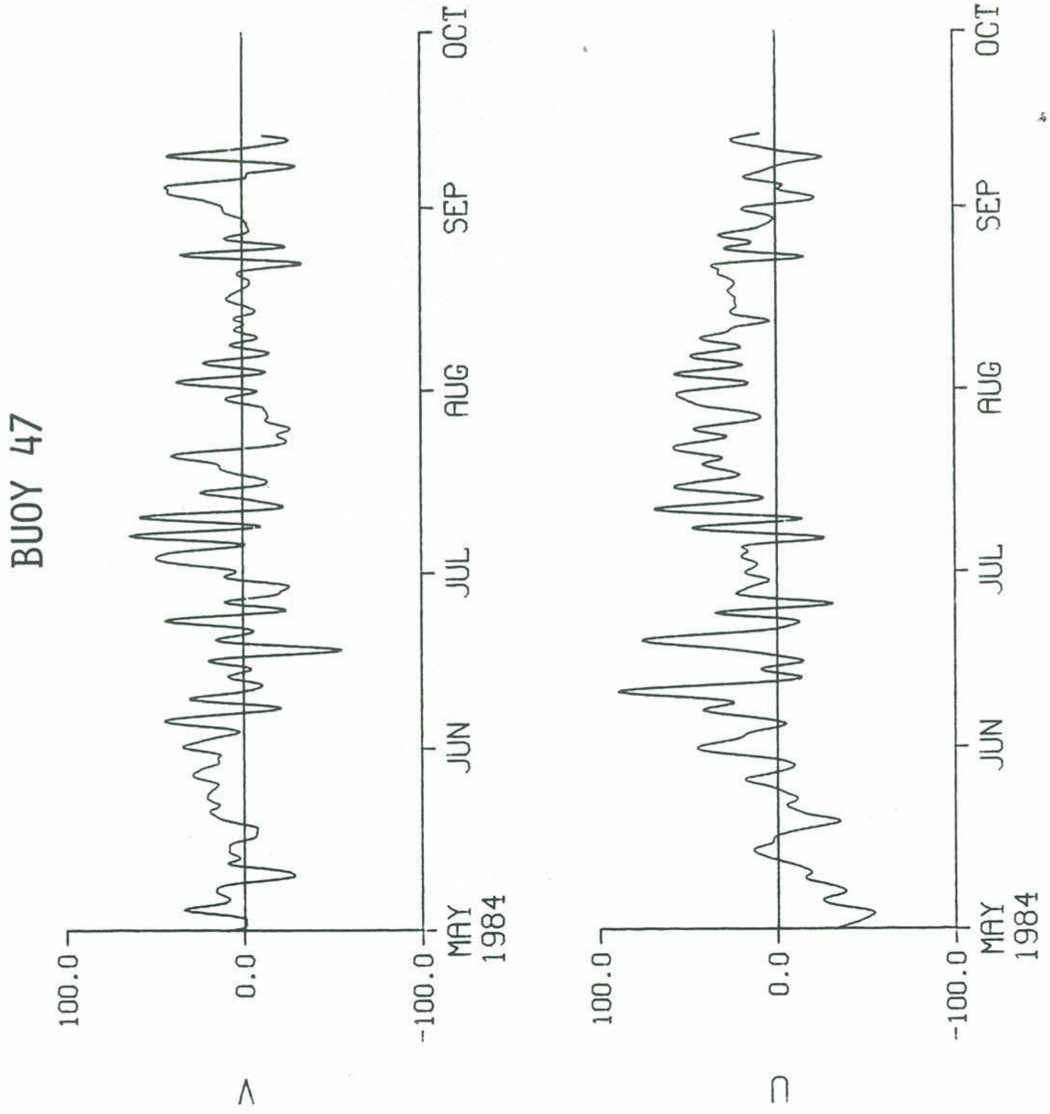

SOUTH EQUATORIAL CURRENT (SEQUAL BUOYS)
10N
0
10S
10E
0
10W
20W
30W
40W
50W
60W

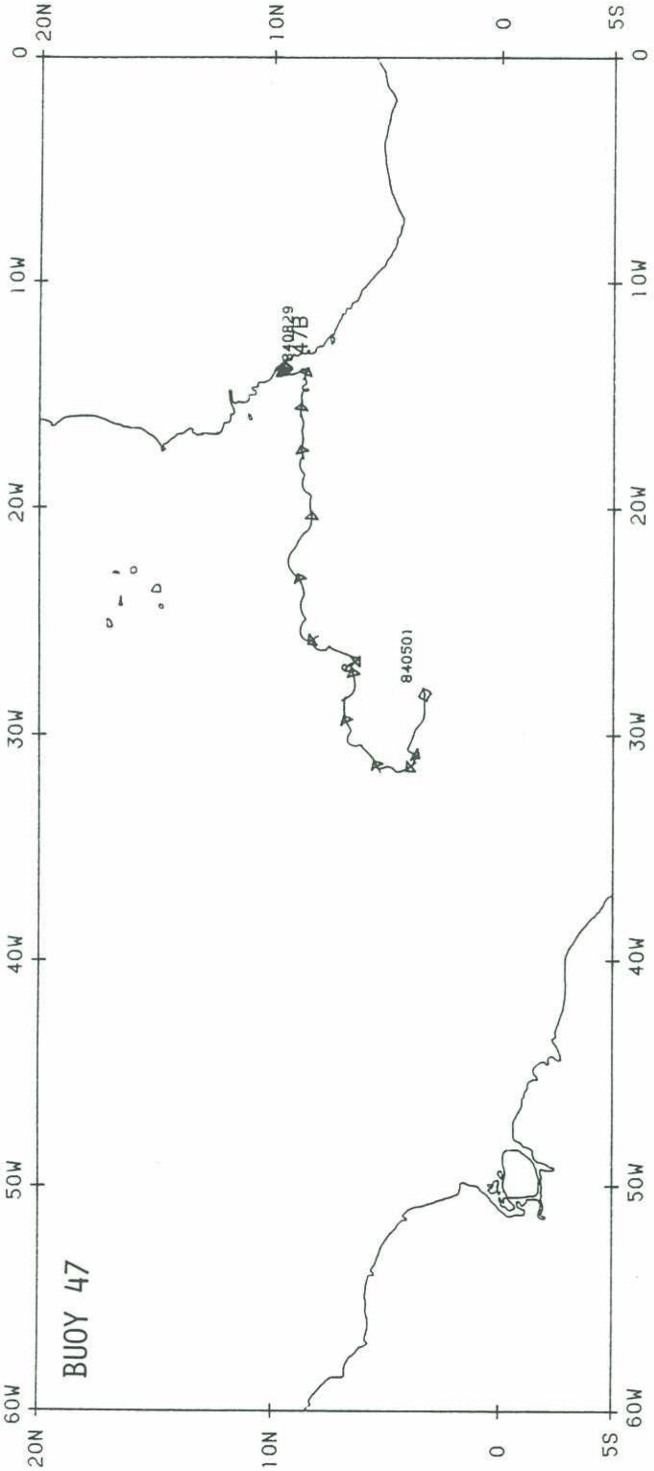
Figure 30

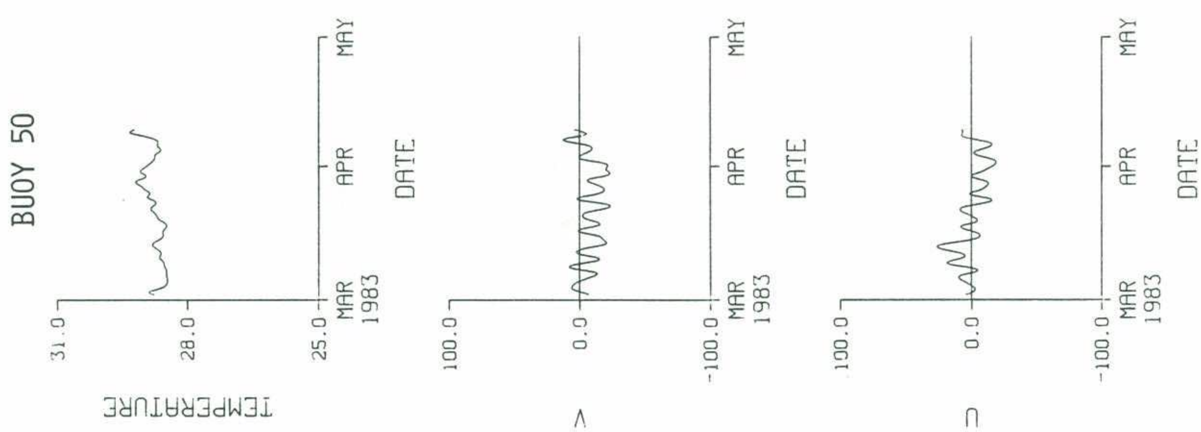


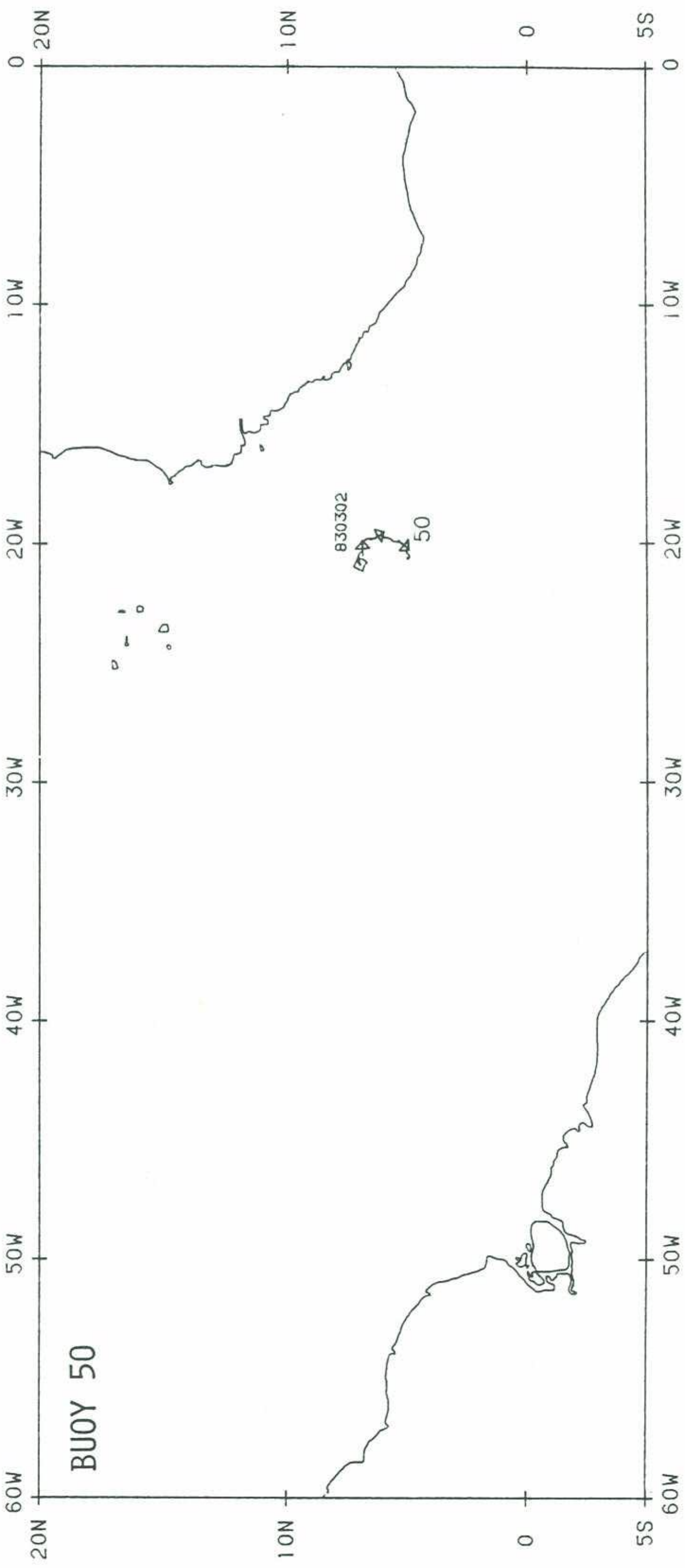
SOUTH EQUATORIAL CURRENT (FOCAL BUOYS)
10E
0
10W
20W
30W
40W
50W
60W
10N
0
10S

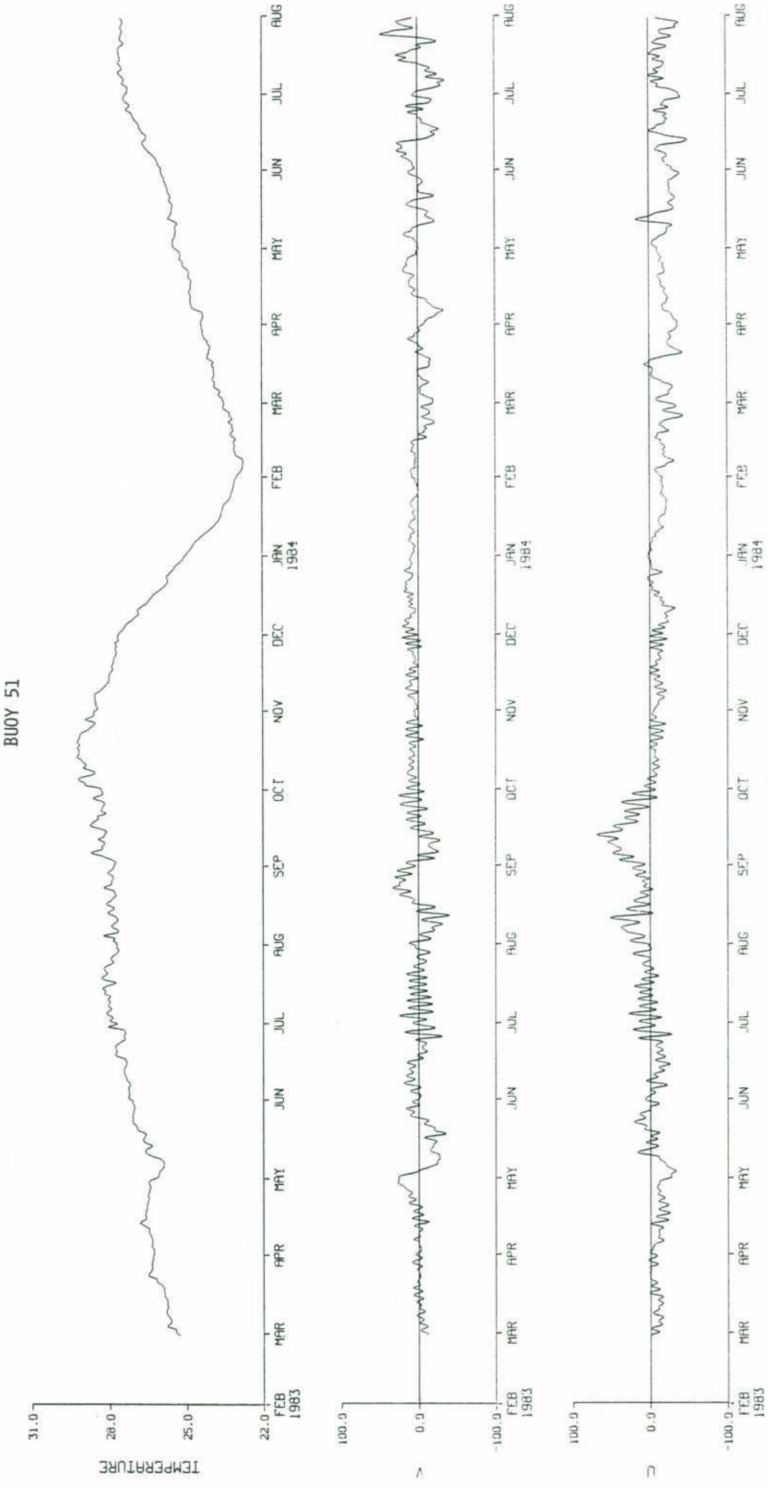
Figure 31

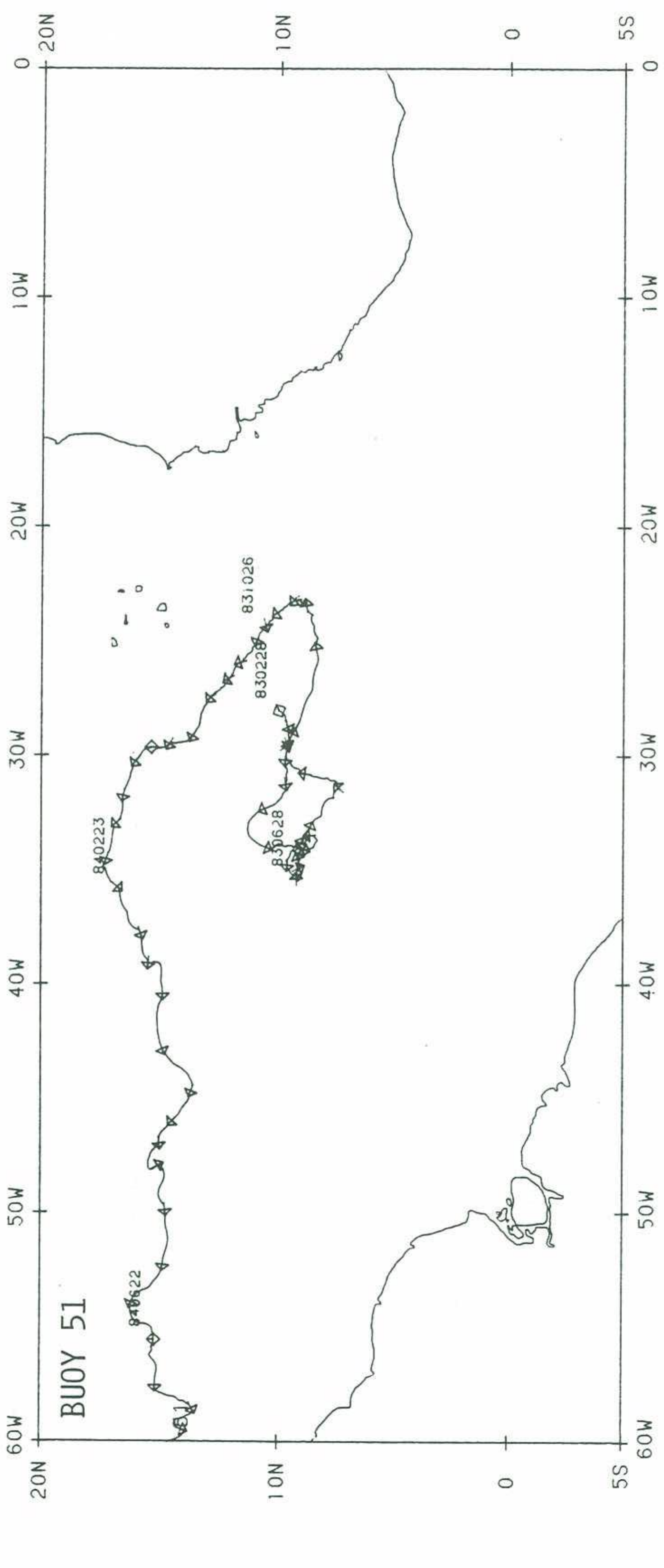

BUOY 47
V
100.0
0.0
-100.0
MAY 1984
JUN
JUL
AUG
SEP
OCT
U
100.0
0.0
-100.0
MAY 1984
JUN
JUL
AUG
SEP
OCT

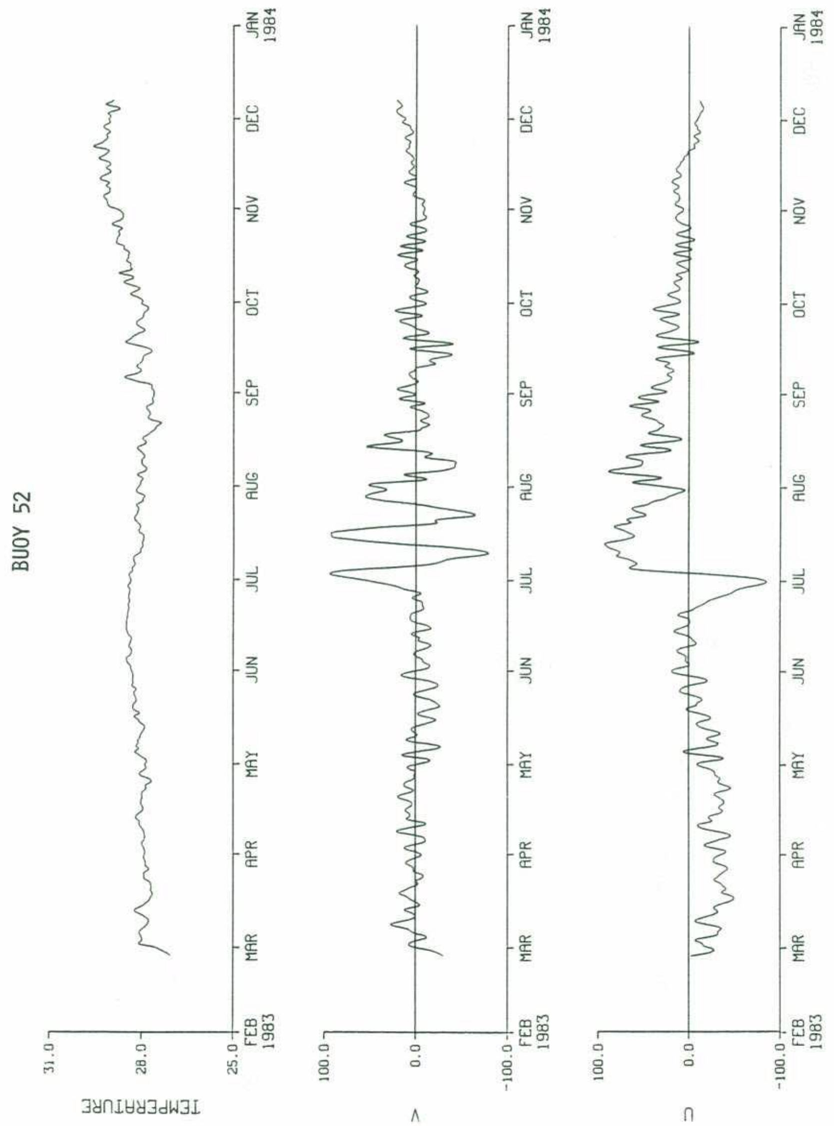

BUOY 47
840829
47B
840501
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

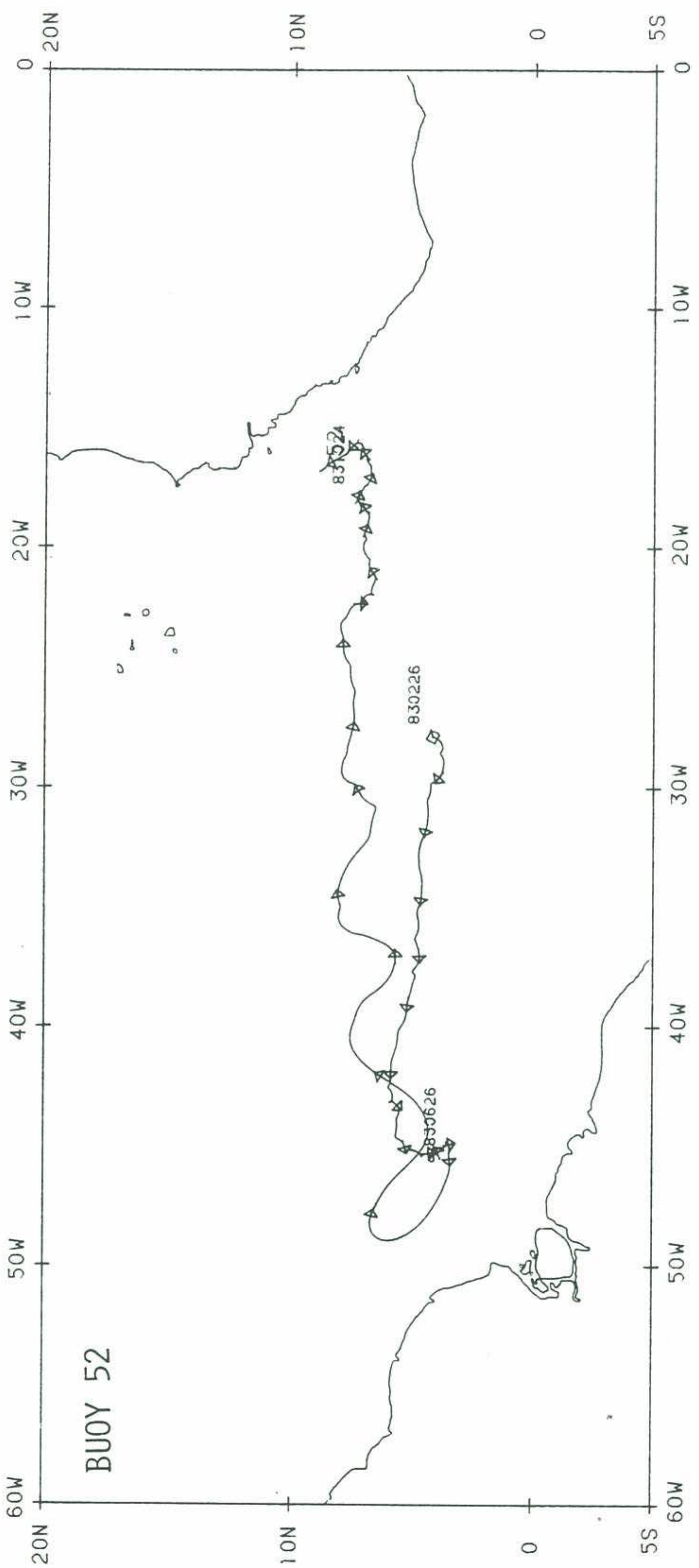

BUOY 50
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
MAR 1983
APR
MAY
DATE

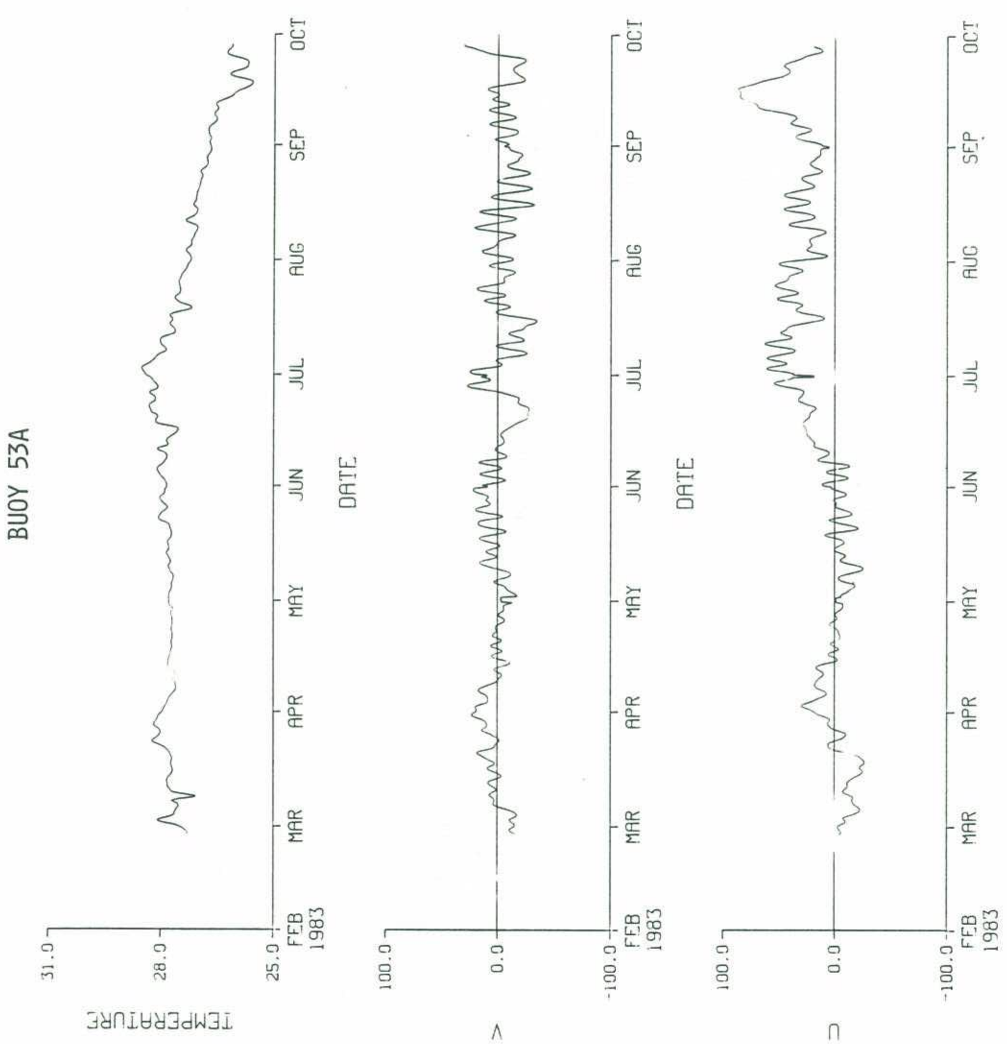

BUOY 50
830302
50
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

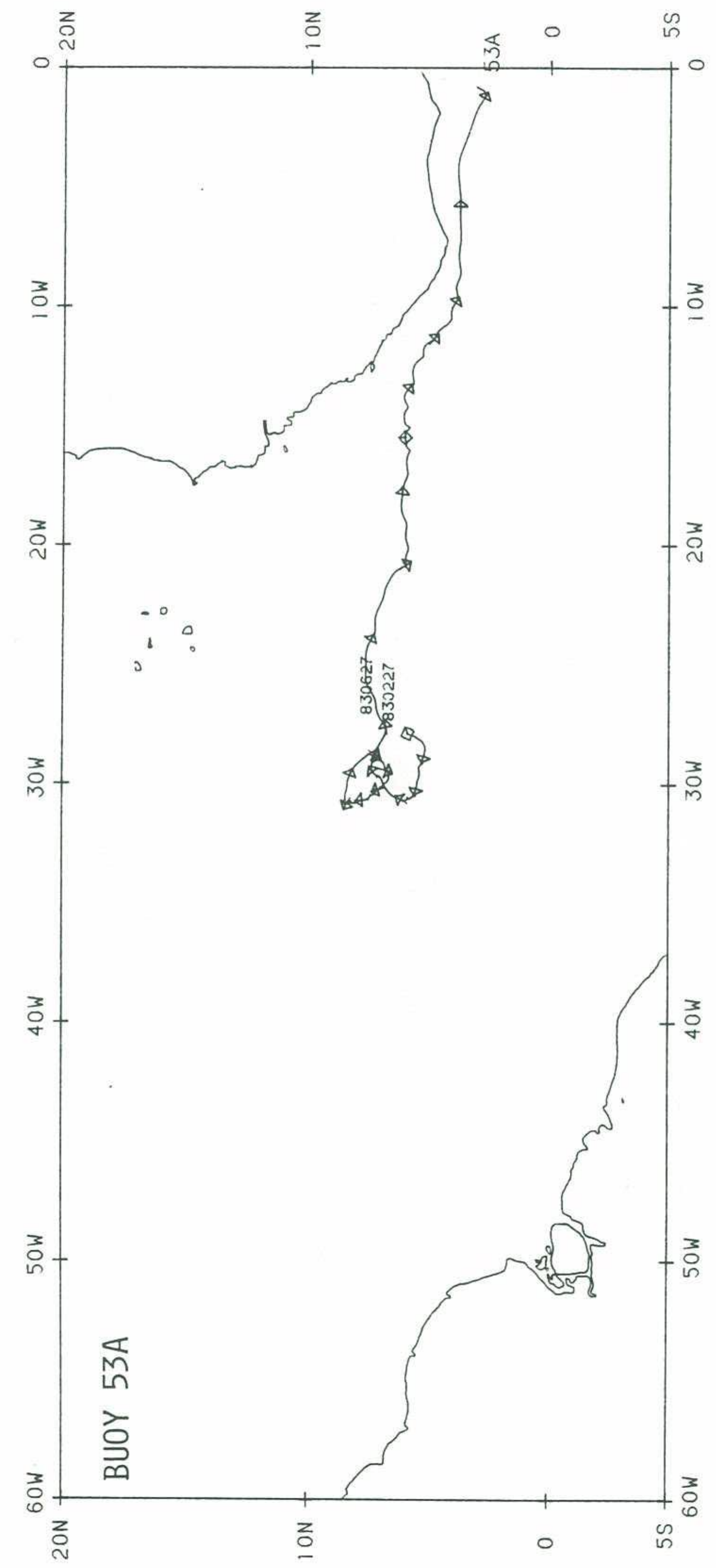

BUOY 51
TEMPERATURE
31.0
28.0
25.0
22.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
FEB 1983
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN 1984
FEB
MAR
APR
MAY
JUN
JUL
AUG

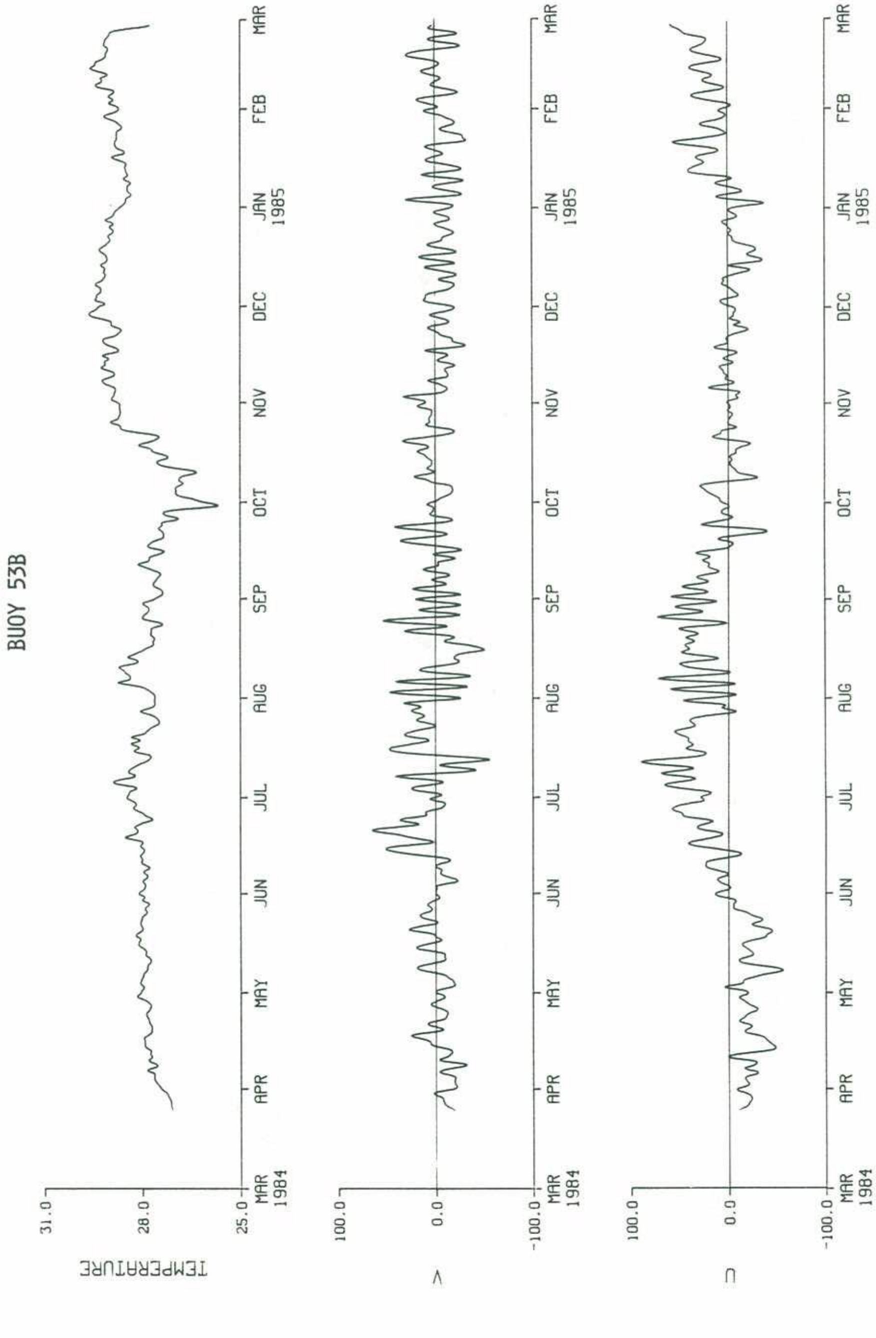

BUOY 51
831026
830228
830628
840223
840622
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

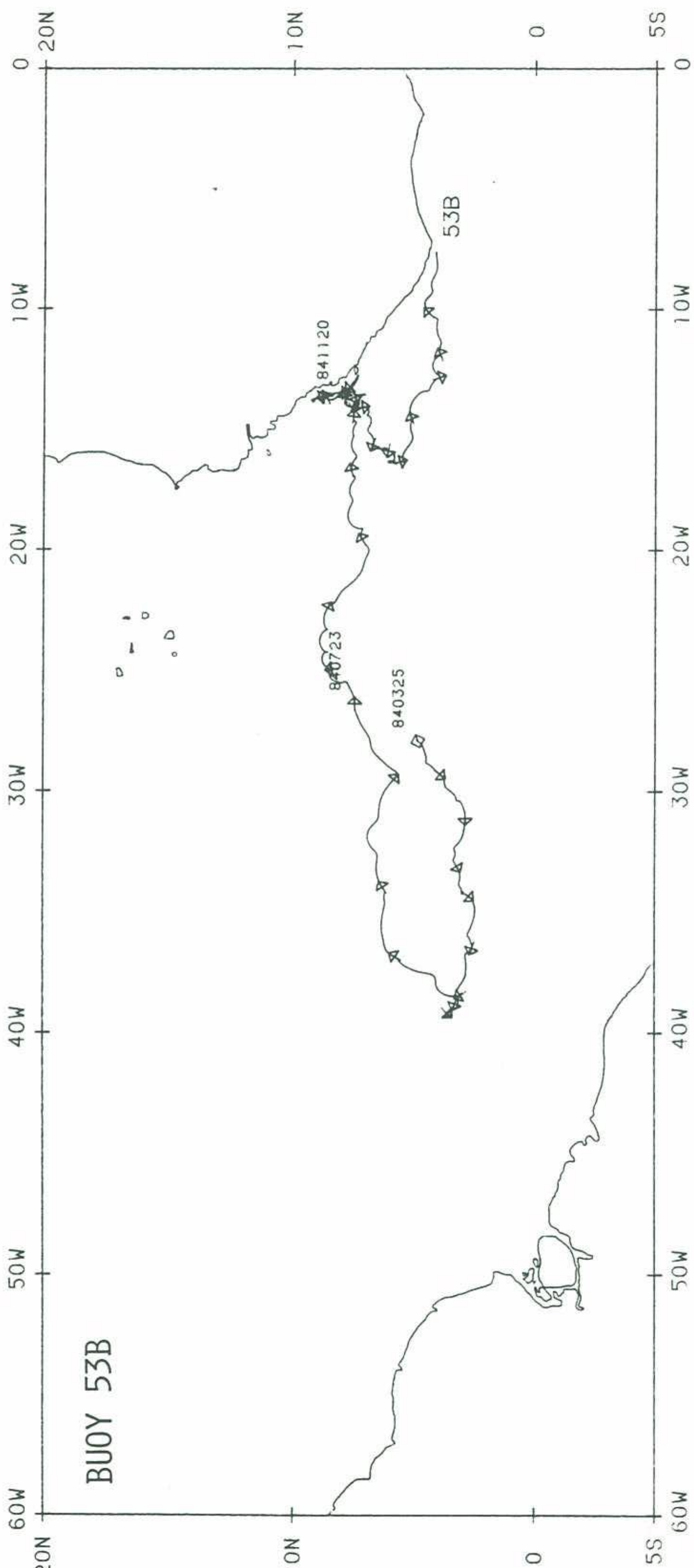

BUOY 52
TEMPERATURE
31.0
28.0
25.0
V
U
100.0
0.0
-100.0
FEB 1983
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN 1984

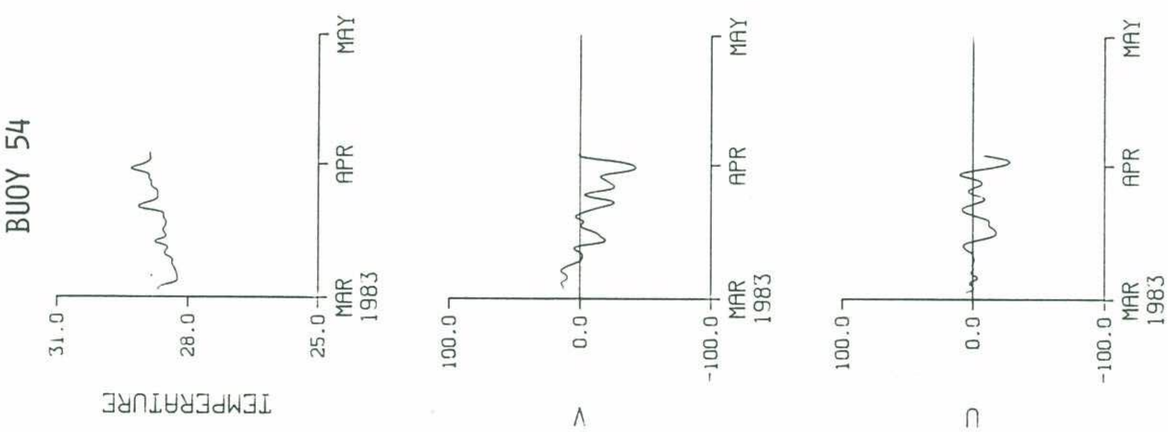

BUOY 52
830226
20N
10N
0
5S
10W
20W
30W
40W
50W
60W

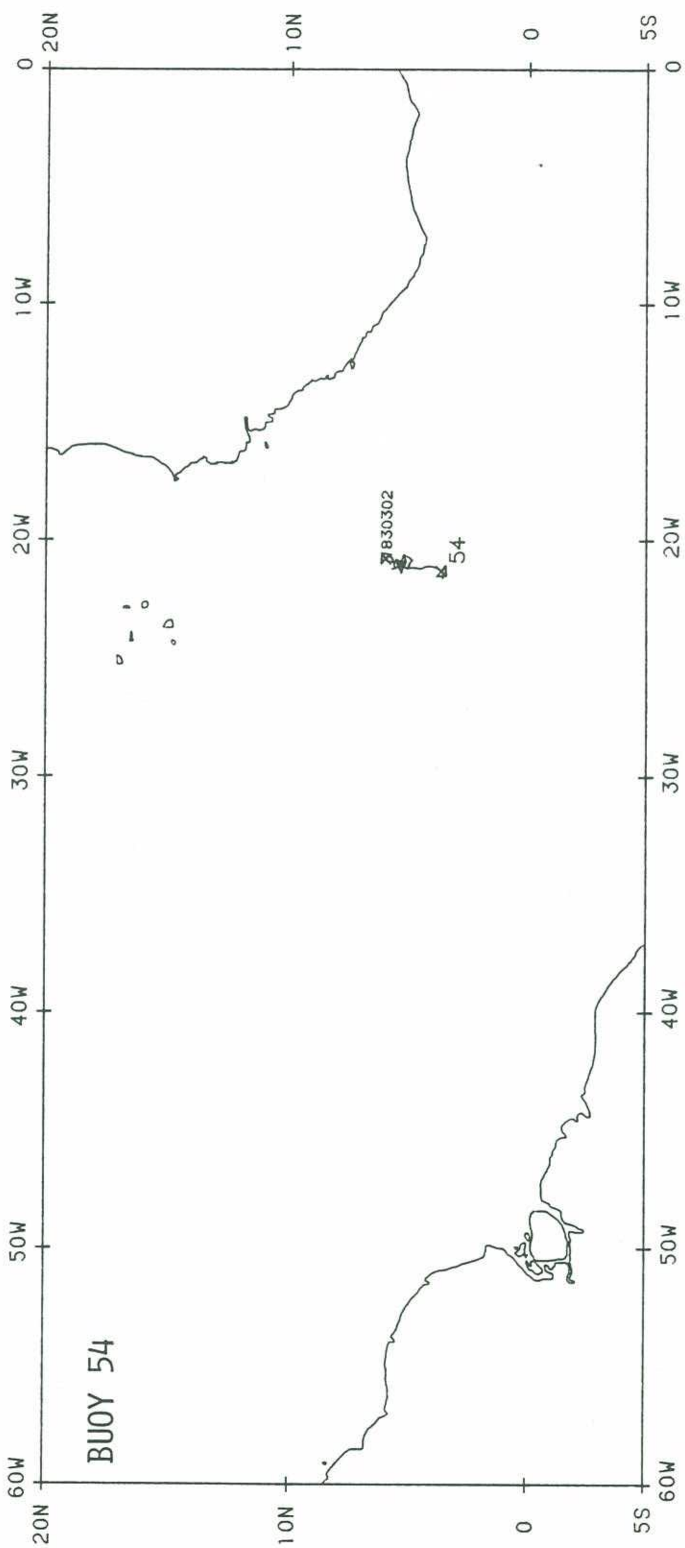

BUOY 53A
TEMPERATURE
31.0
28.0
25.0
V
U
100.0
0.0
-100.0
FEB 1983
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
DATE


BUOY 53A
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0
53A
830627
830227

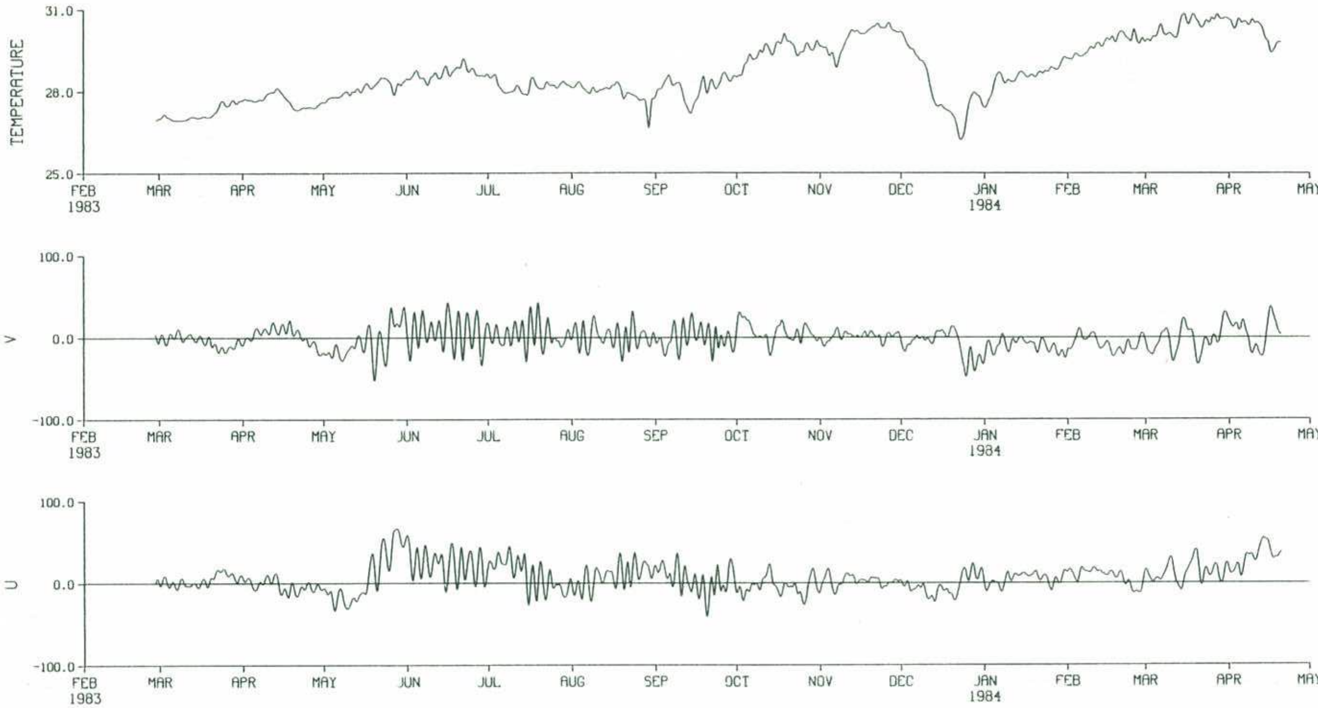

BUOY 53B
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
MAR 1984
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN 1985
FEB
MAR

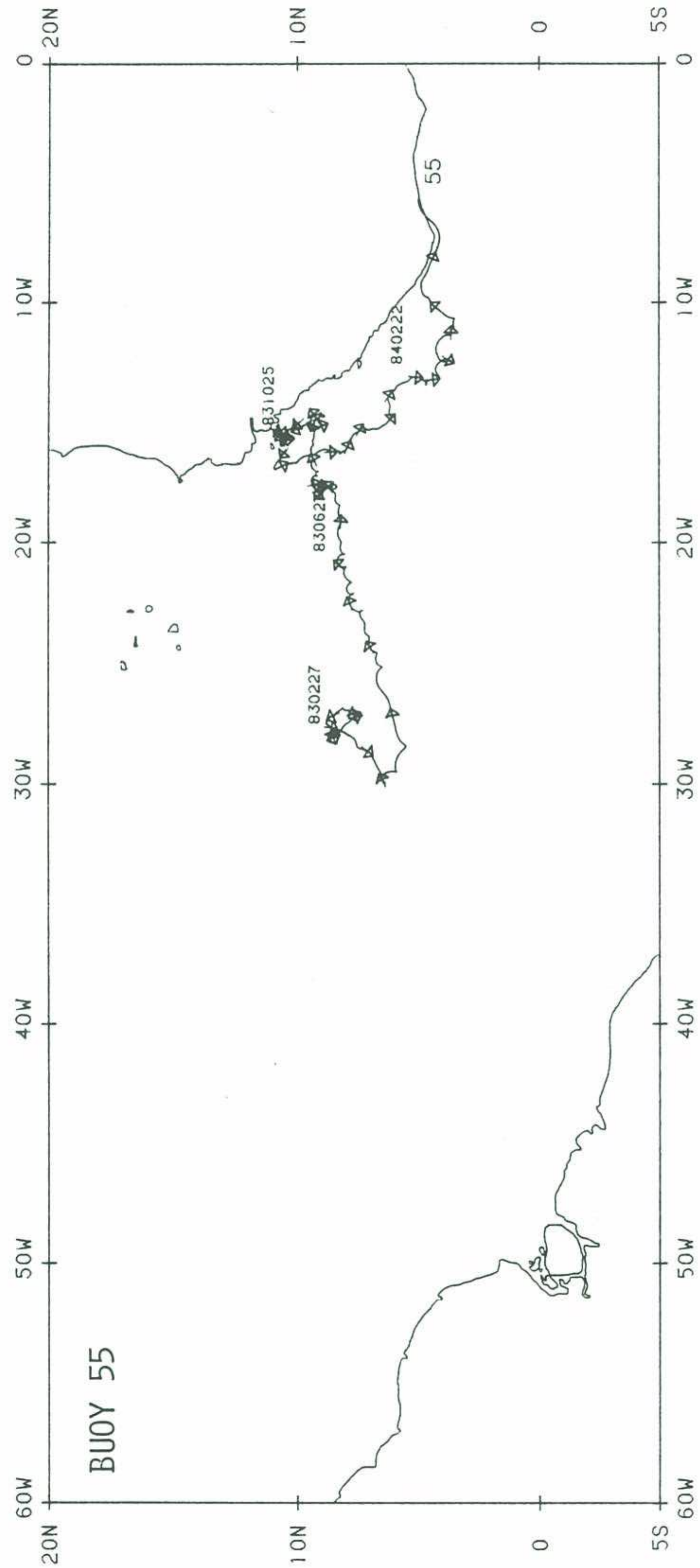

BUOY 53B
53B
841120
840723
840325
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

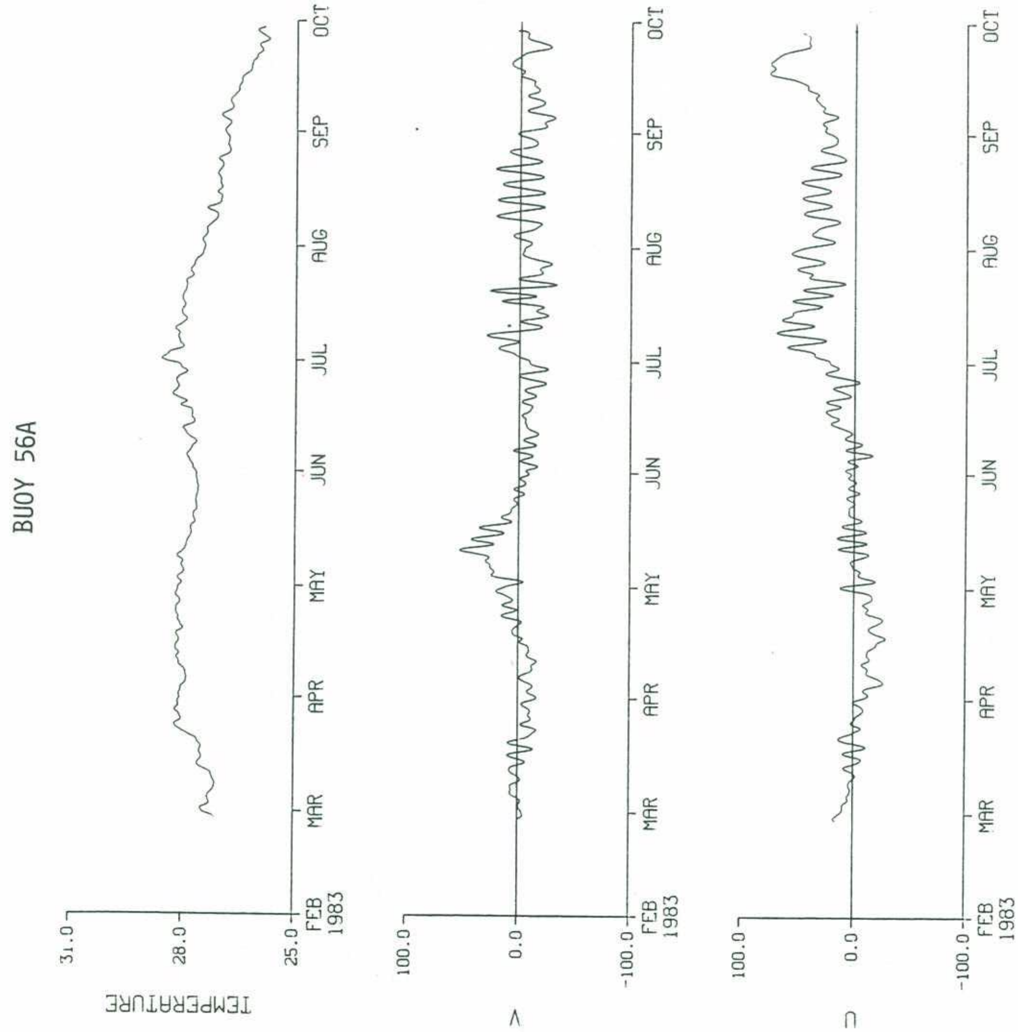

BUOY 54
TEMPERATURE
31.0
28.0
25.0
MAR
1983
APR
MAY
V
100.0
0.0
-100.0
U

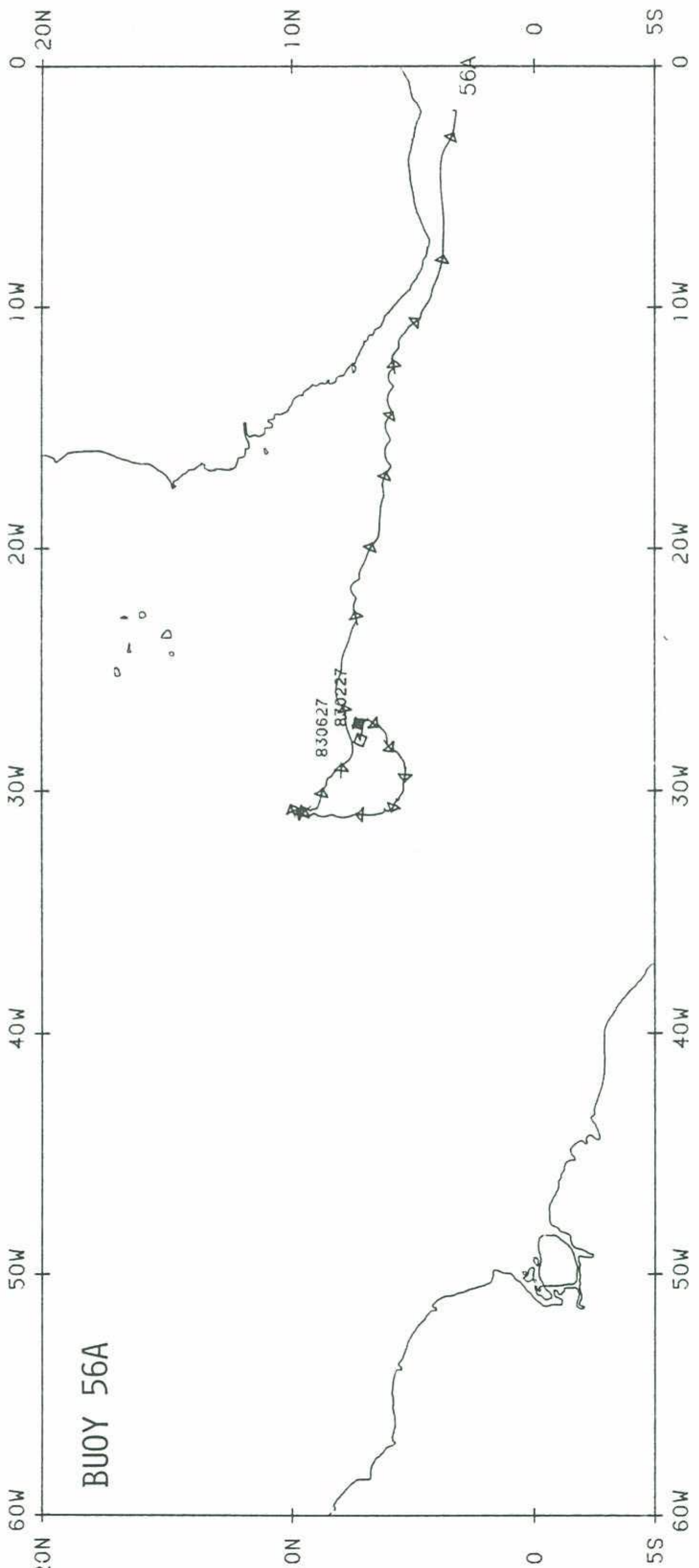

BUOY 54
830302
54
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0

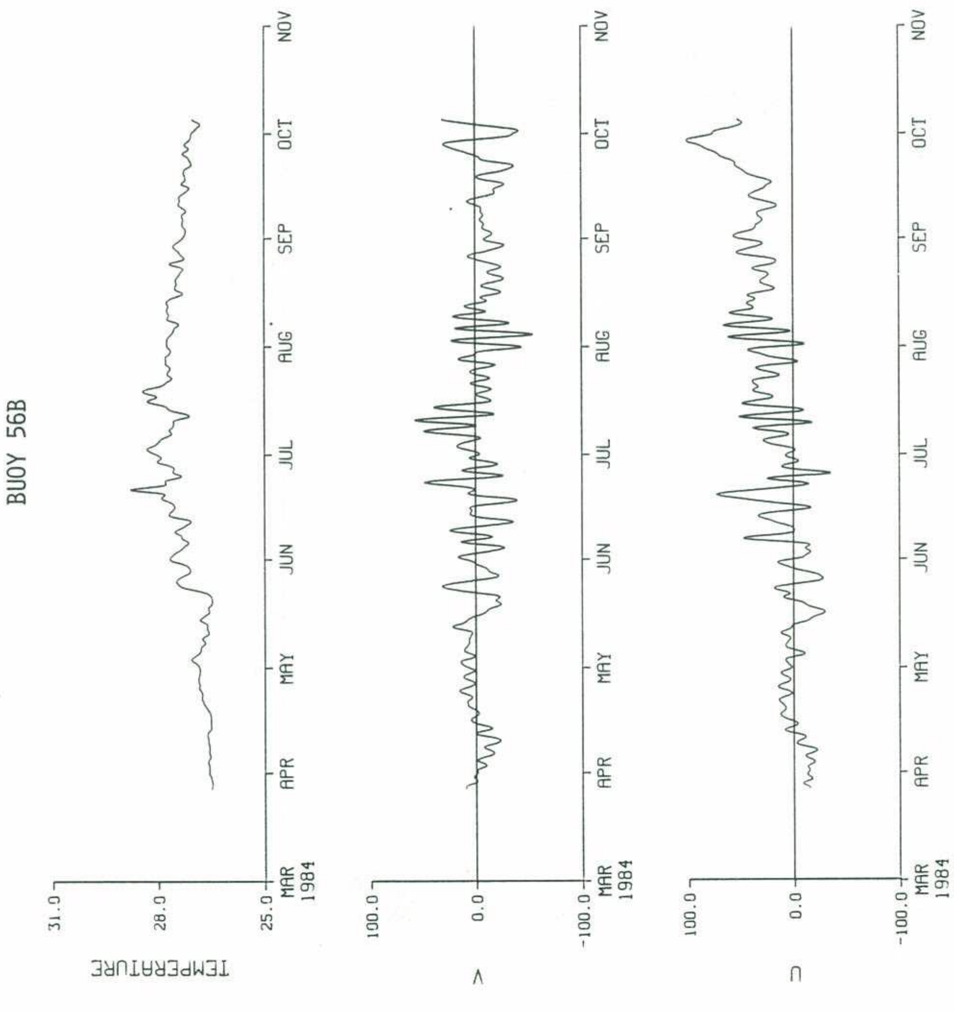
BUOY 55

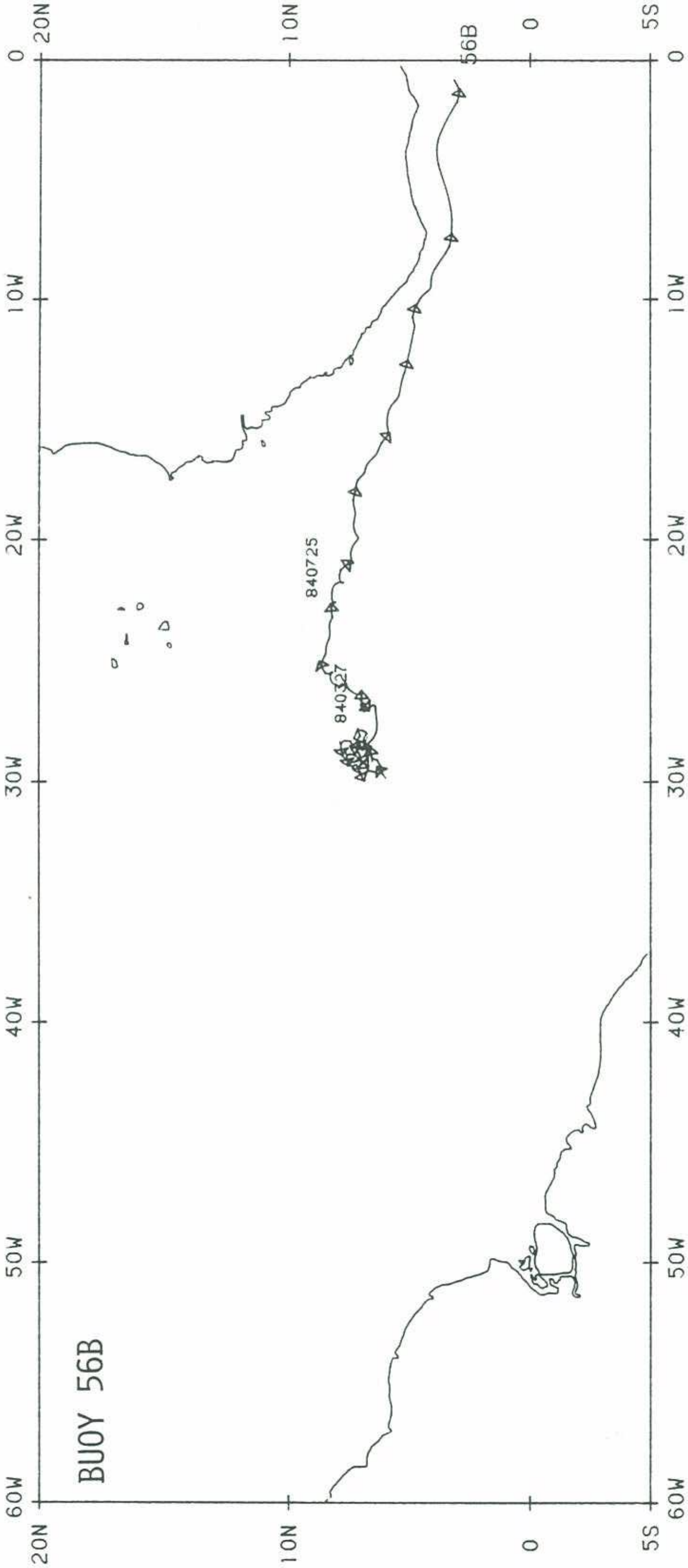

TEMPERATURE
31.0
28.0
25.0
V
U
100.0
0.0
-100.0
FEB
1983
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
1984
FEB
MAR
APR
MAY


BUOY 55
55
840222
831025
830227
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

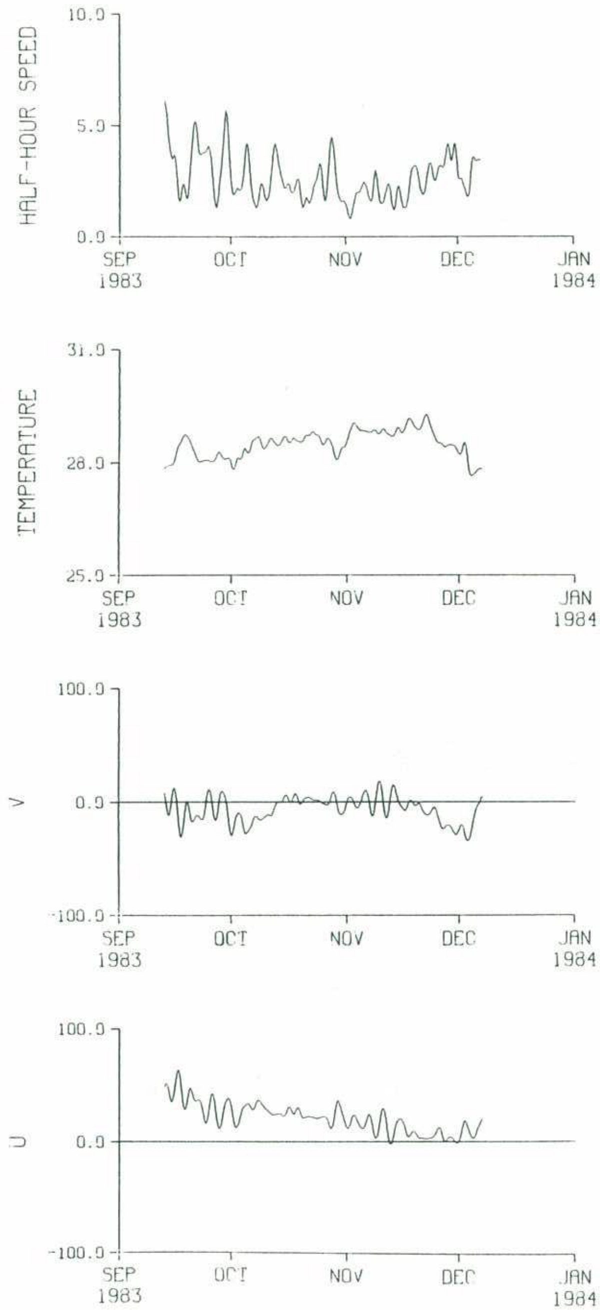

BUOY 56A
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
FEB 1983
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT

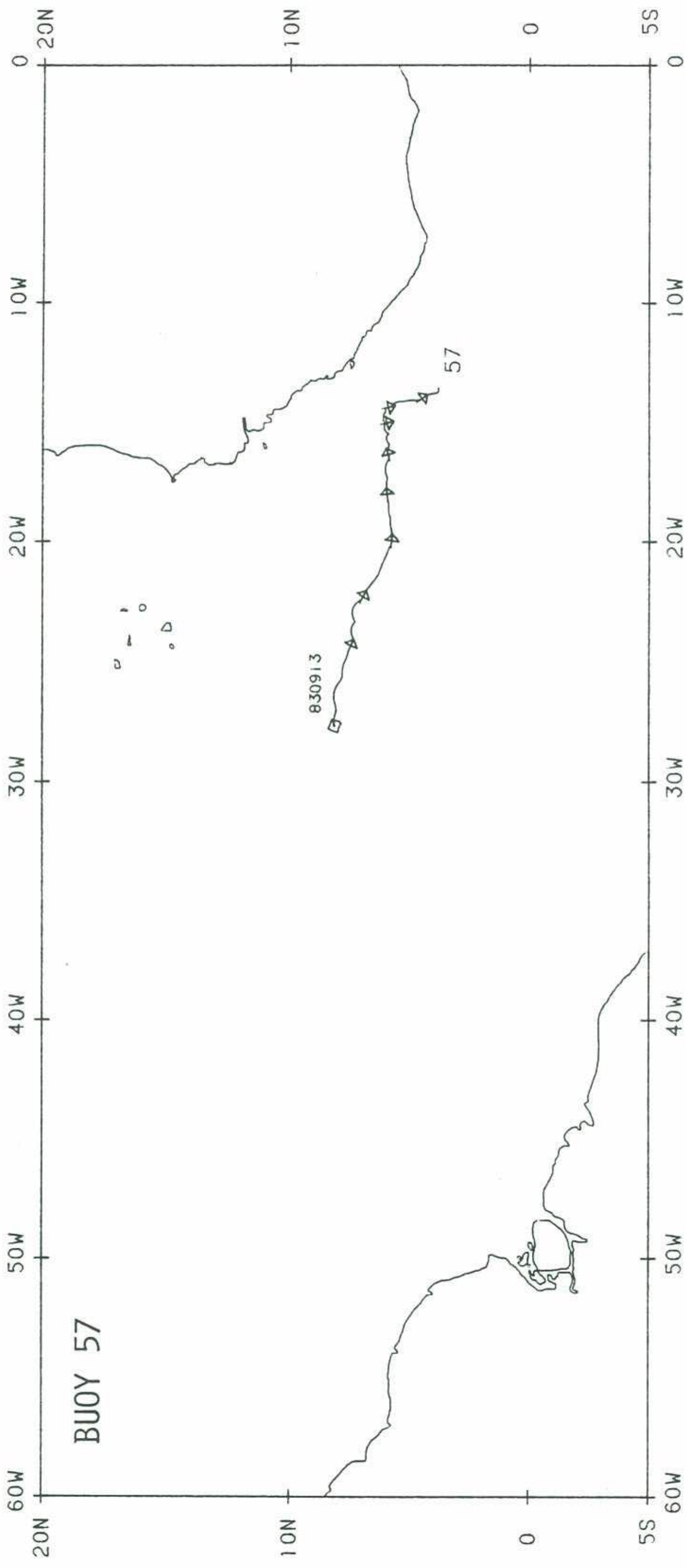

BUOY 56A
56A
830627
830227
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

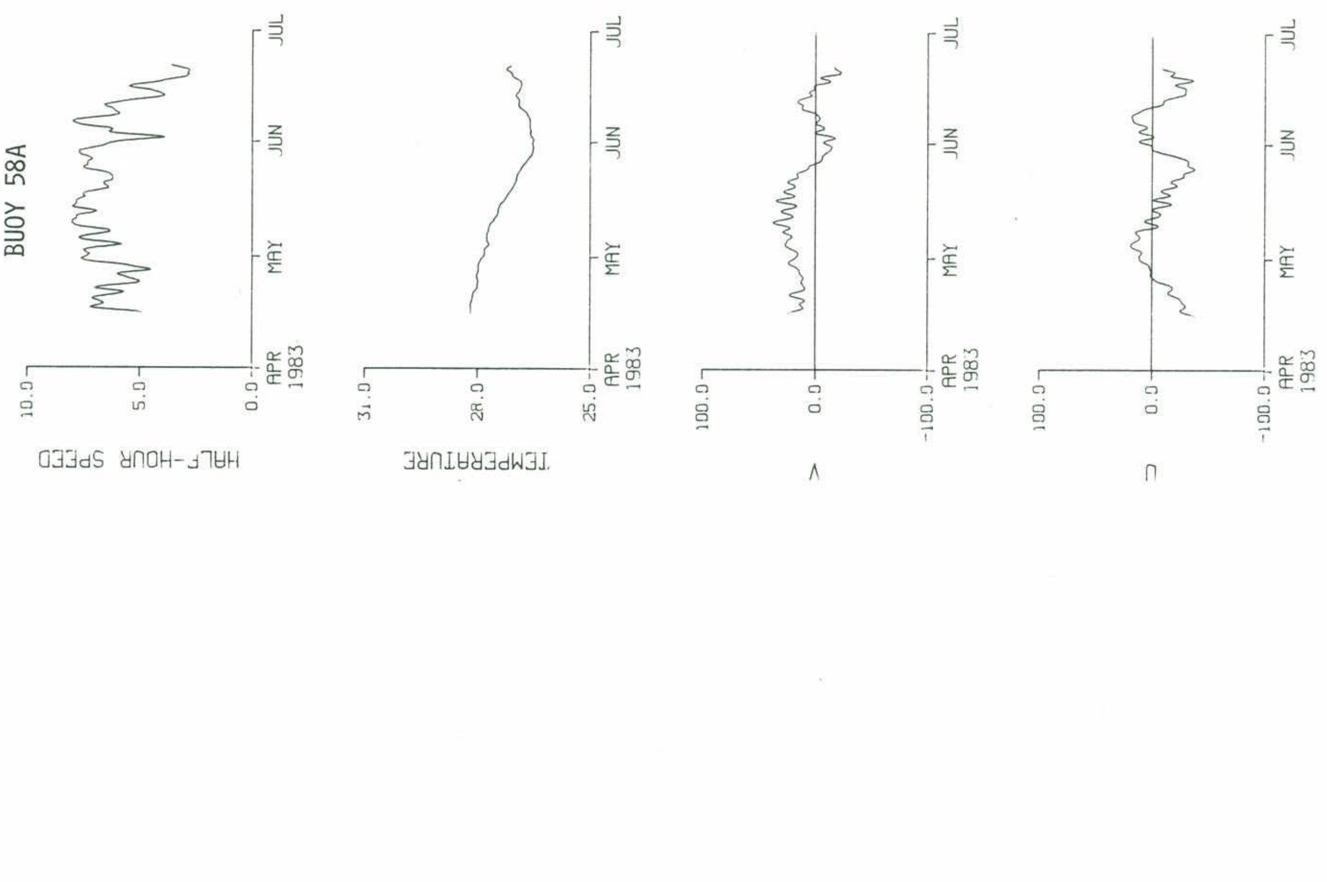

BUOY 56B
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
MAR 1984
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV

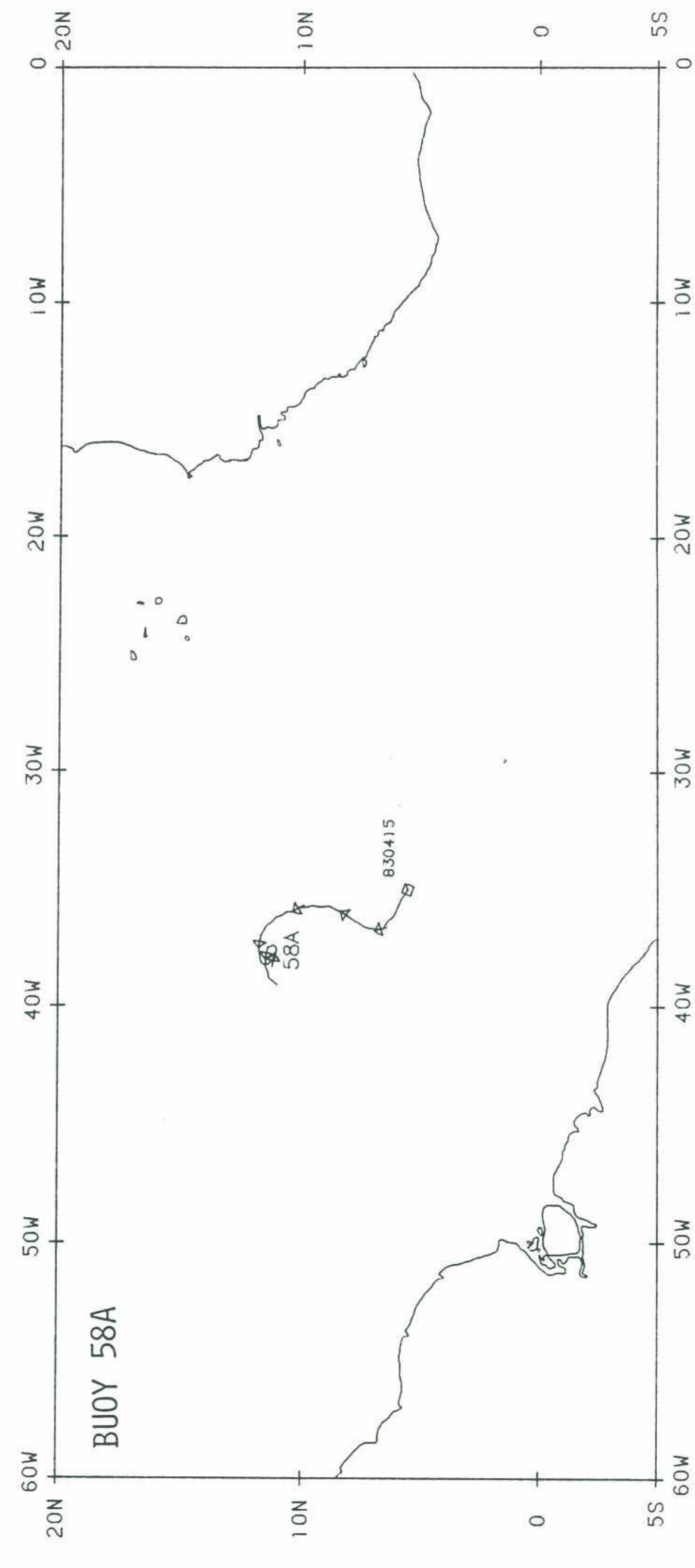

BUOY 56B
56B
840725
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0

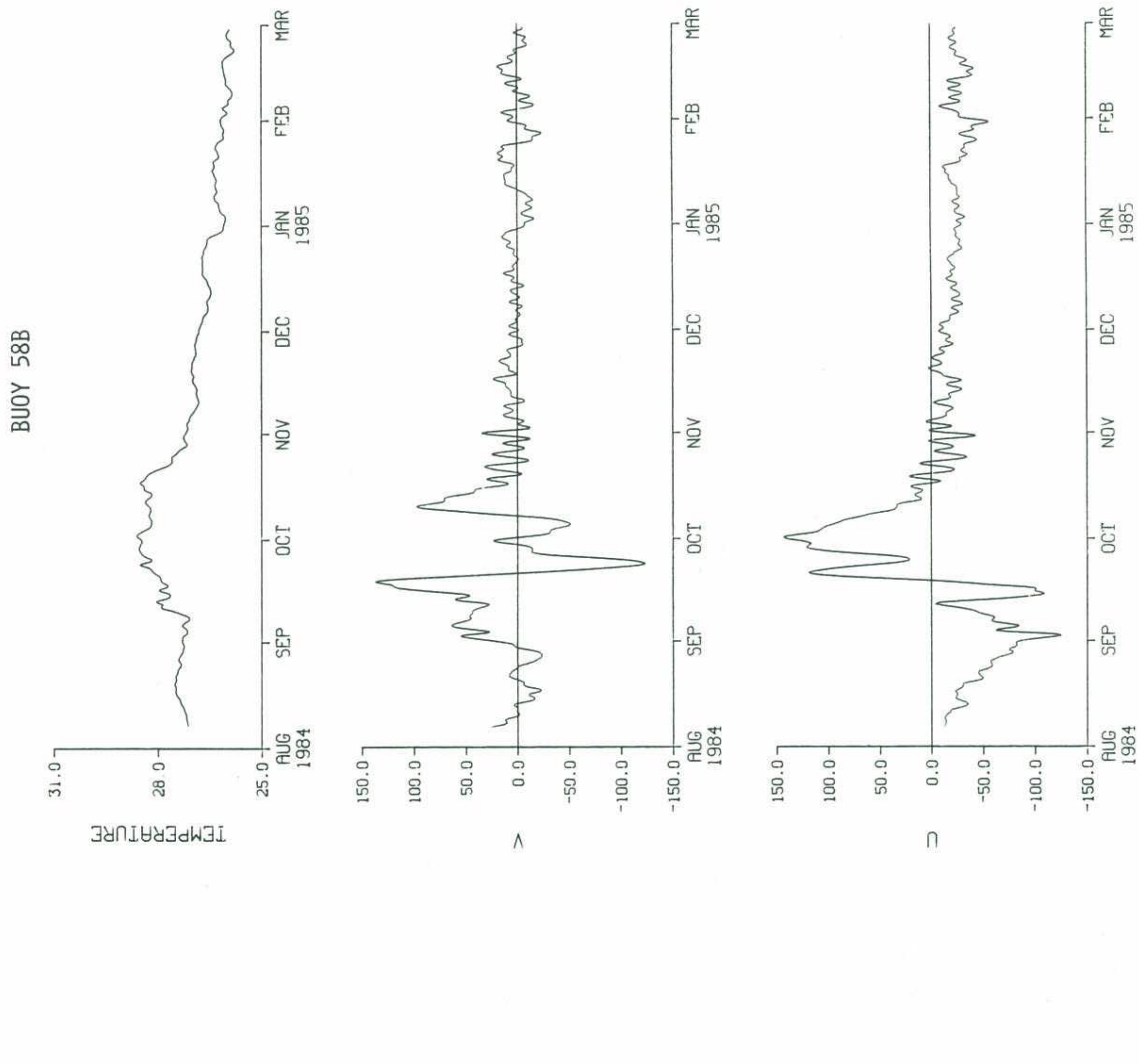
BUOY 57

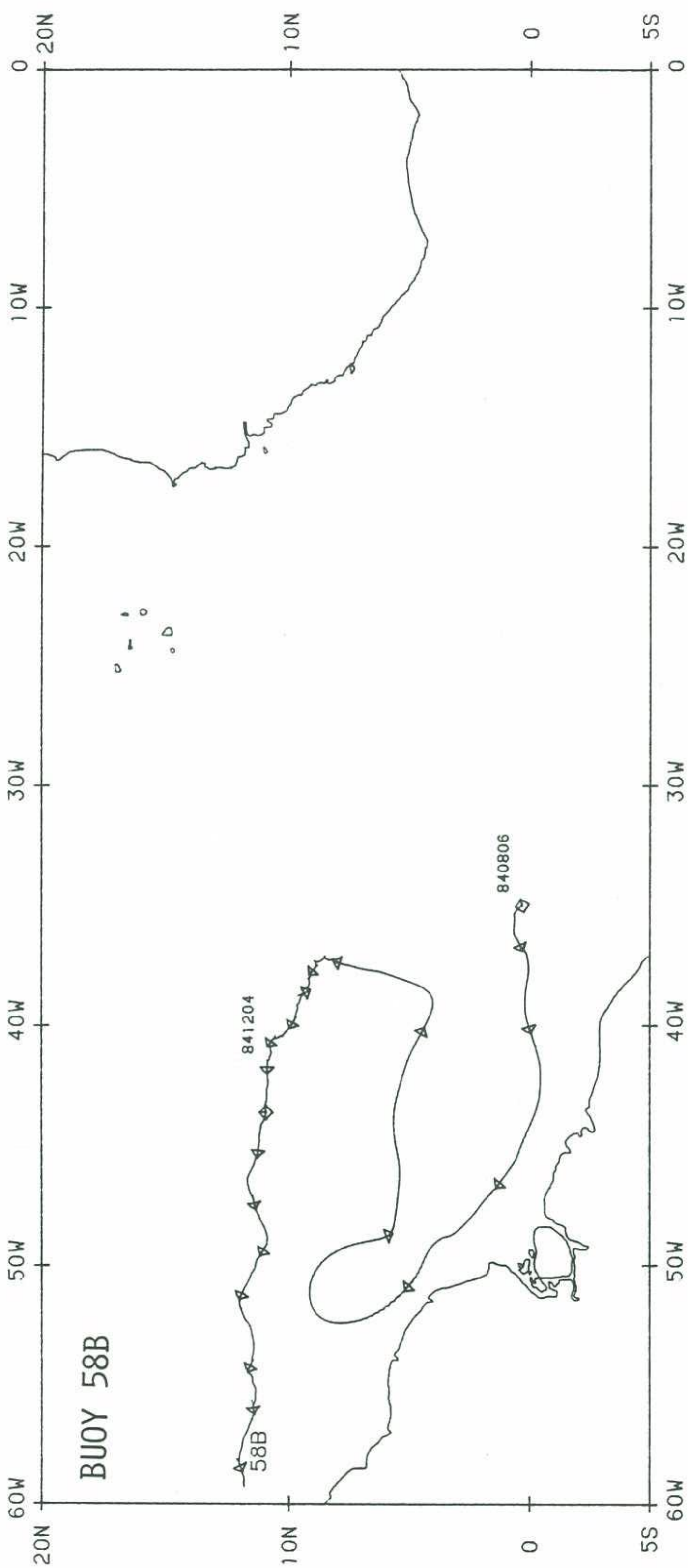

HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
SEP 1983
OCT
NOV
DEC
JAN 1984

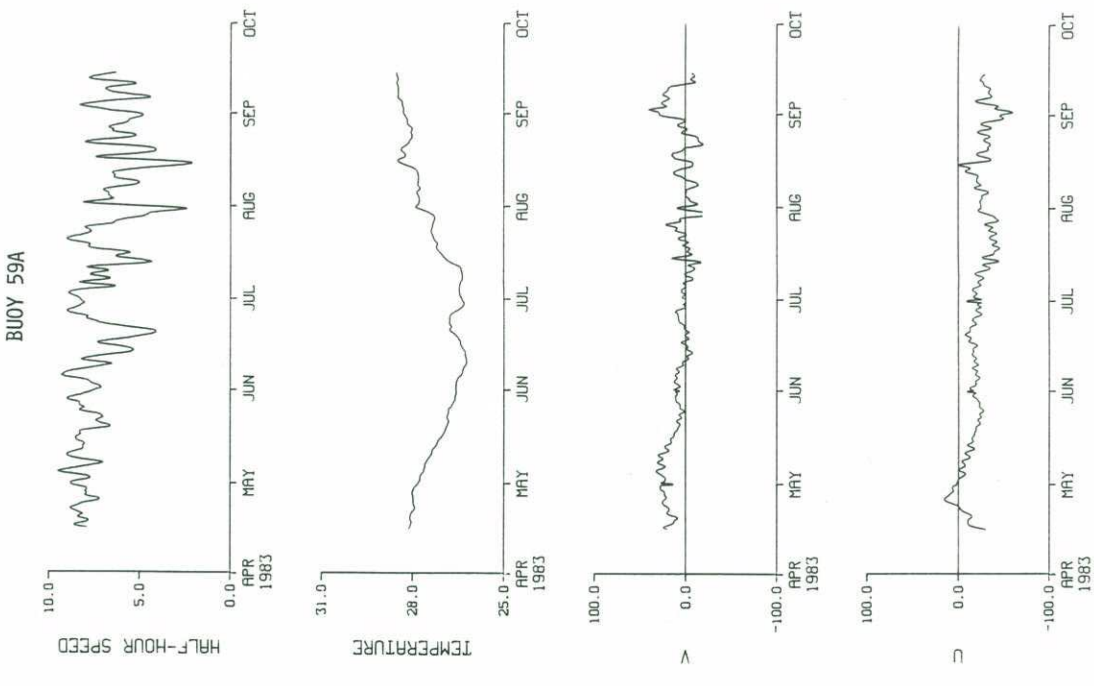

BUOY 57
57
830913
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

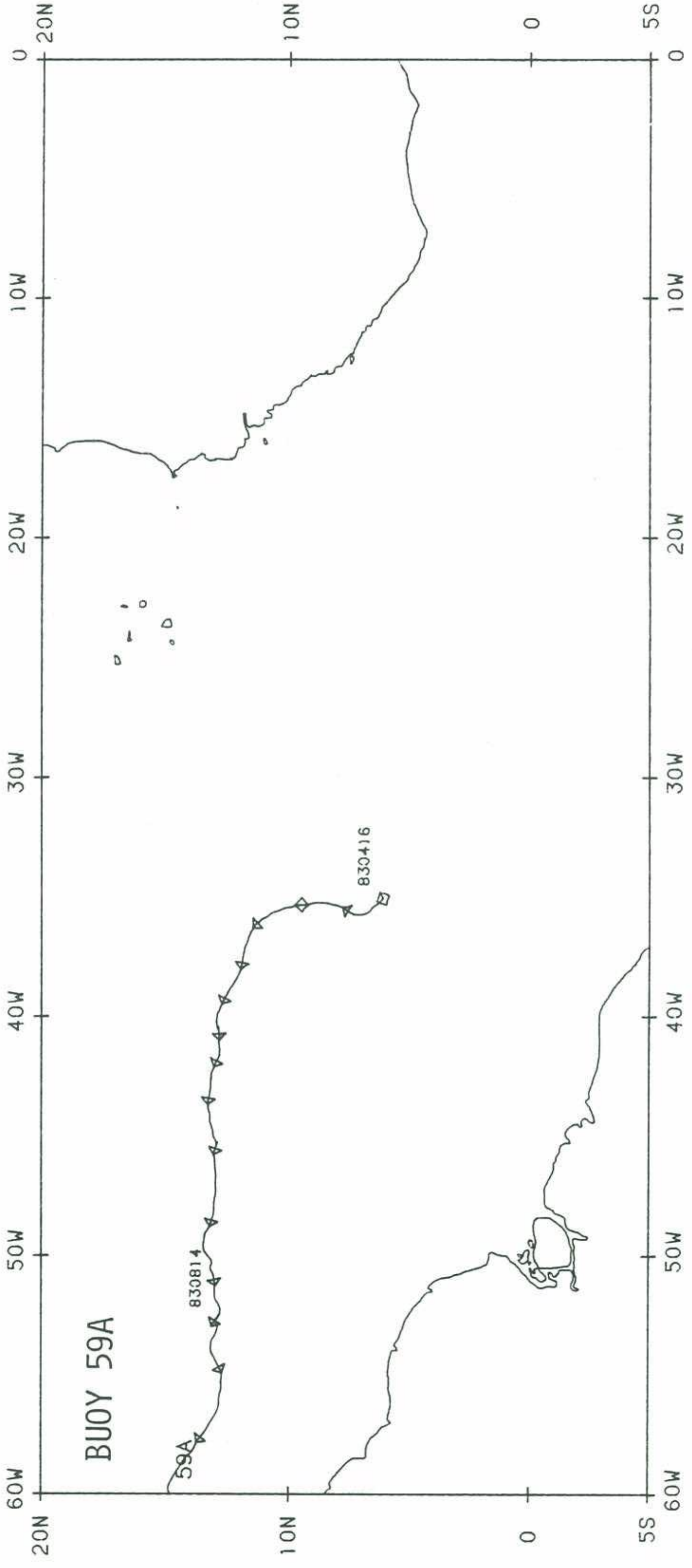

BUOY 58A
HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
APR
1983
MAY
JUN
JUL


BUOY 58A
58A
830415
60W
50W
40W
30W
20W
10W
0
20N
10N
0
5S

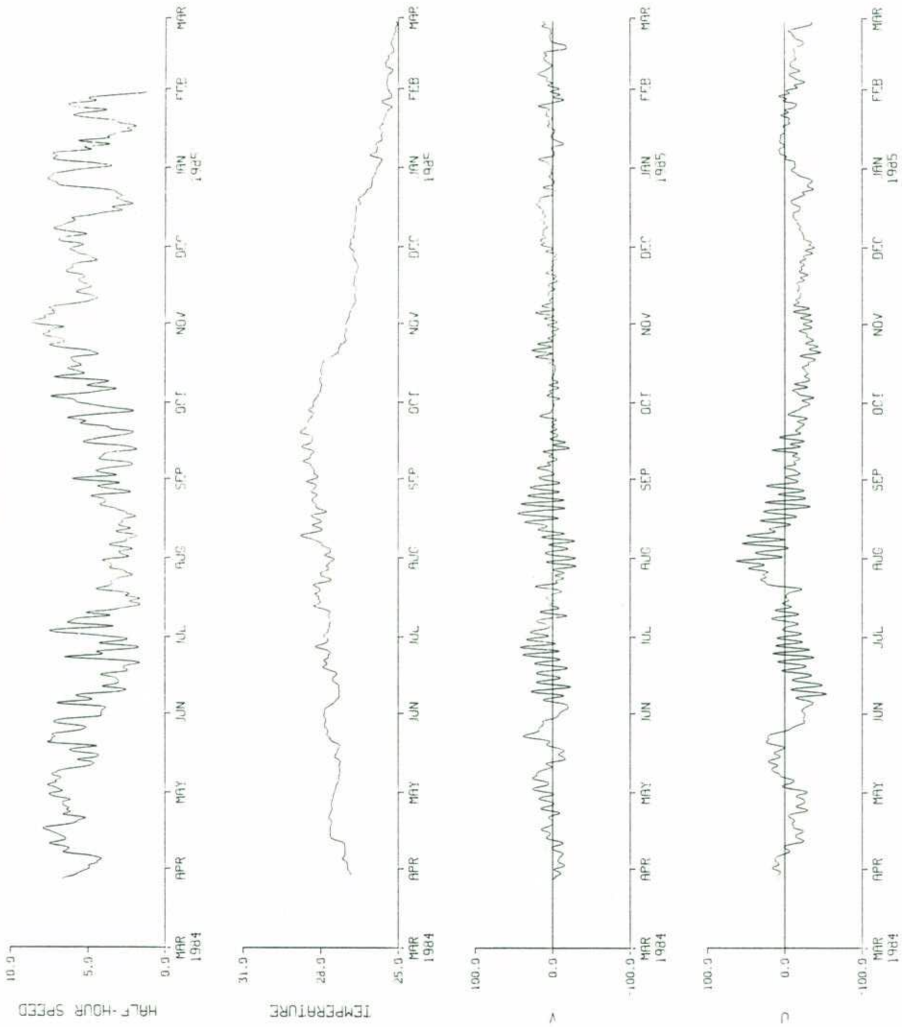

BUOY 58B
TEMPERATURE
31.0
28.0
25.0
V
U
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
AUG 1984
SEP
OCT
NOV
DEC
JAN 1985
FEB
MAR

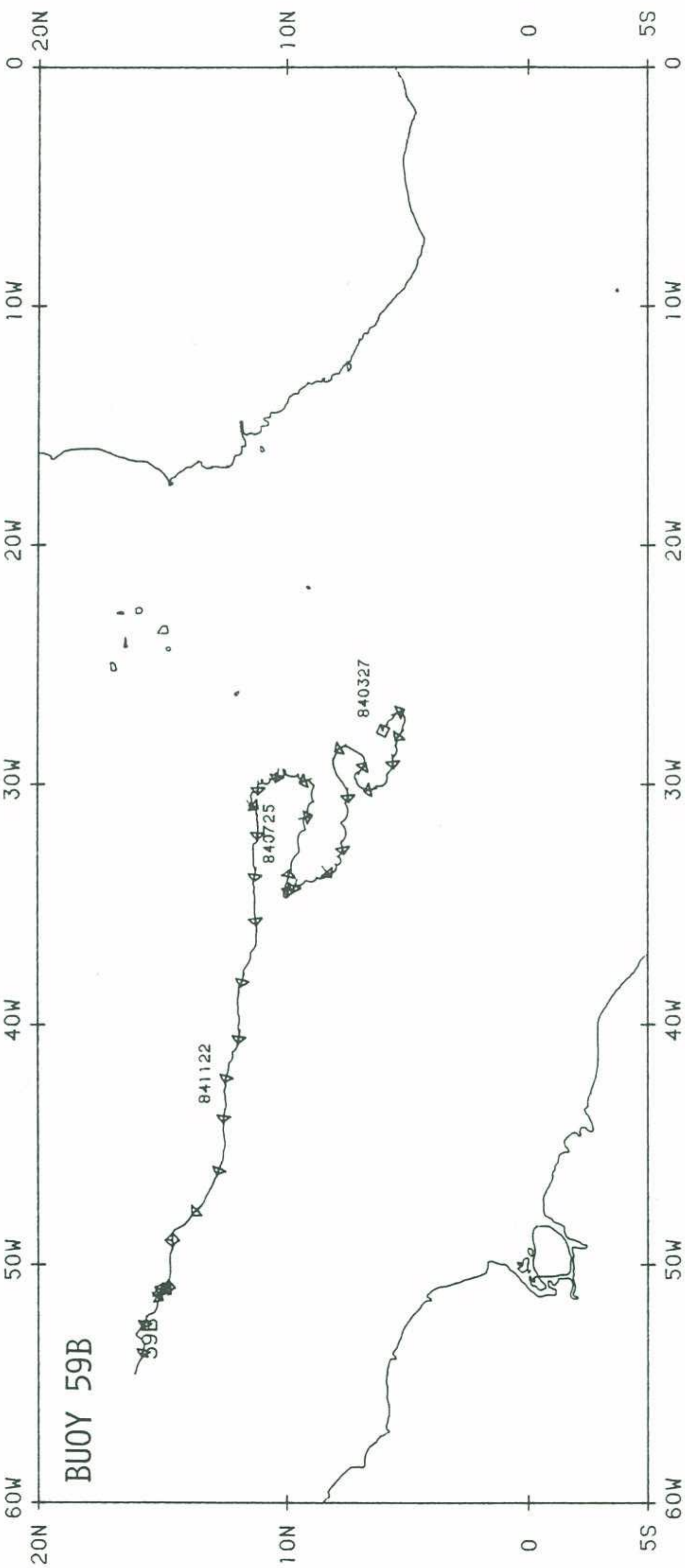

BUOY 58B
58B
841204
840806
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

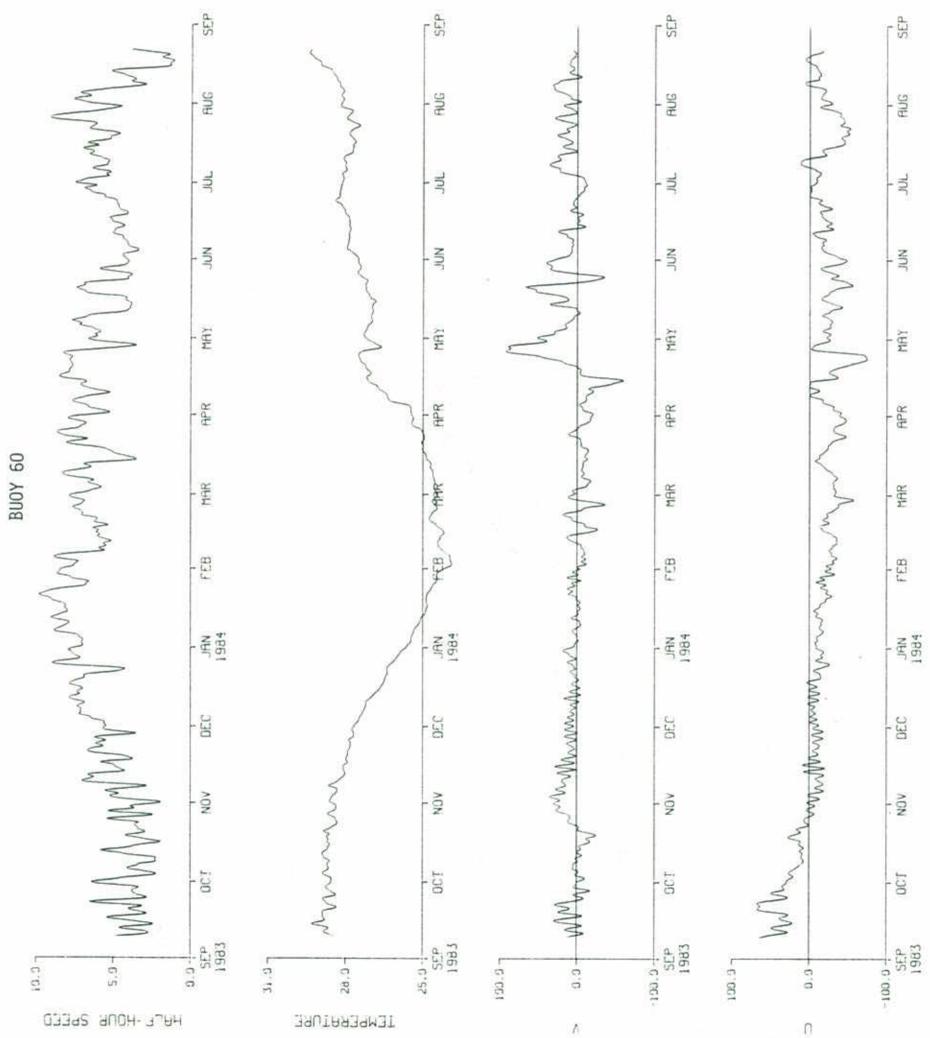

BUOY 59A
HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
APR 1983
MAY
JUN
JUL
AUG
SEP
OCT

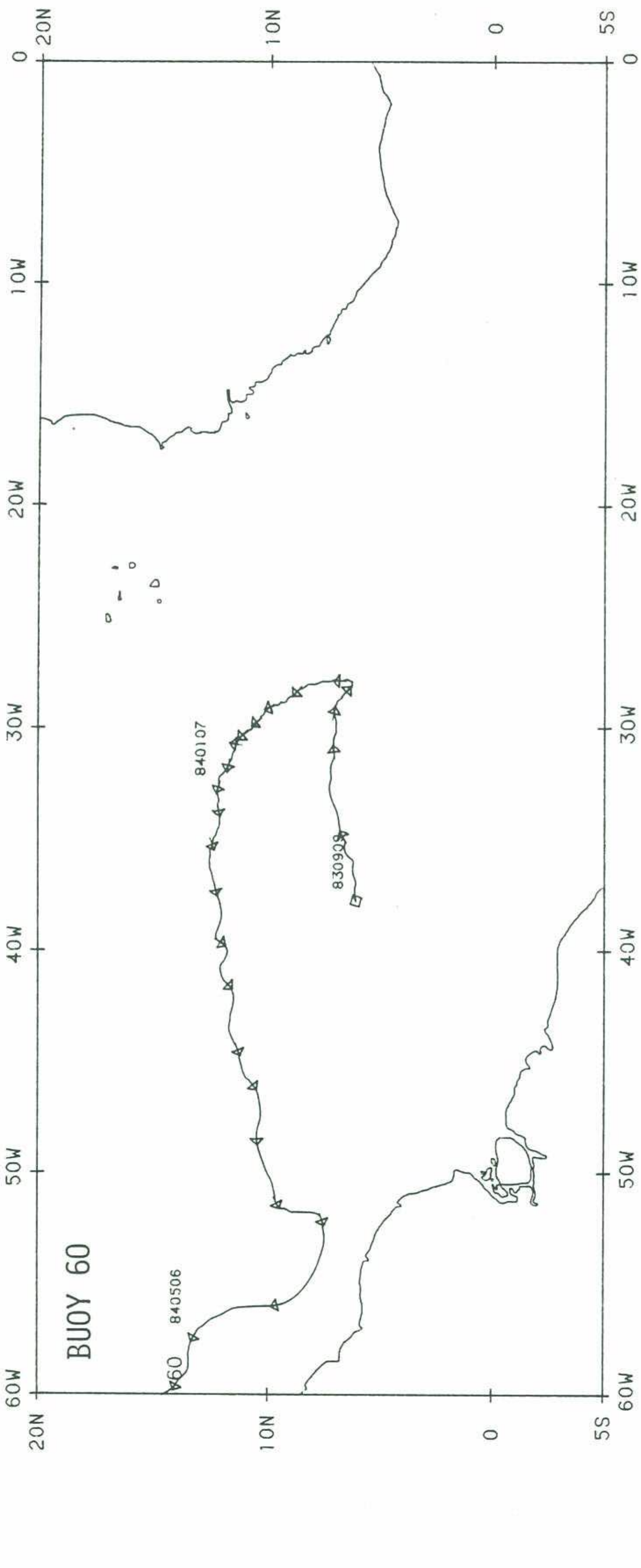

BUOY 59A
59A
830814
830416
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0

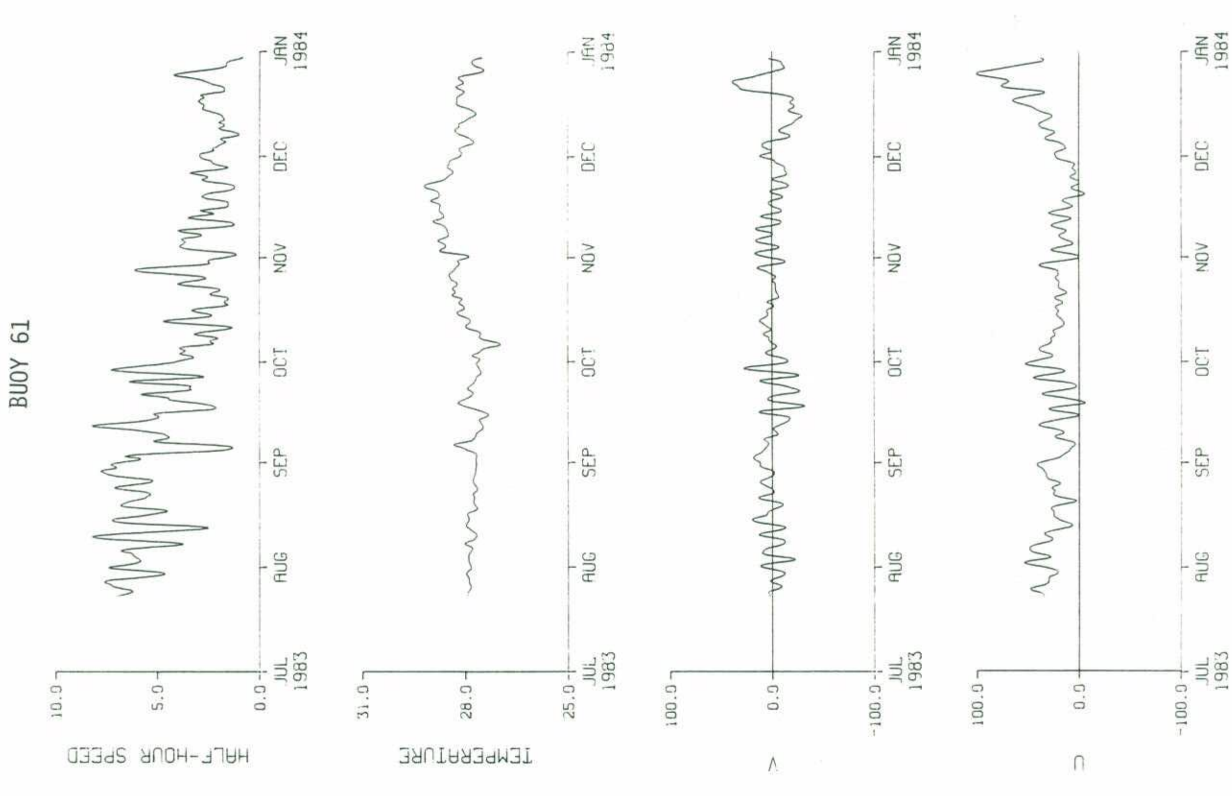
BUOY 59B

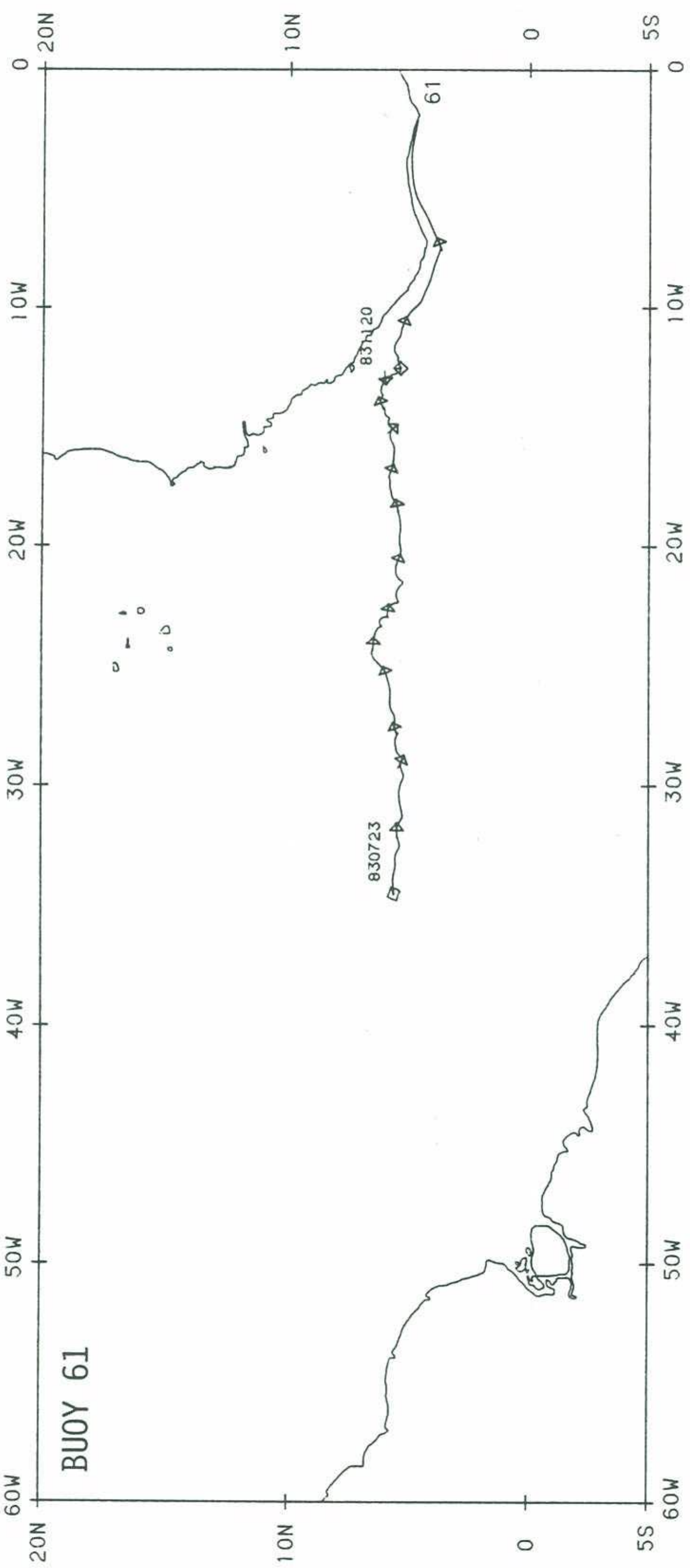

HALF-HOUR SPEED
TEMPERATURE
V
U
MAR 1984
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN 1985
FEB
MAR


BUOY 59B
59B
841122
840725
840327
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0

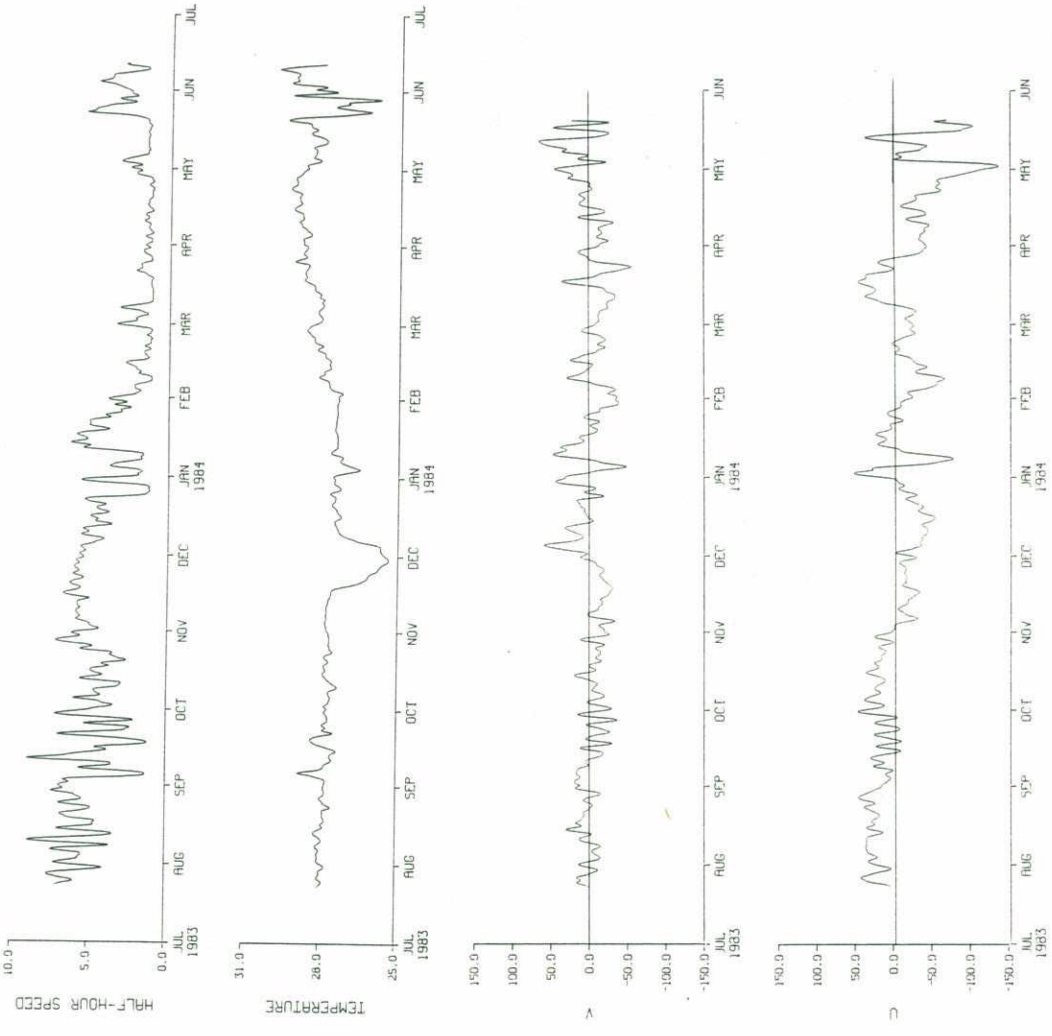

BUOY 60
HALF-HOUR SPEED
TEMPERATURE
V
U
SEP 1983
OCT
NOV
DEC
JAN 1984
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

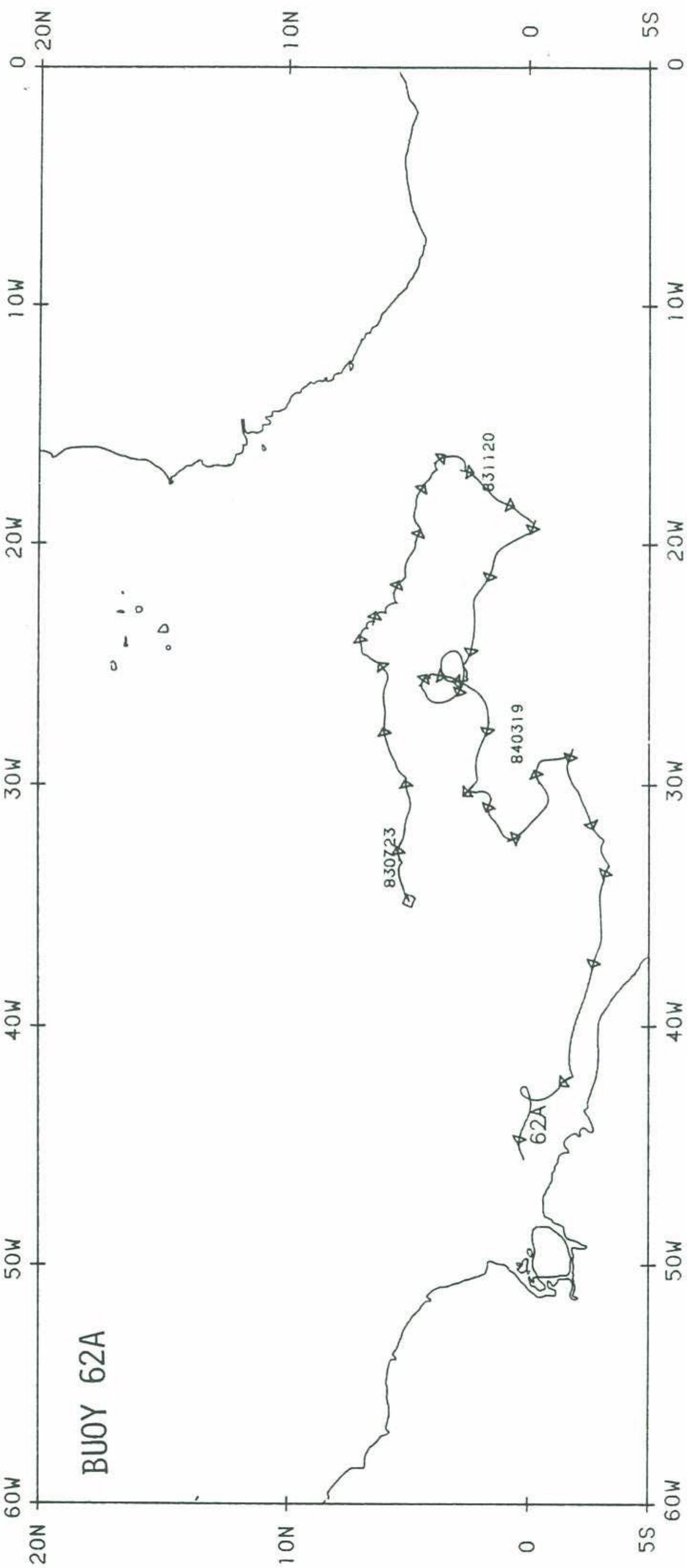

BUOY 60
840506
840107
830909
60
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0

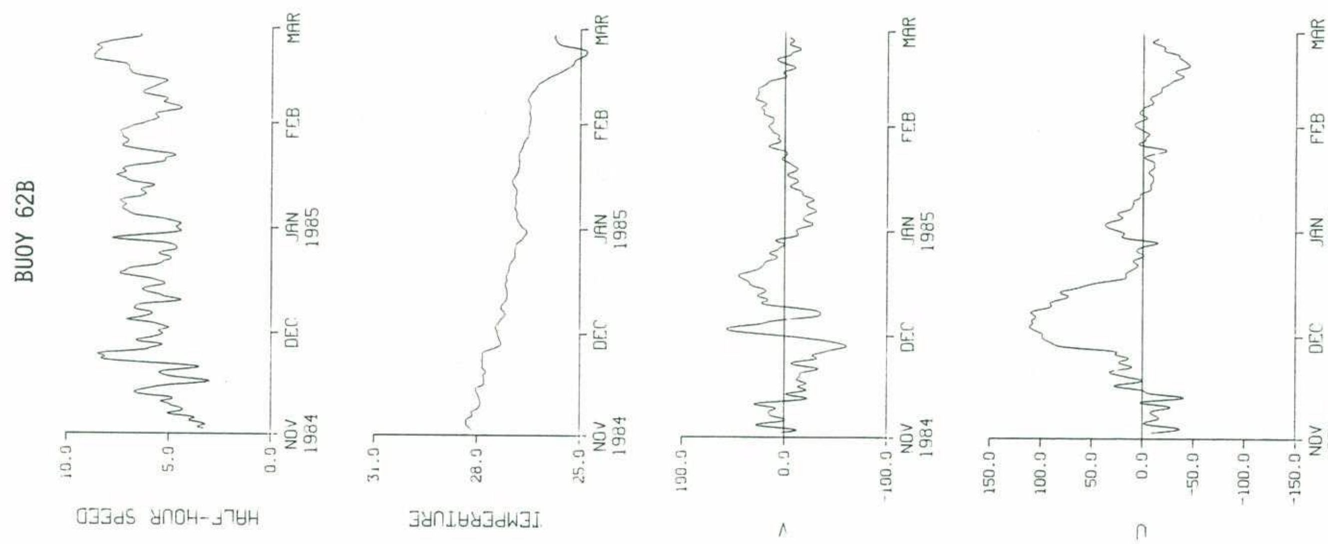

BUOY 61
HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
JUL 1983
AUG
SEP
OCT
NOV
DEC
JAN 1984

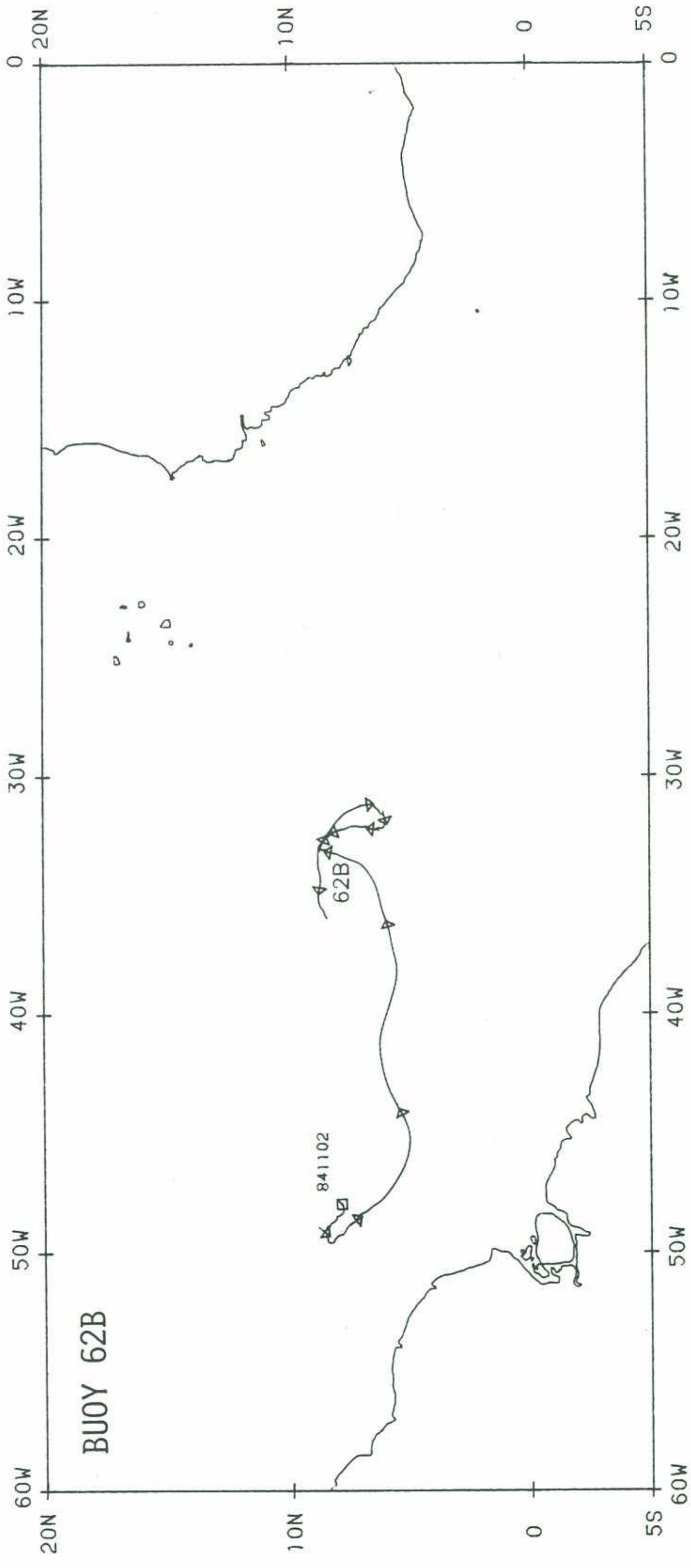

BUOY 61
61
831120
830723
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

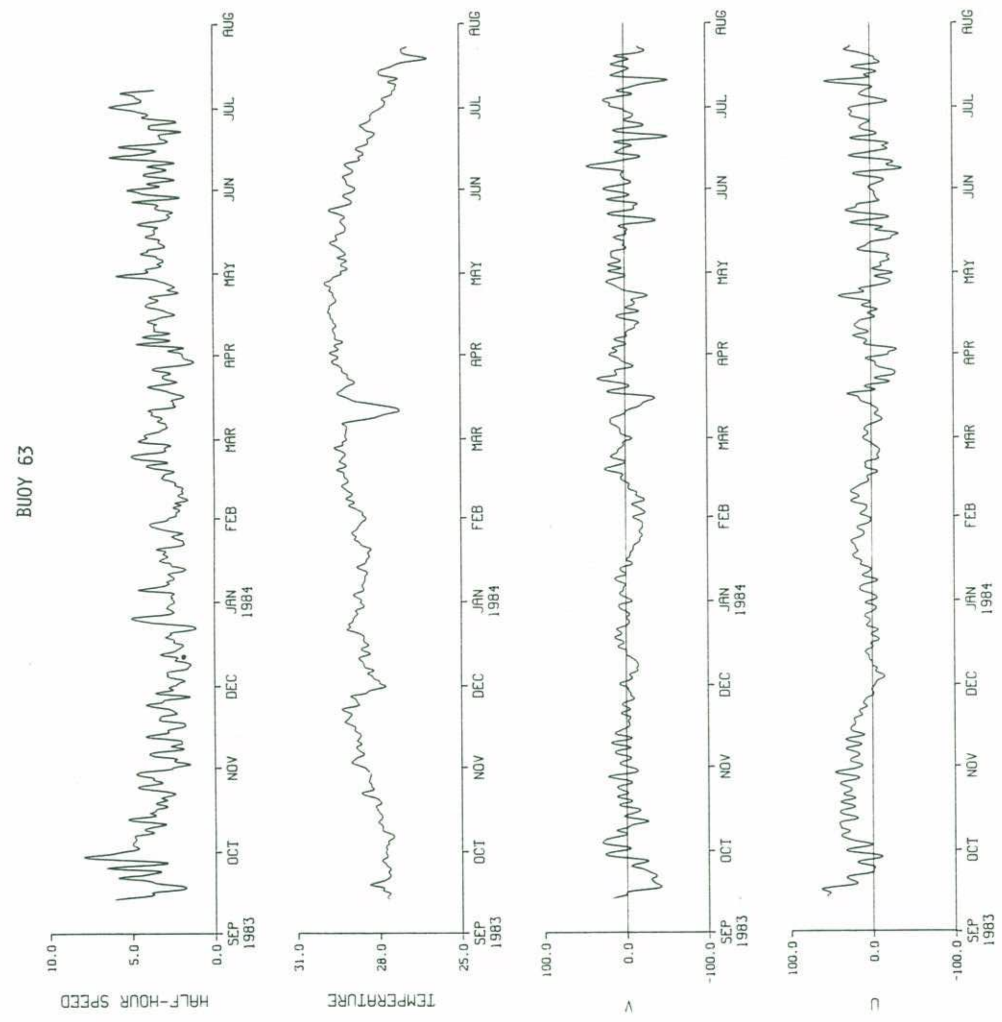
BUOY 62A

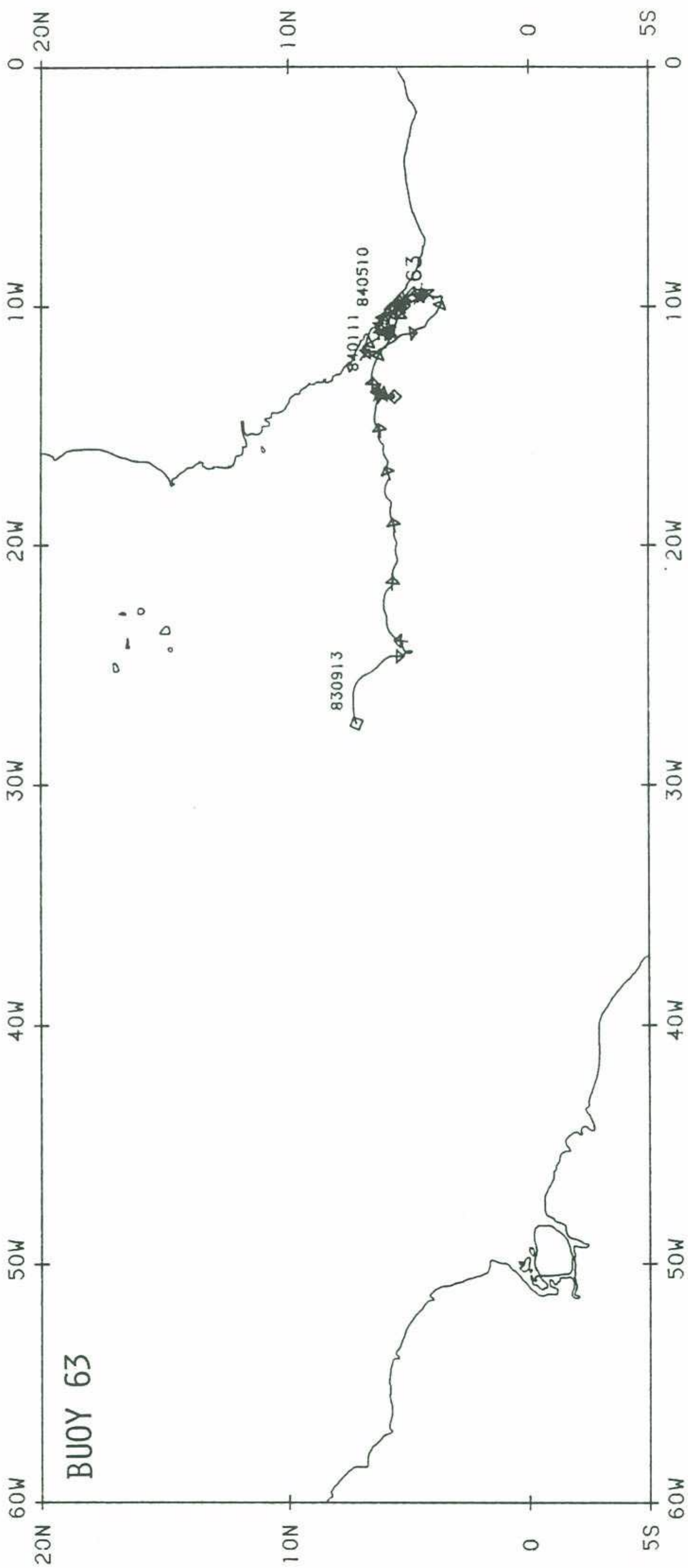

HALF-HOUR SPEED
TEMPERATURE
V
U
JUL 1983
AUG
SEP
OCT
NOV
DEC
JAN 1984
FEB
MAR
APR
MAY
JUN
JUL

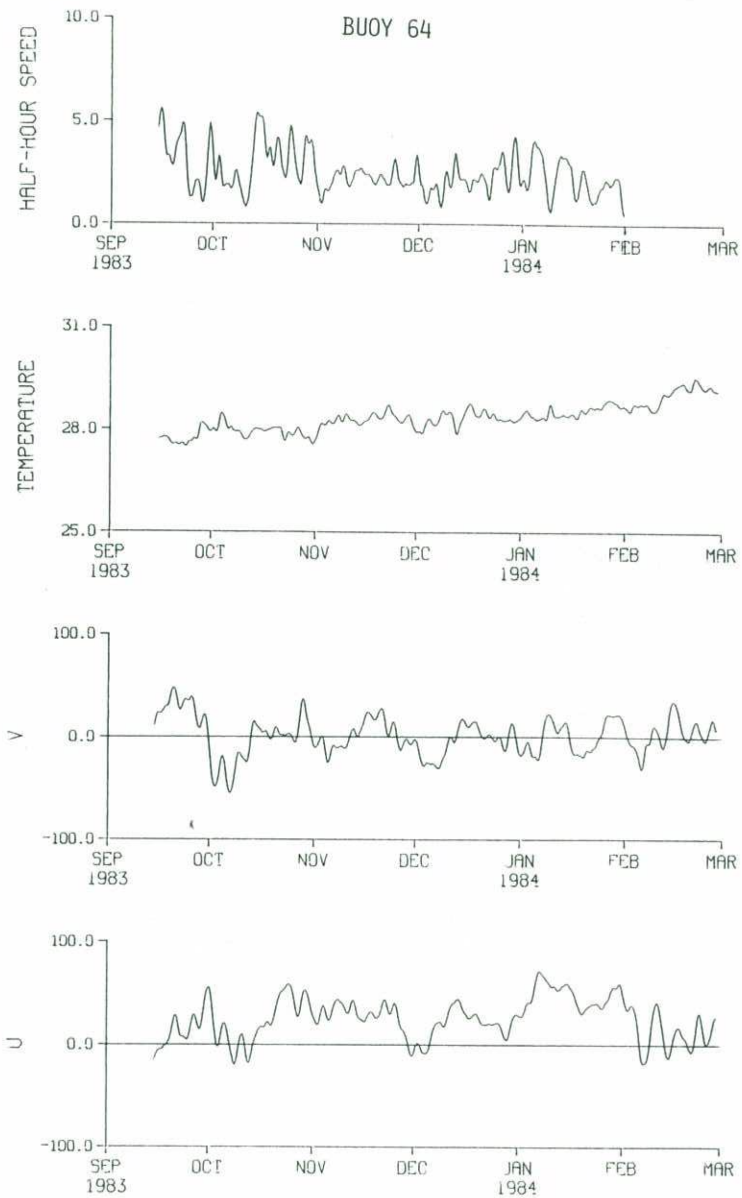

BUOY 62A
830723
831120
840319
62A
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

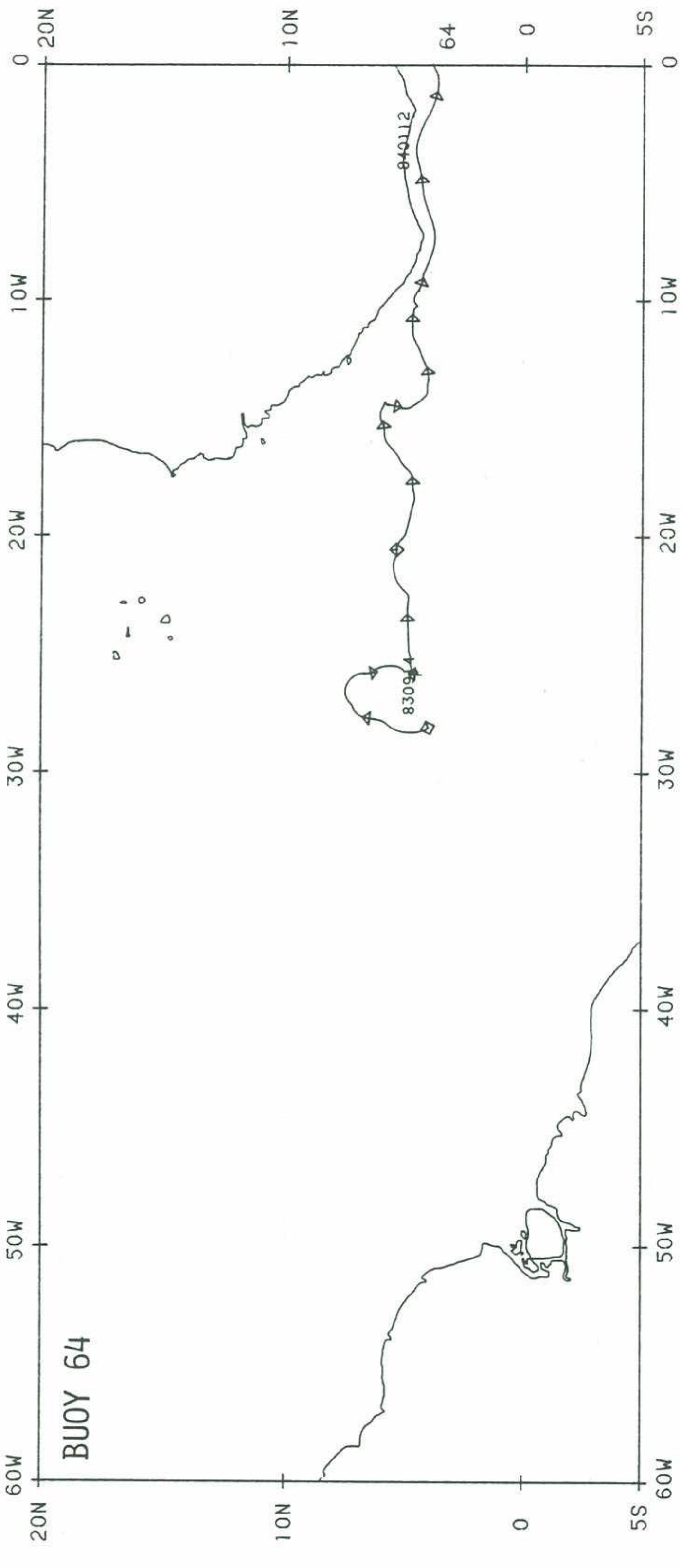

BUOY 62B
HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
NOV 1984
DEC
JAN 1985
FEB
MAR


BUOY 62B
62B
841102
20N
10N
0
5S
60W
50W
40W
30W
20W
10W

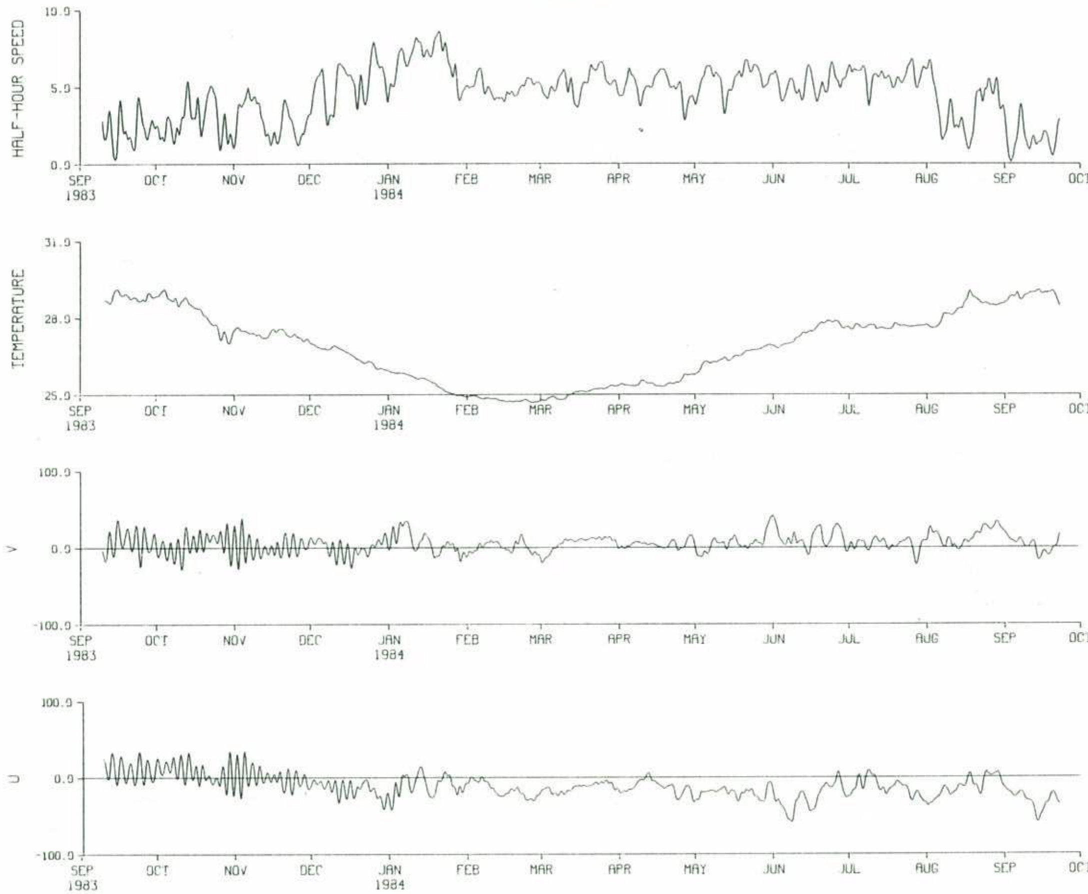

BUOY 63
HALF-HOUR SPEED
TEMPERATURE
V
U
10.0
5.0
0.0
31.0
28.0
25.0
100.0
0.0
-100.0
SEP 1983
OCT
NOV
DEC
JAN 1984
FEB
MAR
APR
MAY
JUN
JUL
AUG

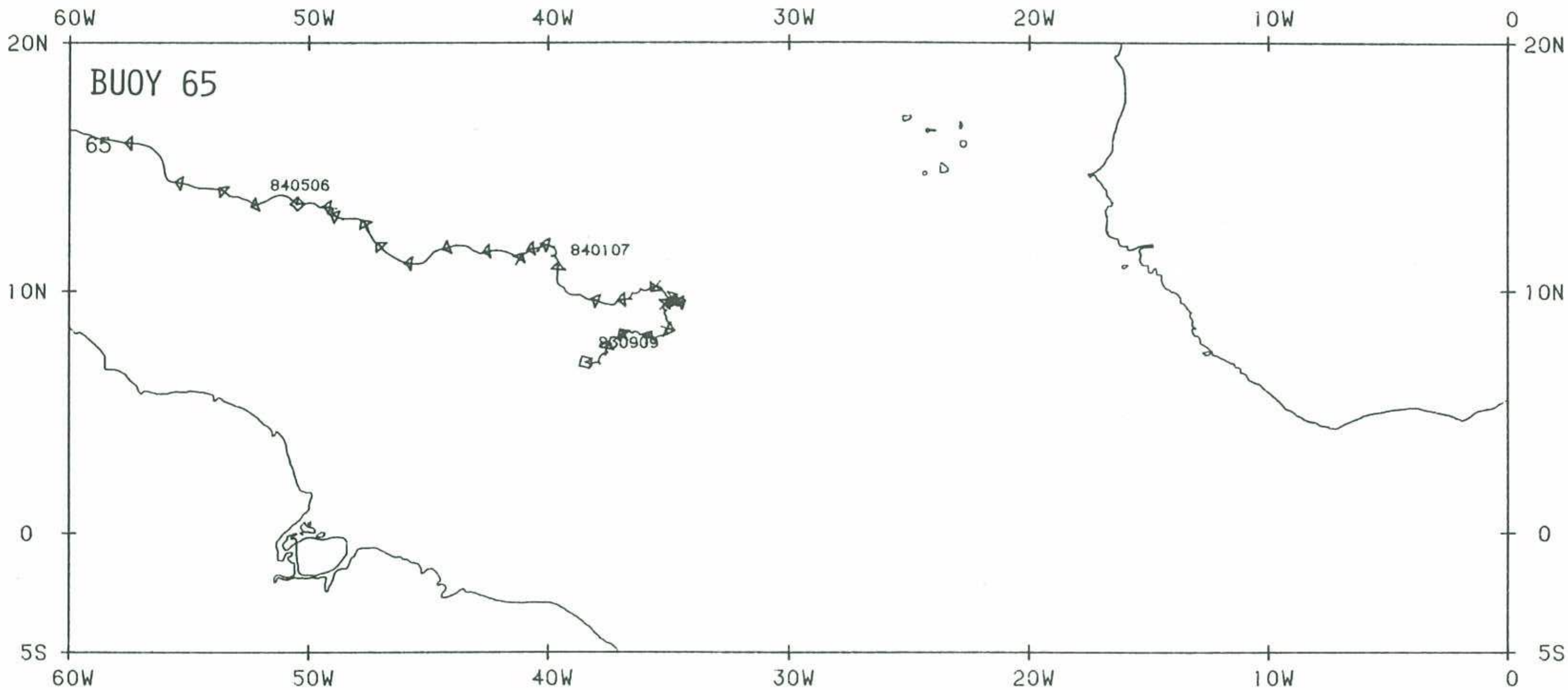

BUOY 63
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0
830913
840111
840510
63


BUOY 64
HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
SEP 1983
OCT
NOV
DEC
JAN 1984
FEB
MAR

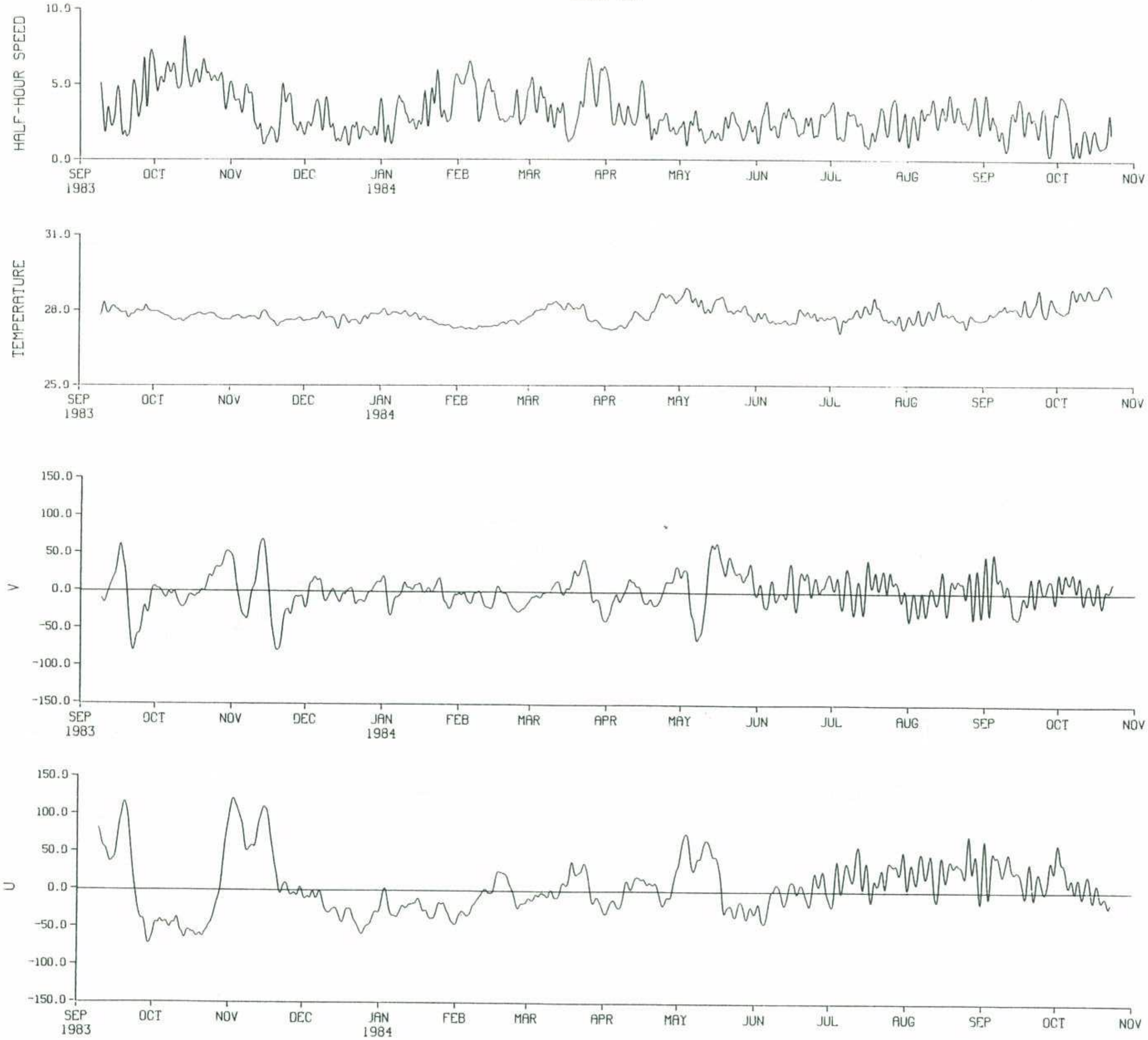

BUOY 64
840112
64
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

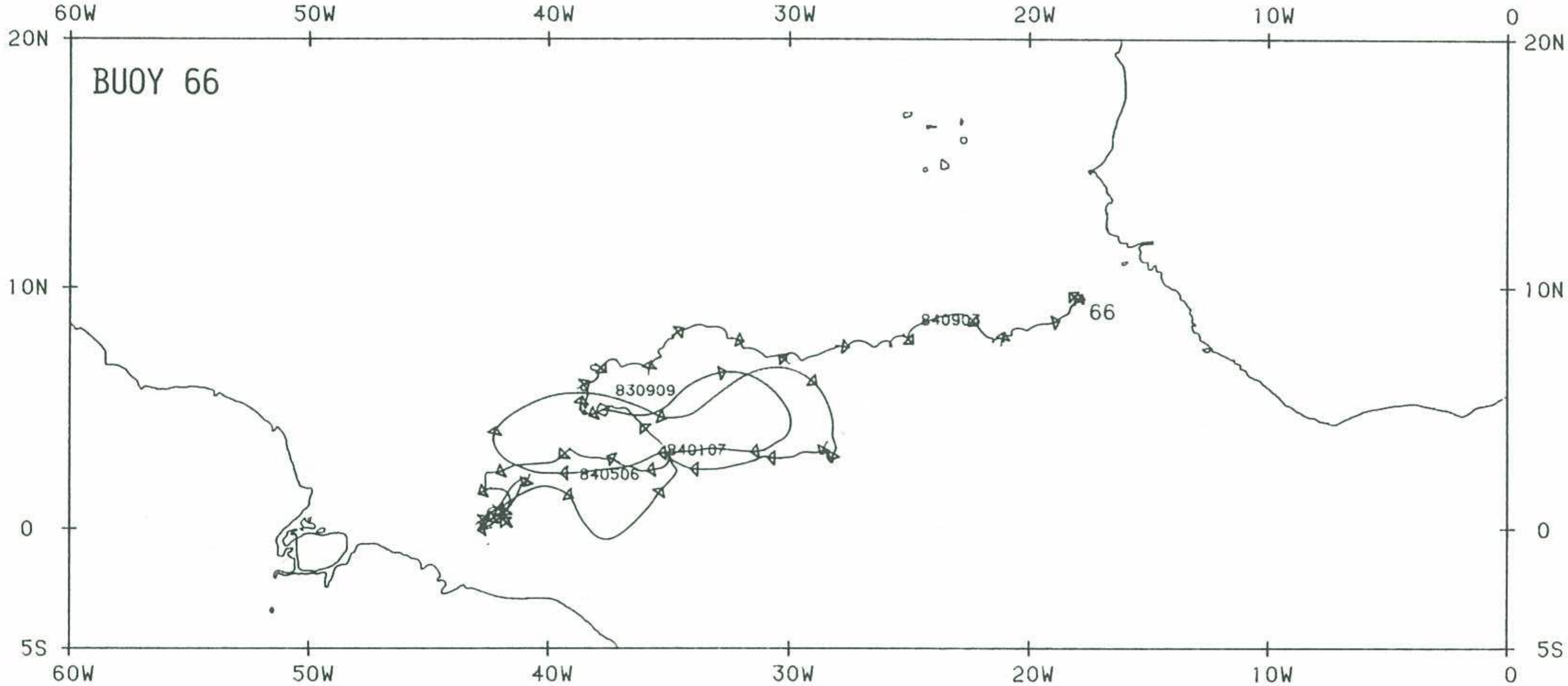
BUOY 65


HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
SEP 1983
OCT
NOV
DEC
JAN 1984
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT

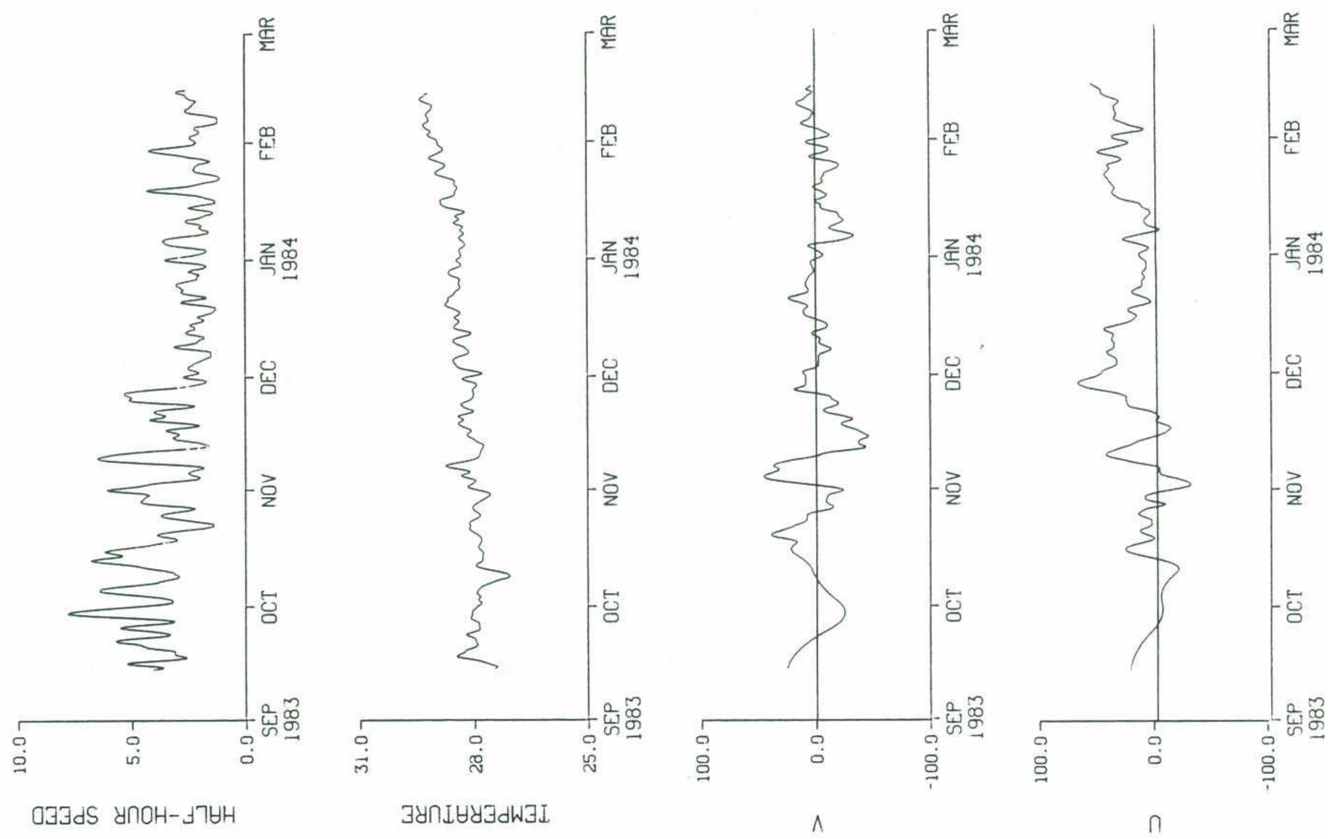

BUOY 65
65
840506
840107
830909
60W
50W
40W
30W
20W
10W
0
20N
10N
0
5S

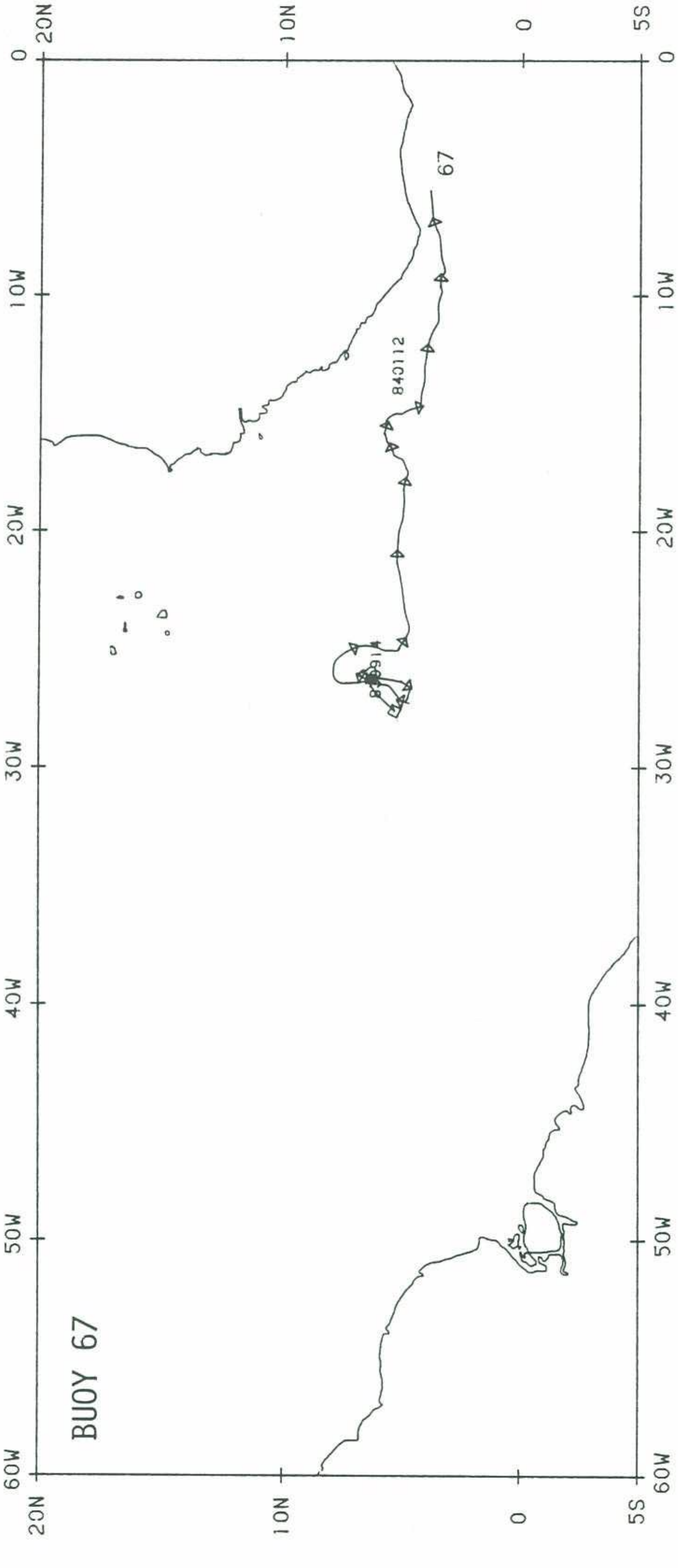
BUOY 66


HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
U
SEP 1983
OCT
NOV
DEC
JAN 1984
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV

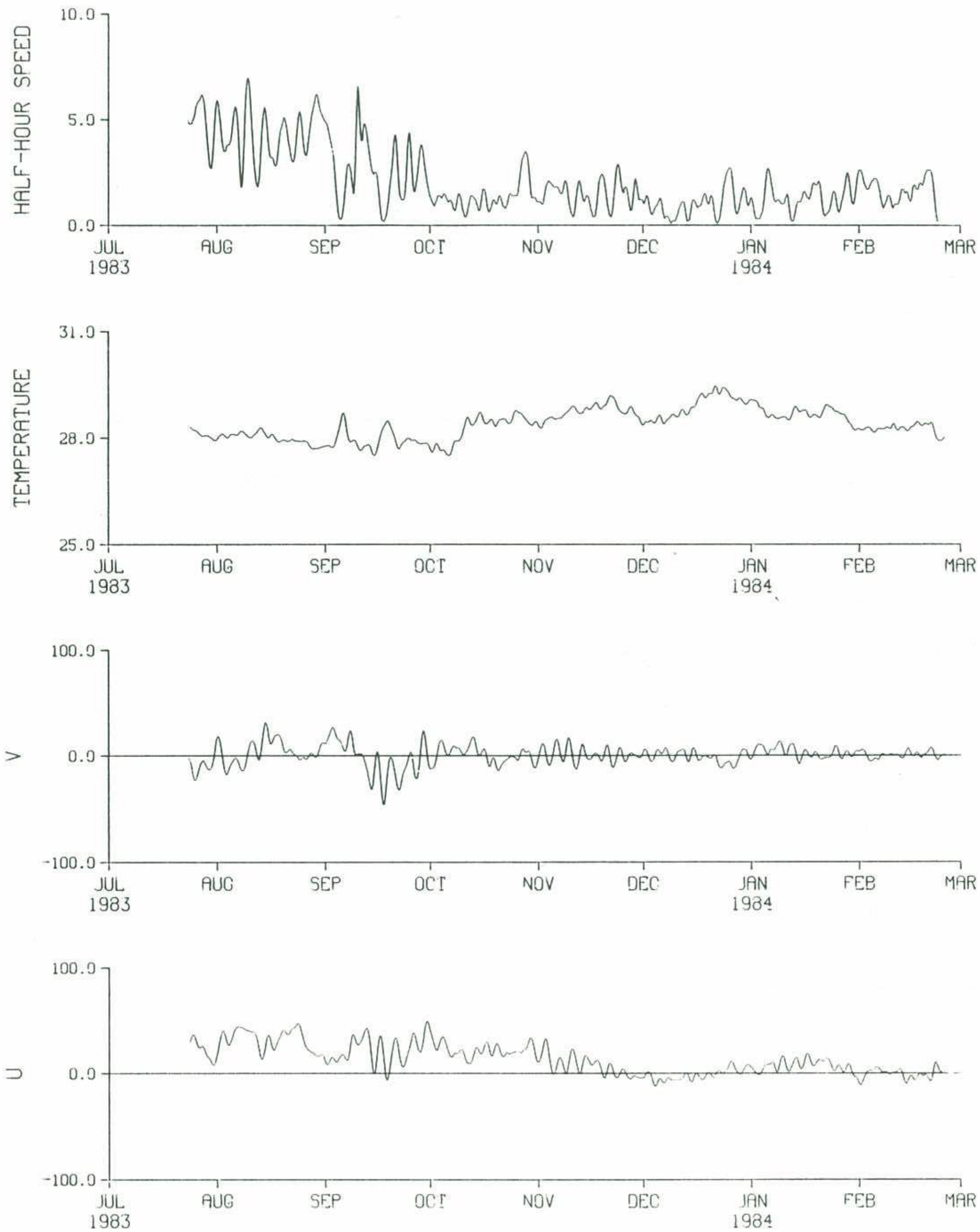

BUOY 66
60W
50W
40W
30W
20W
10W
0
20N
10N
0
5S
66
840903
830909
840107
840506

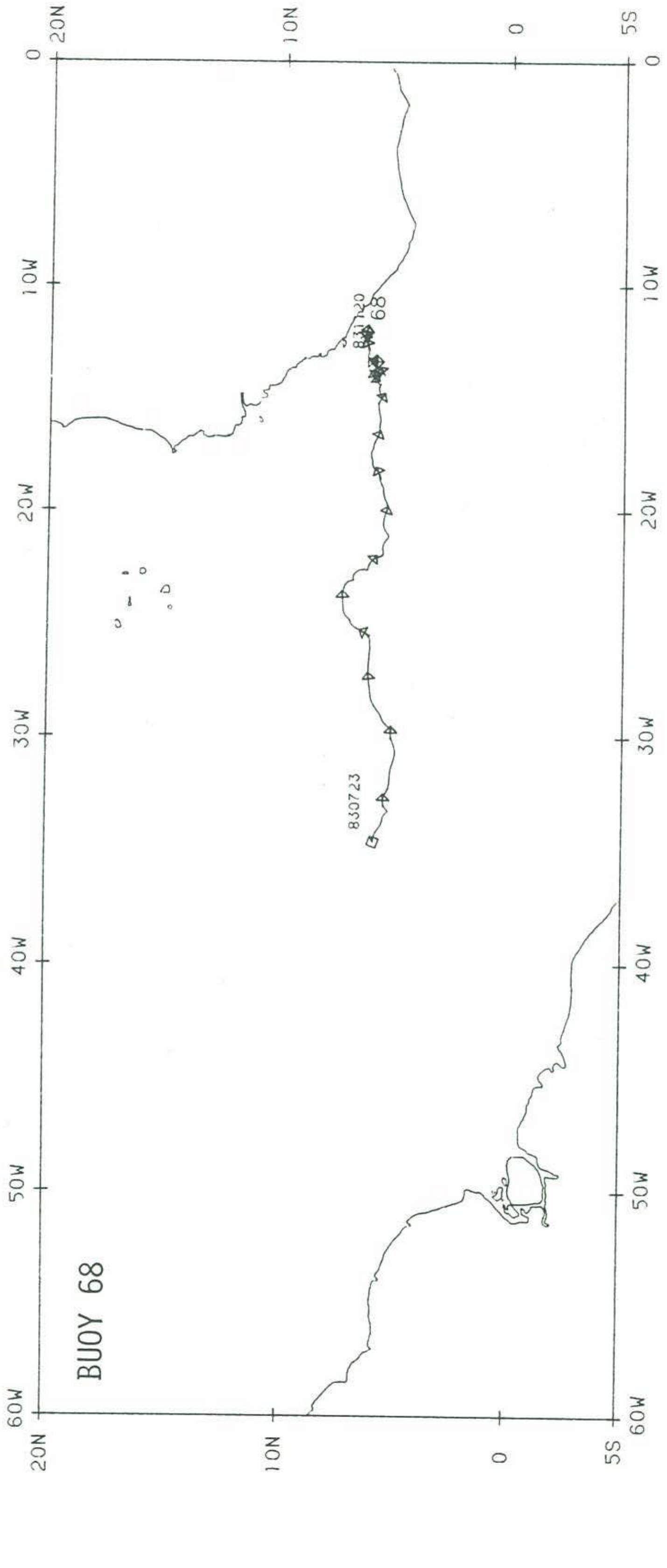
BUOY 67


HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
SEP 1983
OCT
NOV
DEC
JAN 1984
FEB
MAR

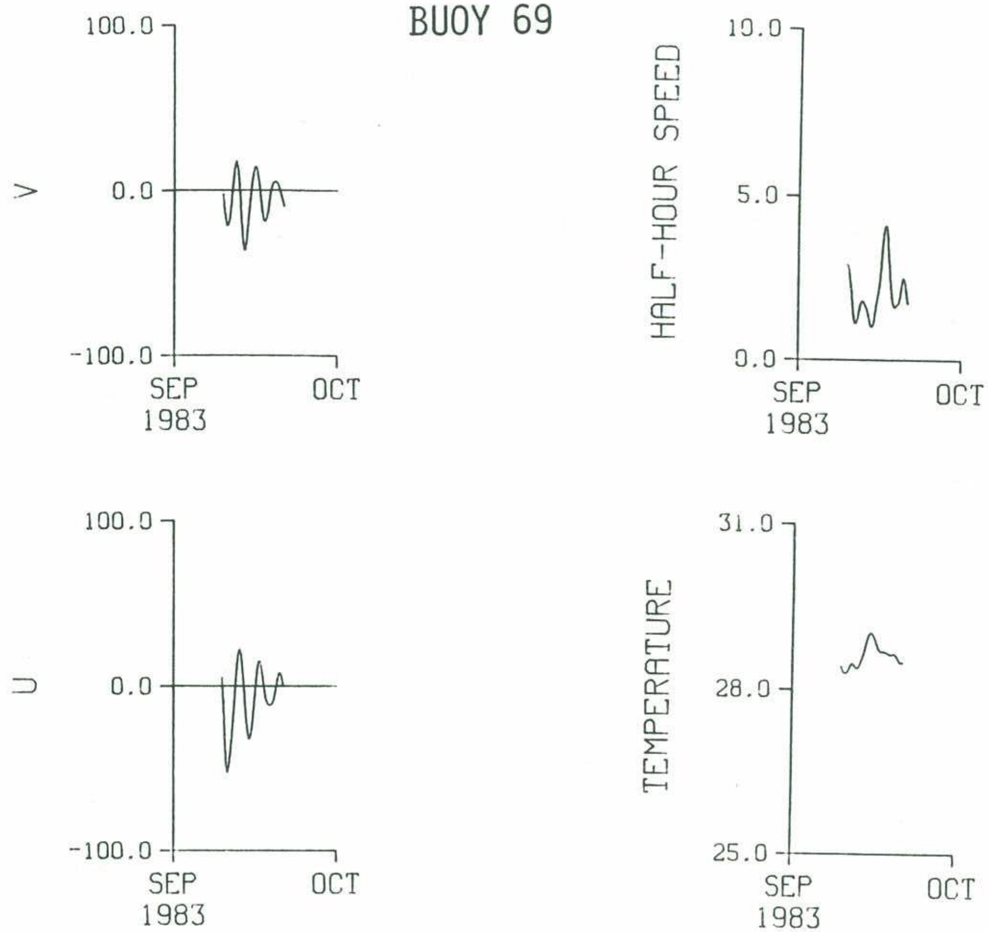

BUOY 67
67
840112
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0

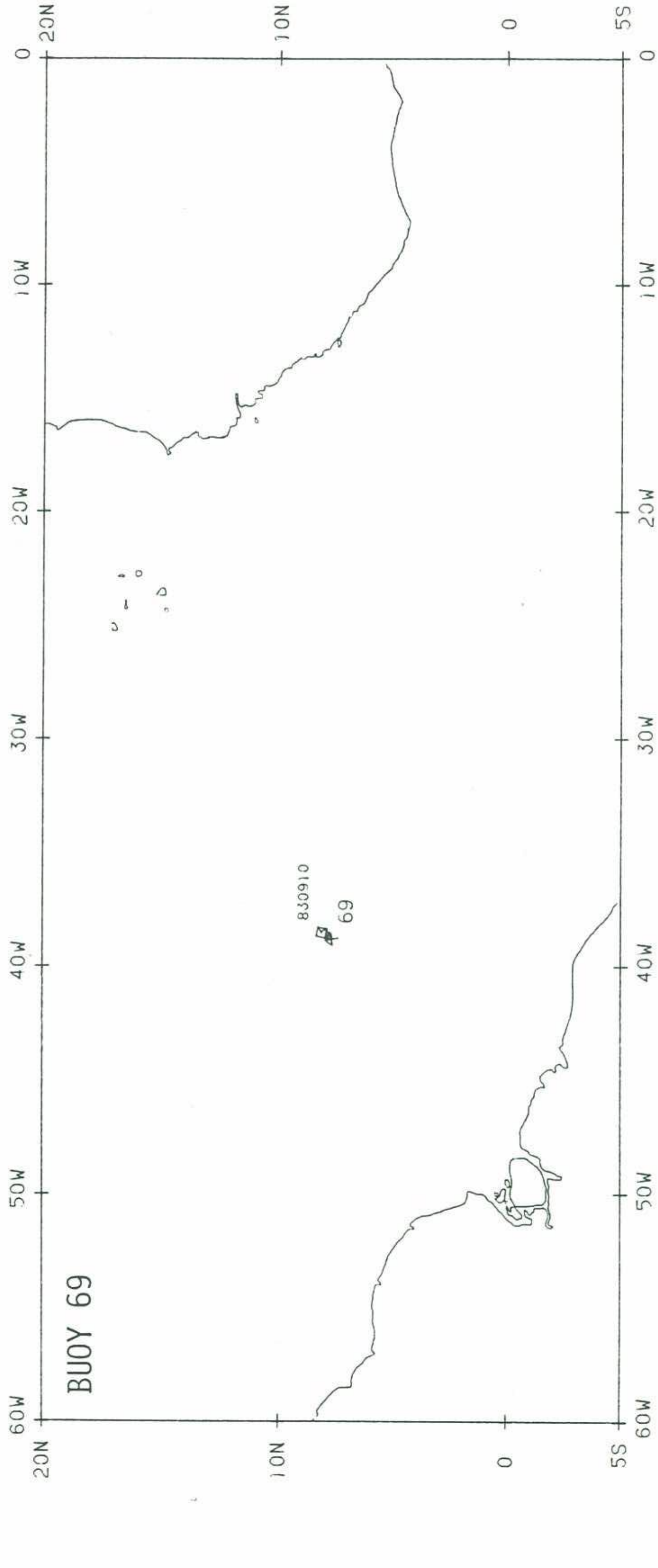
BUOY 68


HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
JUL 1983
AUG
SEP
OCT
NOV
DEC
JAN 1984
FEB
MAR


BUOY 68
830723
831120
68
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0

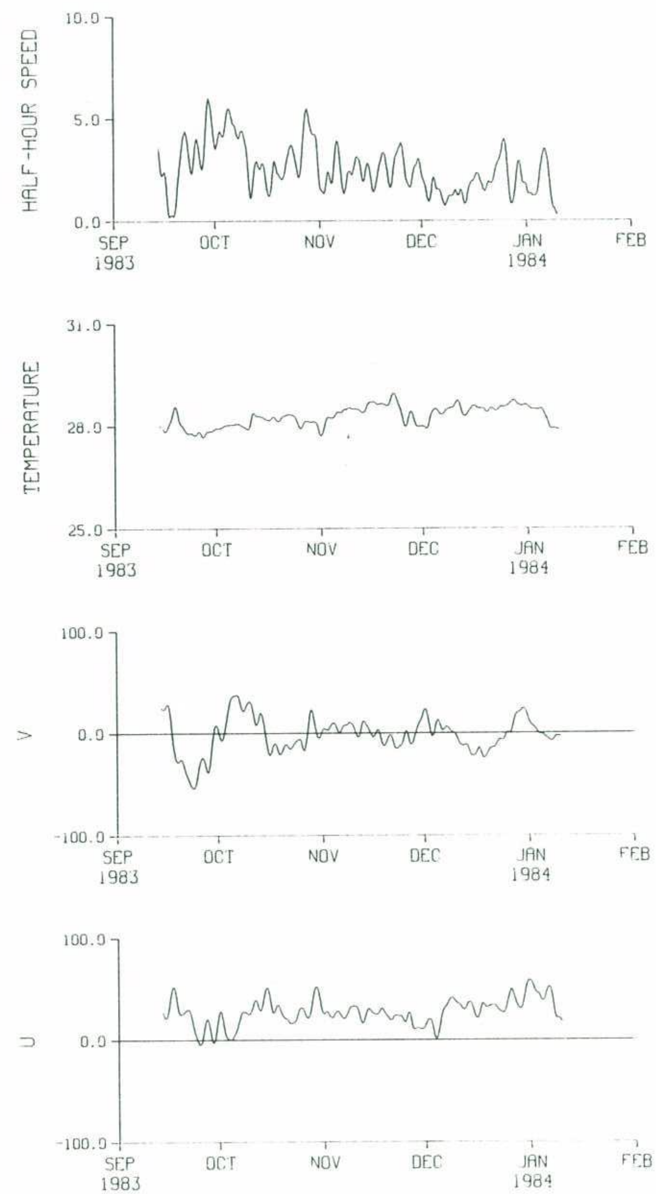
BUOY 69

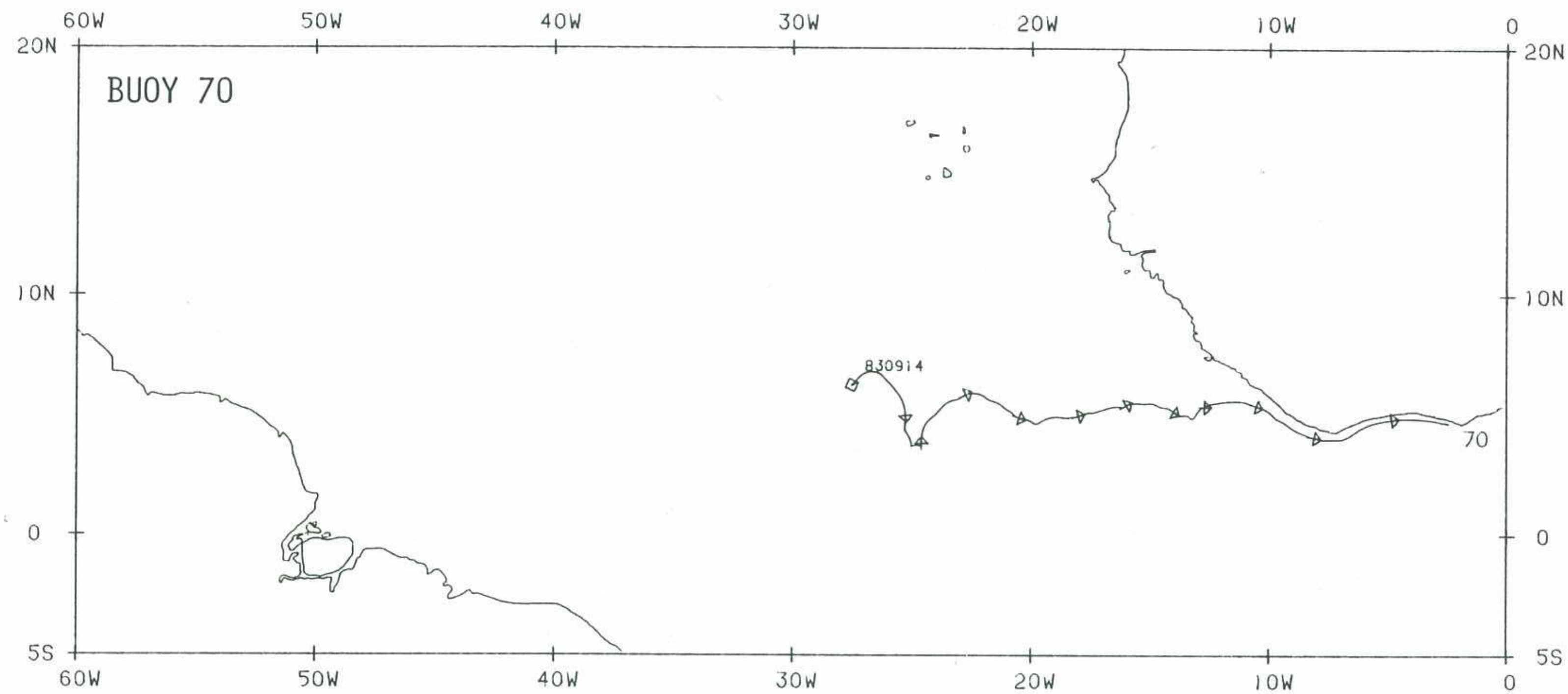

V
100.0
0.0
-100.0
SEP
1983
OCT
U
100.0
0.0
-100.0
SEP
1983
OCT
HALF-HOUR SPEED
10.0
5.0
0.0
SEP
1983
OCT
TEMPERATURE
31.0
28.0
25.0
SEP
1983
OCT

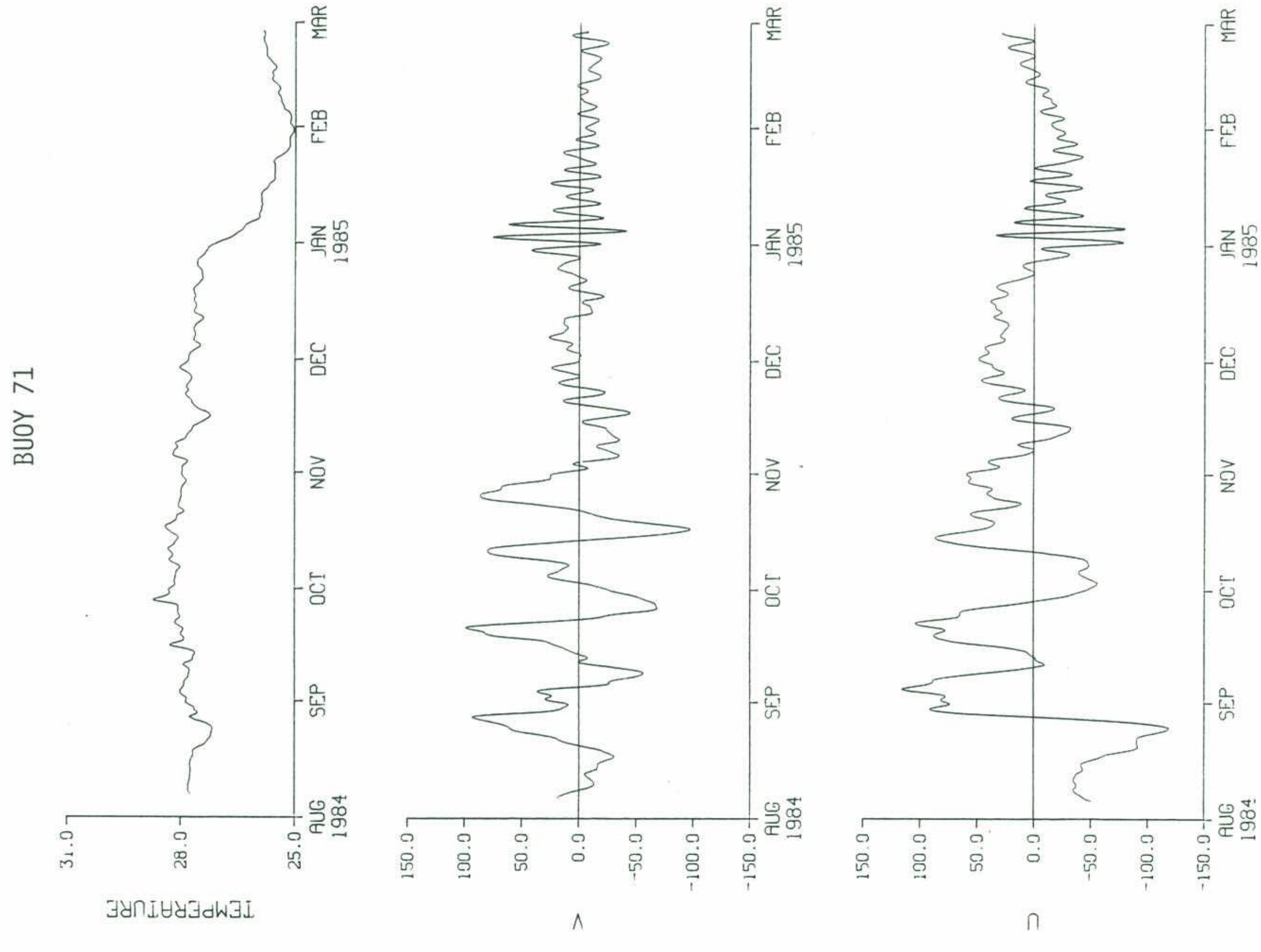


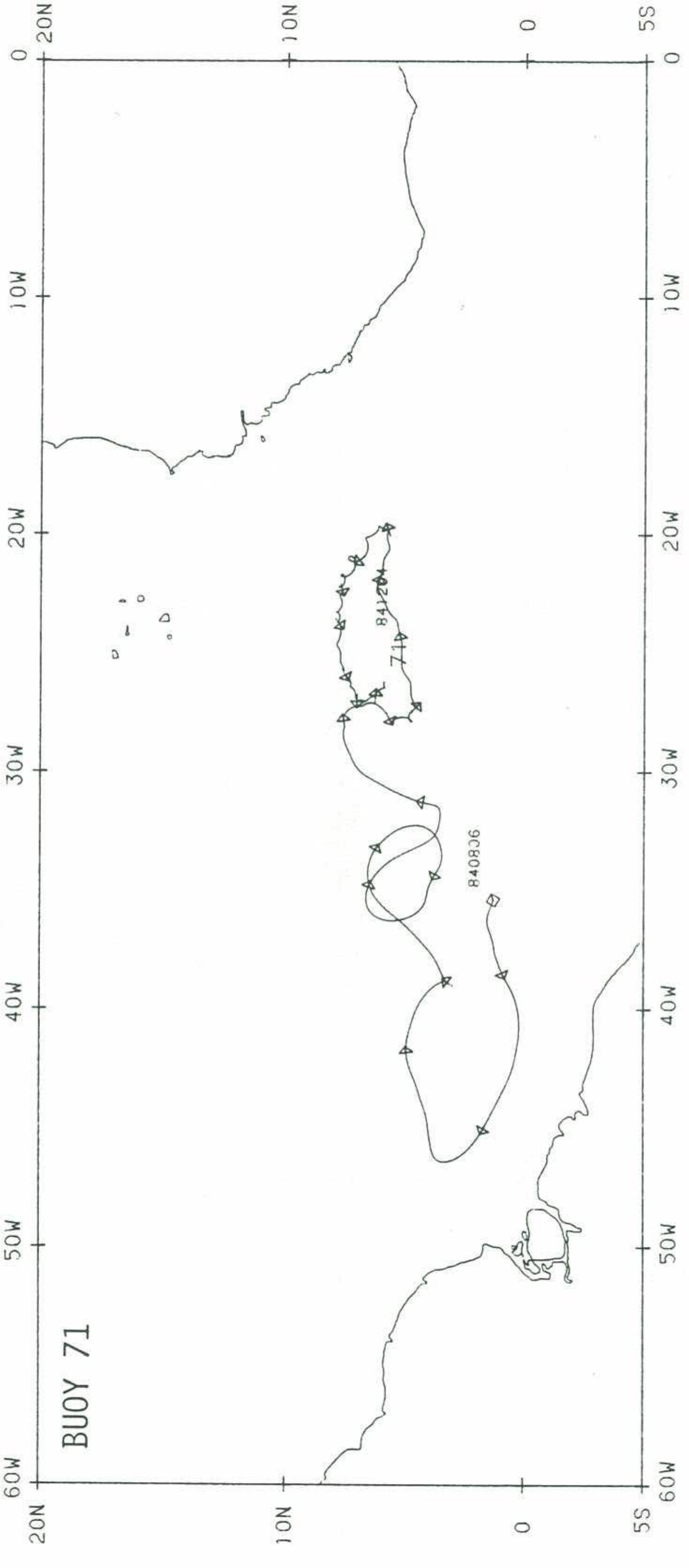
BUOY 69
830910
69
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

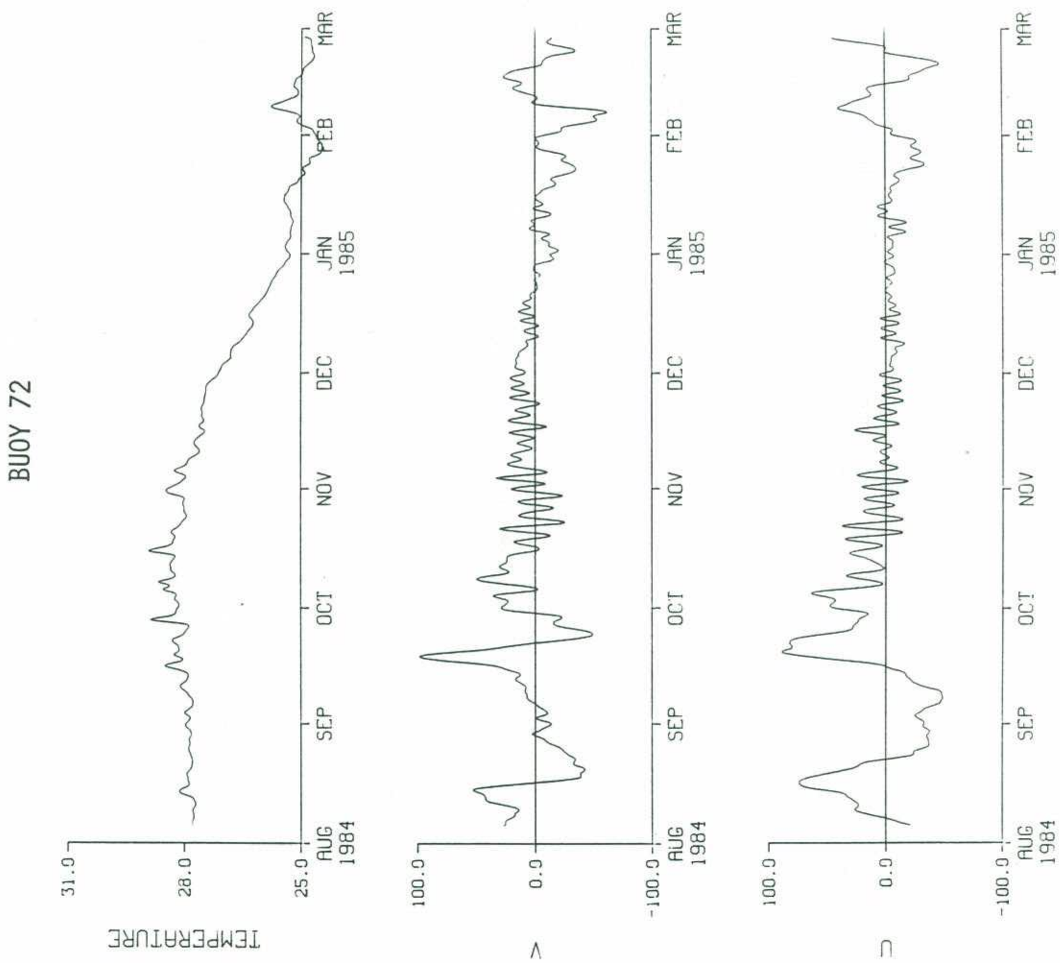
BUOY 70

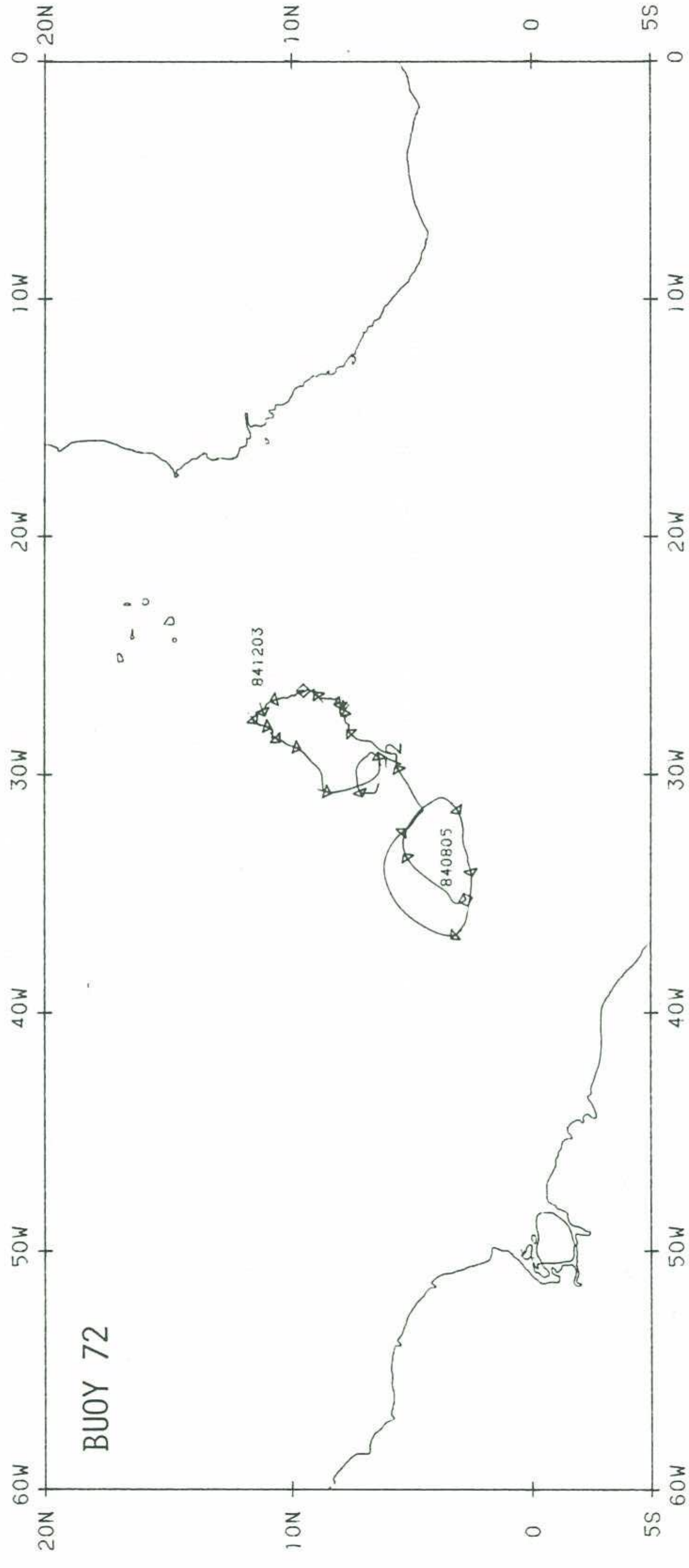

HALF-HOUR SPEED
10.0
5.0
0.0
TEMPERATURE
31.0
28.0
25.0
V
U
100.0
0.0
-100.0
SEP 1983
OCT
NOV
DEC
JAN 1984
FEB

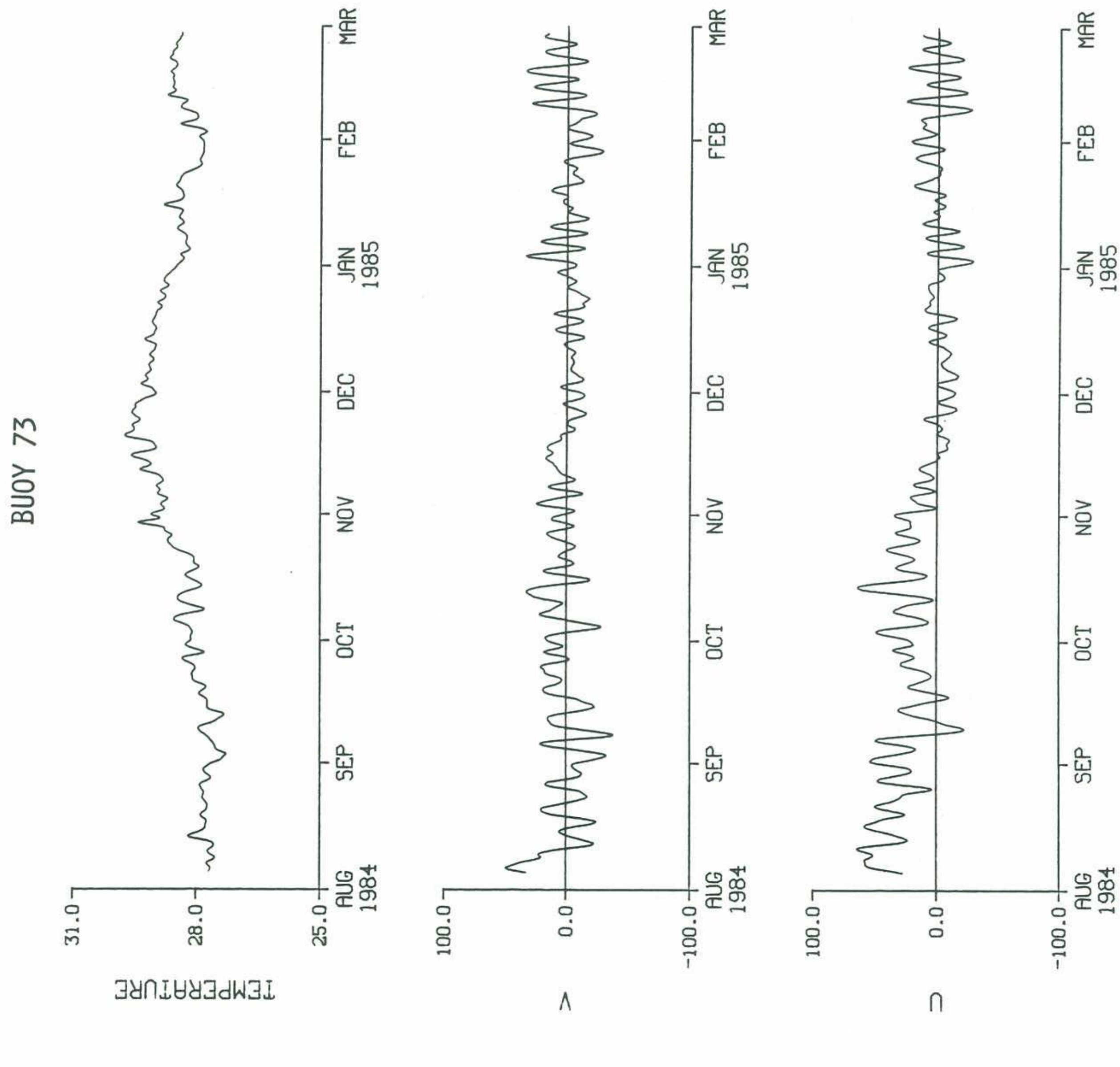

BUOY 70
60W
50W
40W
30W
20W
10W
0
20N
10N
0
5S
830914
70

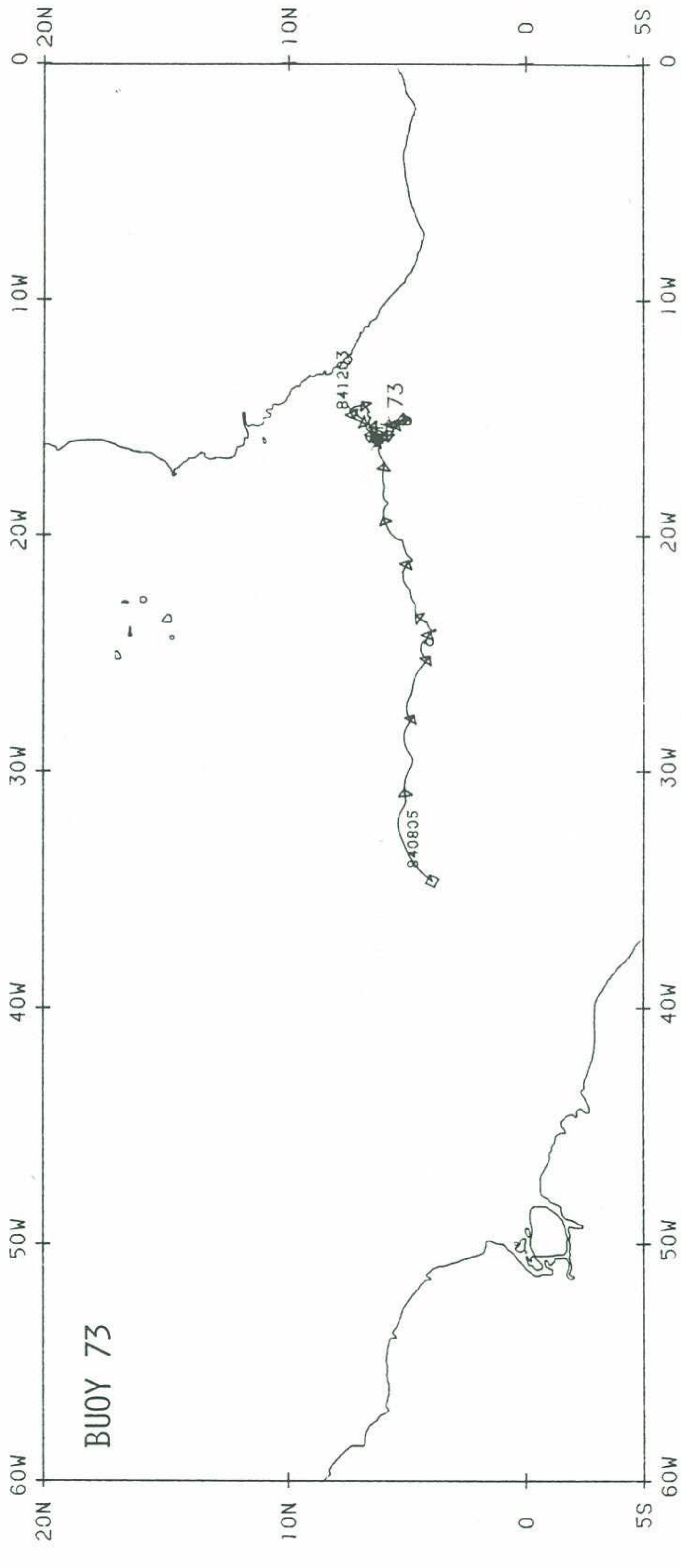

BUOY 71
TEMPERATURE
31.0
28.0
25.0
V
U
150.0
100.0
50.0
0.0
-50.0
-100.0
-150.0
AUG 1984
SEP
OCT
NOV
DEC
JAN 1985
FEB
MAR

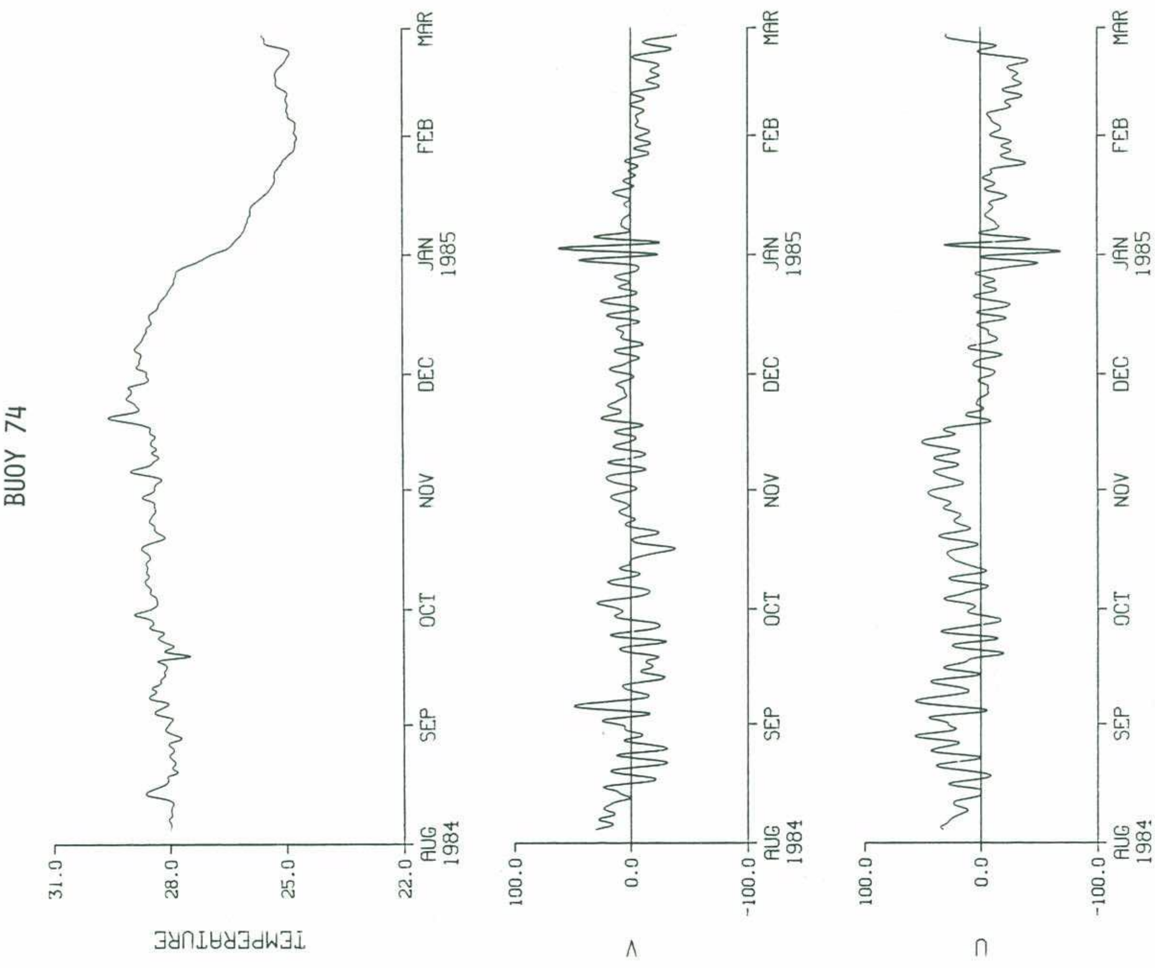

BUOY 71
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W
841204
71
840806

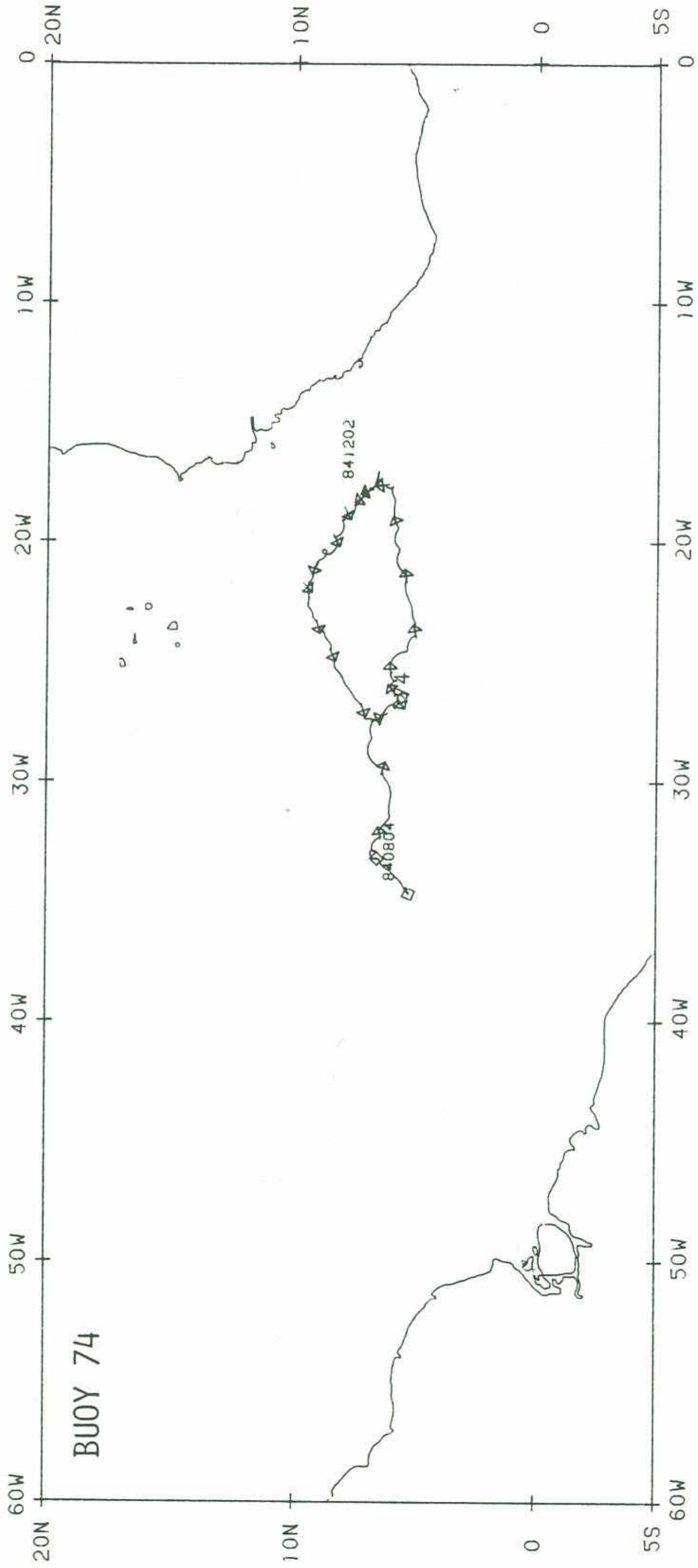

BUOY 72
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
AUG 1984
SEP
OCT
NOV
DEC
JAN 1985
FEB
MAR


BUOY 72
841203
840805
20N
10N
0
5S
60W
50W
40W
30W
20W
10W
0


BUOY 73
TEMPERATURE
31.0
28.0
25.0
V
100.0
0.0
-100.0
U
100.0
0.0
-100.0
AUG 1984
SEP
OCT
NOV
DEC
JAN 1985
FEB
MAR


BUOY 73
841203
840805
73
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W


BUOY 74
TEMPERATURE
31.0
28.0
25.0
22.0
V
U
100.0
0.0
-100.0
AUG 1984
SEP
OCT
NOV
DEC
JAN 1985
FEB
MAR


BUOY 74
841202
840804
20N
10N
0
5S
0
10W
20W
30W
40W
50W
60W

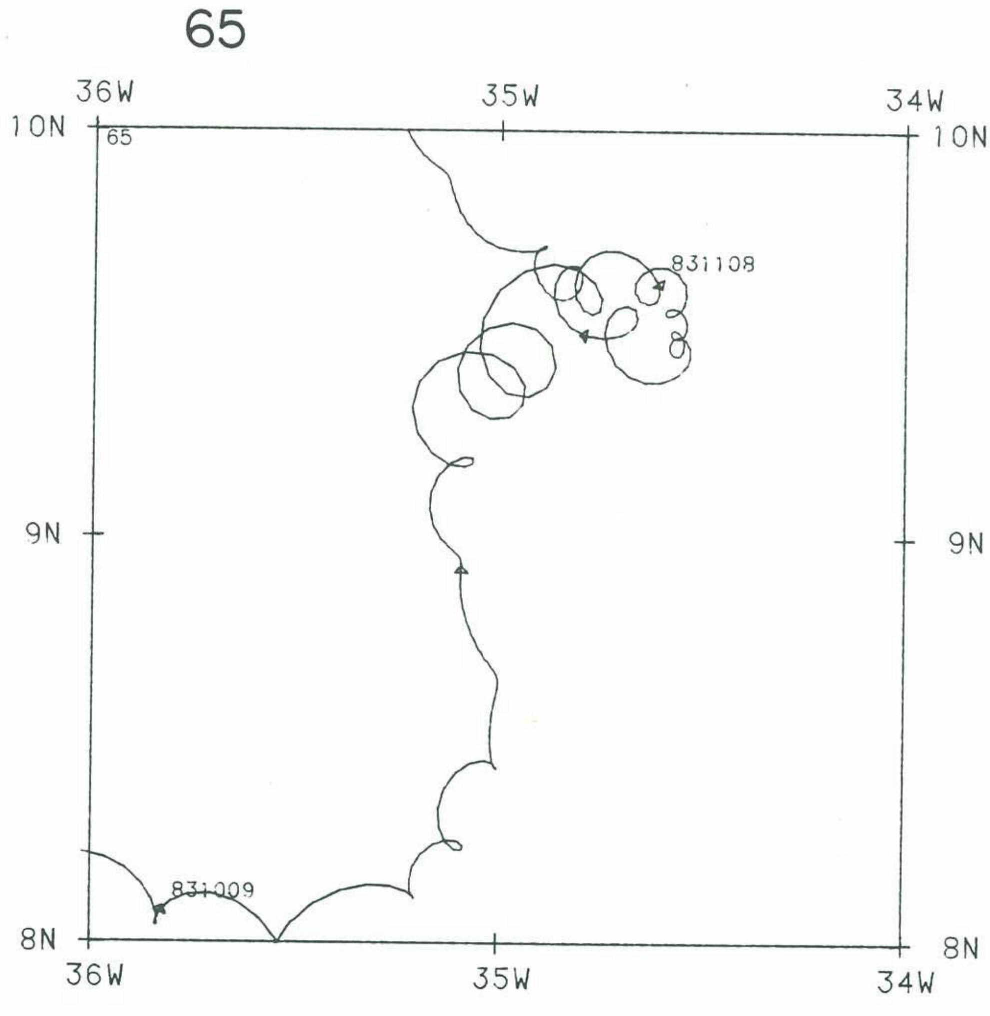


Figure 94: Trajectory of buoy 65. Individual loops have a period of approximately three days. Arrows are spaced at 15 days.

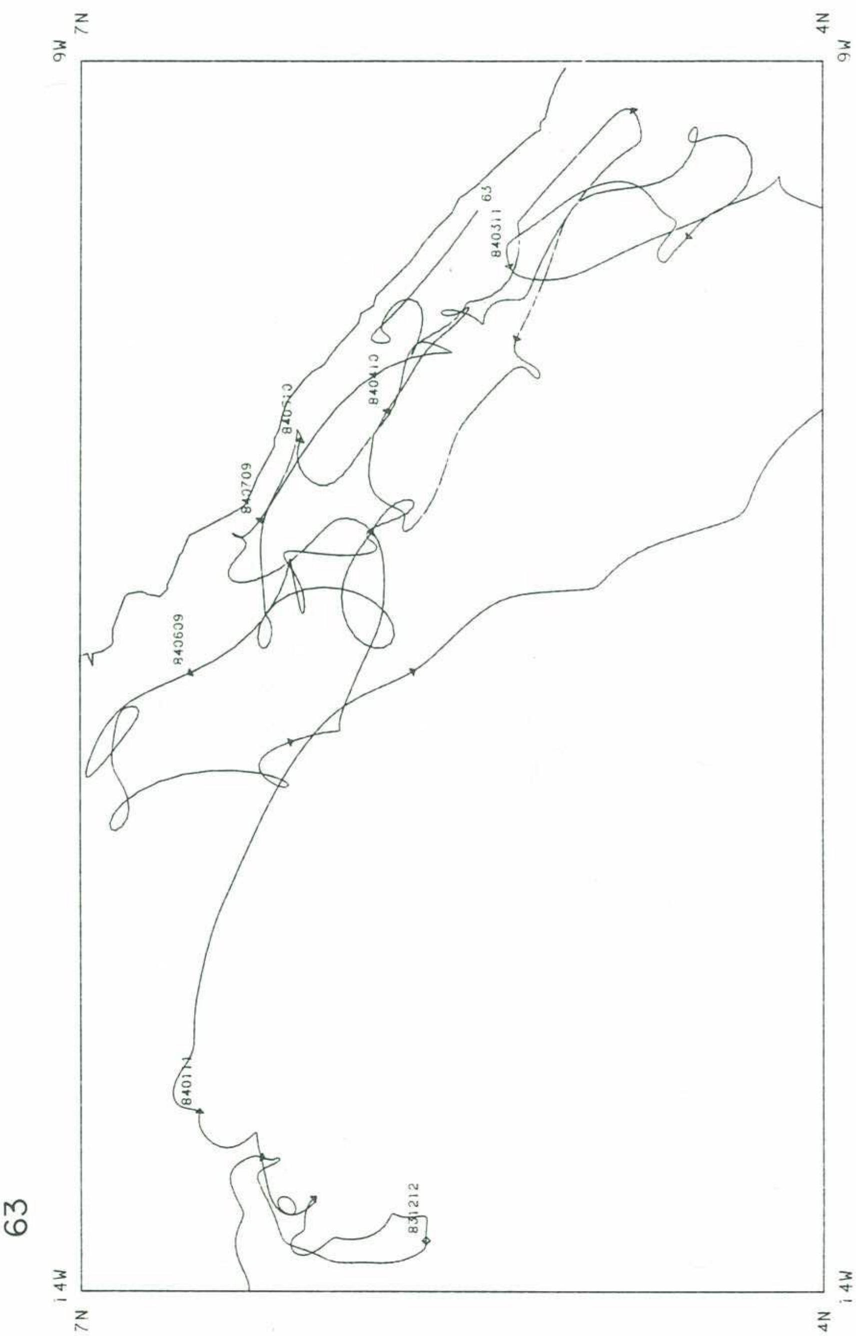


Figure 95: Trajectory of buoy 63 which hovered near the coast of Africa for eight months. Arrows are spaced at 15 days.

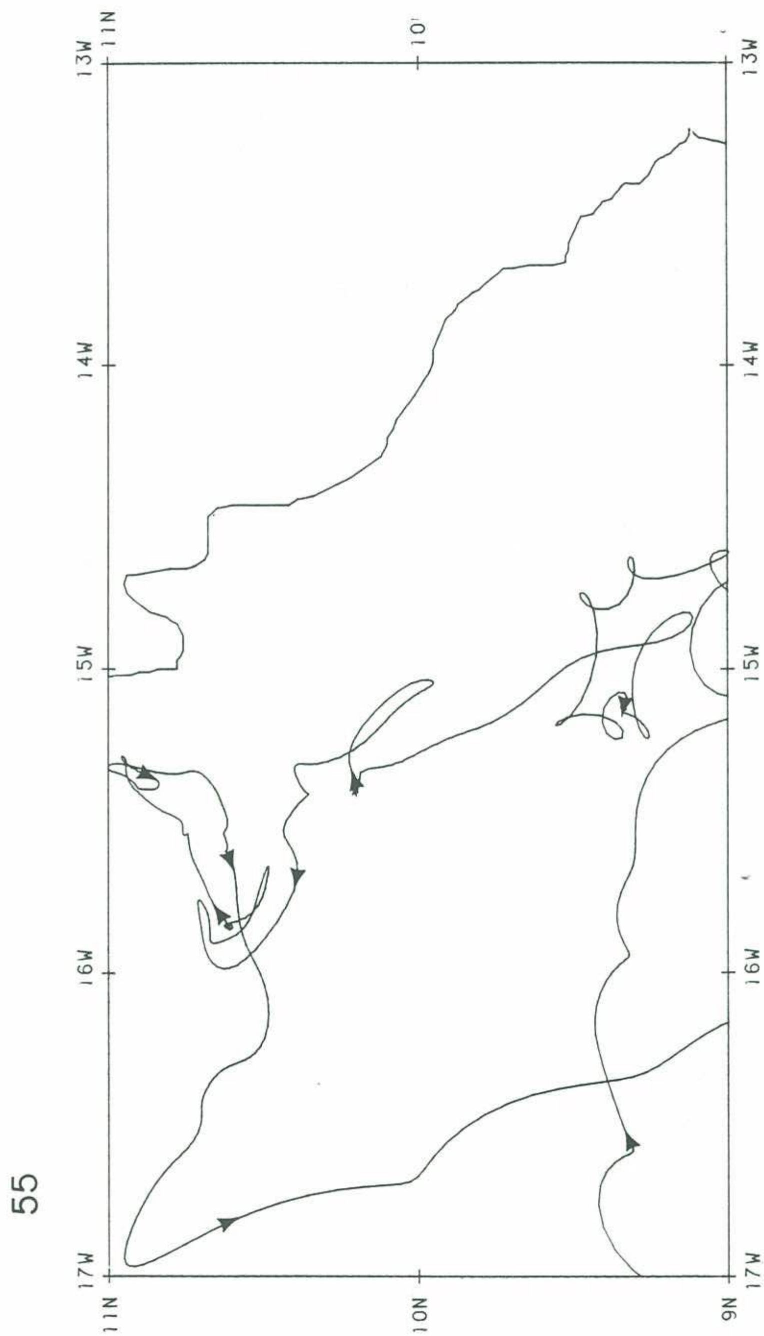


Figure 96: Trajectory of buoy 55 off the coast of Africa (smoothed with a two-day Gaussian filter).

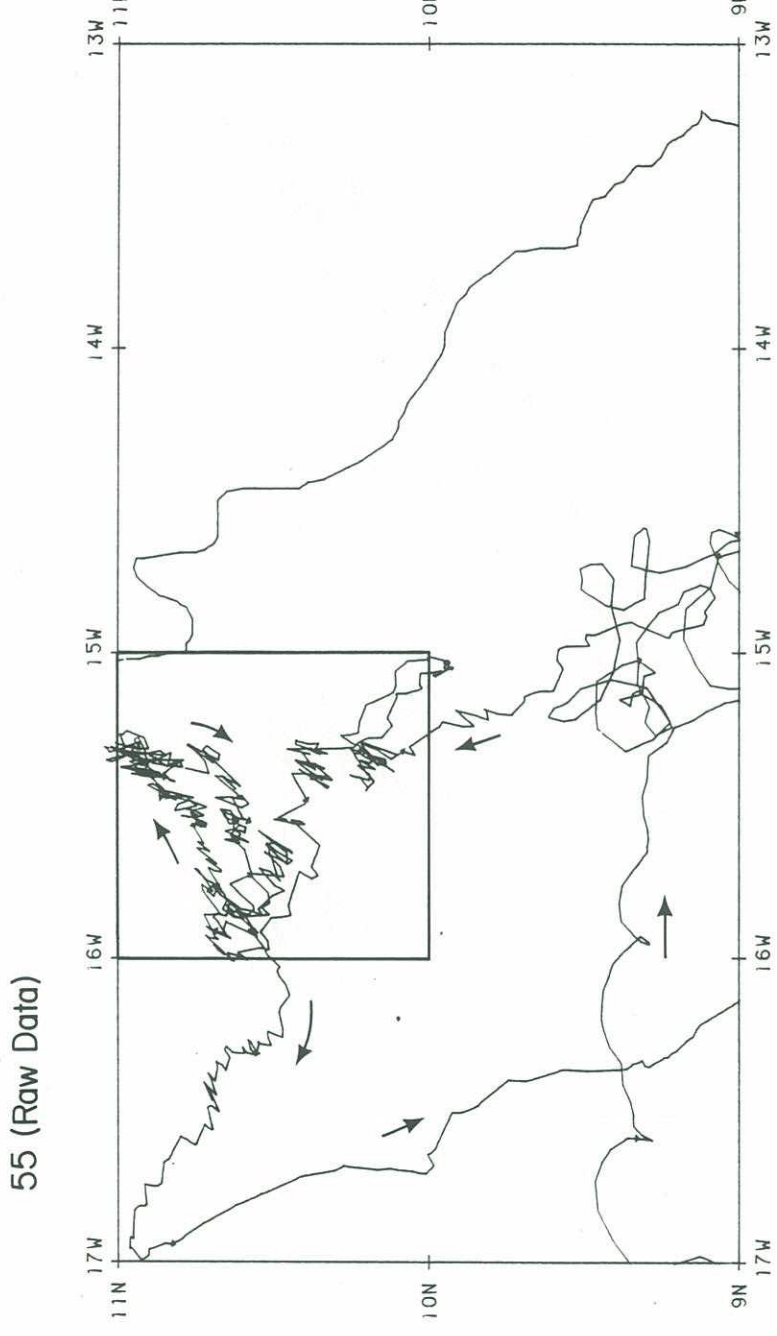


Figure 97: Trajectory (unsmoothed) of buoy 55 showing tidal fluctuations. The trajectory in the box 10-11N, 15-16W is given in Figure 98.

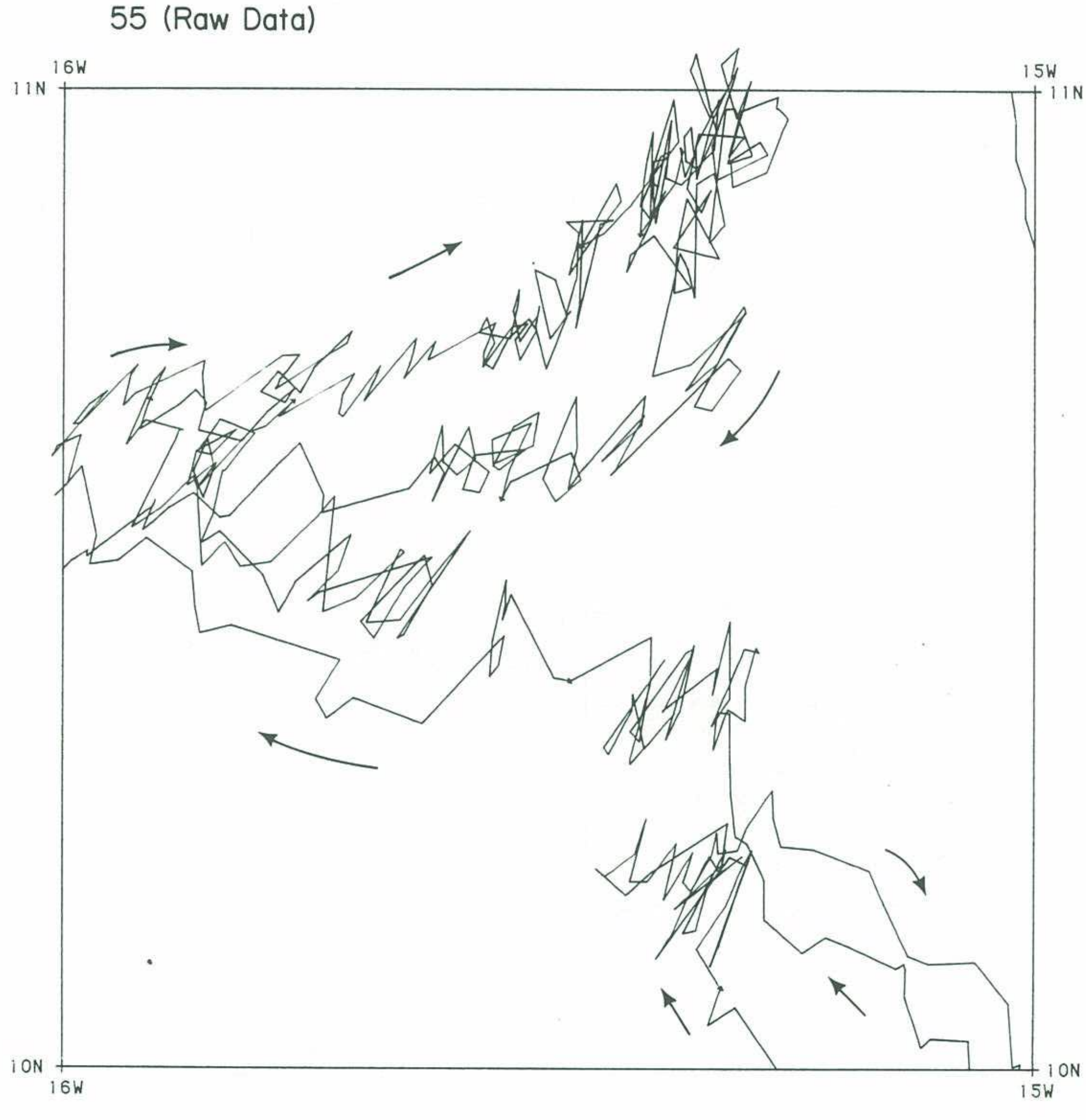


Figure 98: Unsmoothed trajectory of buoy 55 on the continental shelf off Guinea-Bissau showing tidal fluctuations.

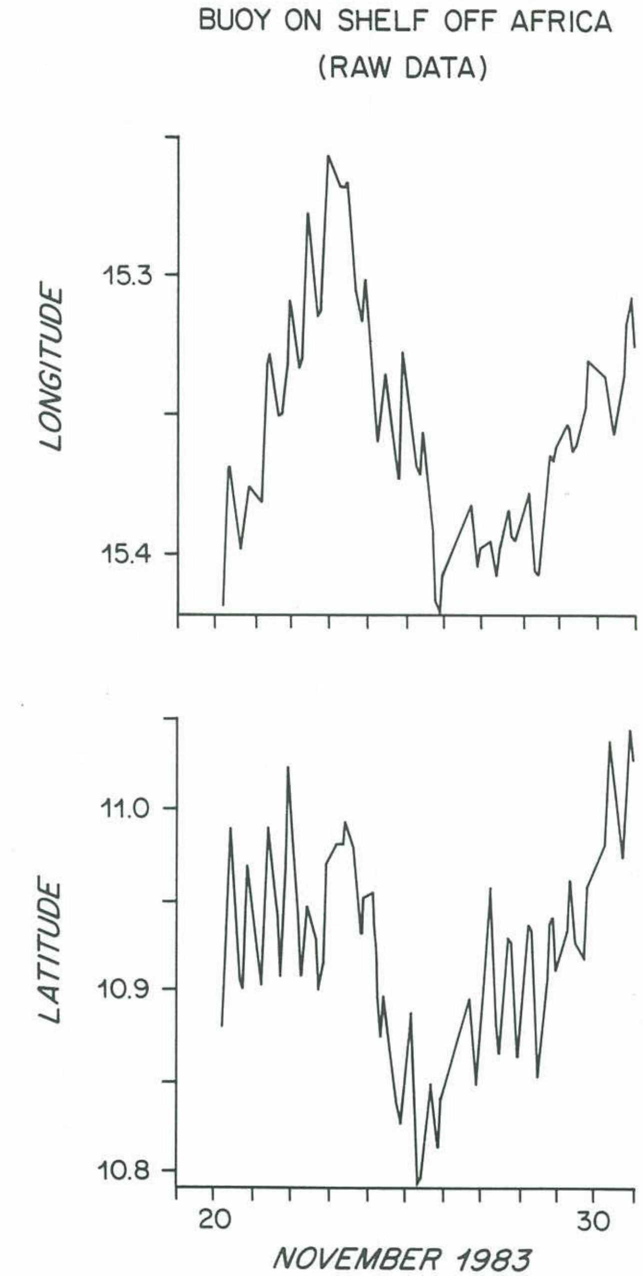


Figure 99: Time series (unsmoothed) of latitude and longitude of buoy 55 on the continental shelf off Guinea-Bissau showing strong semi-diurnal tidal variations.

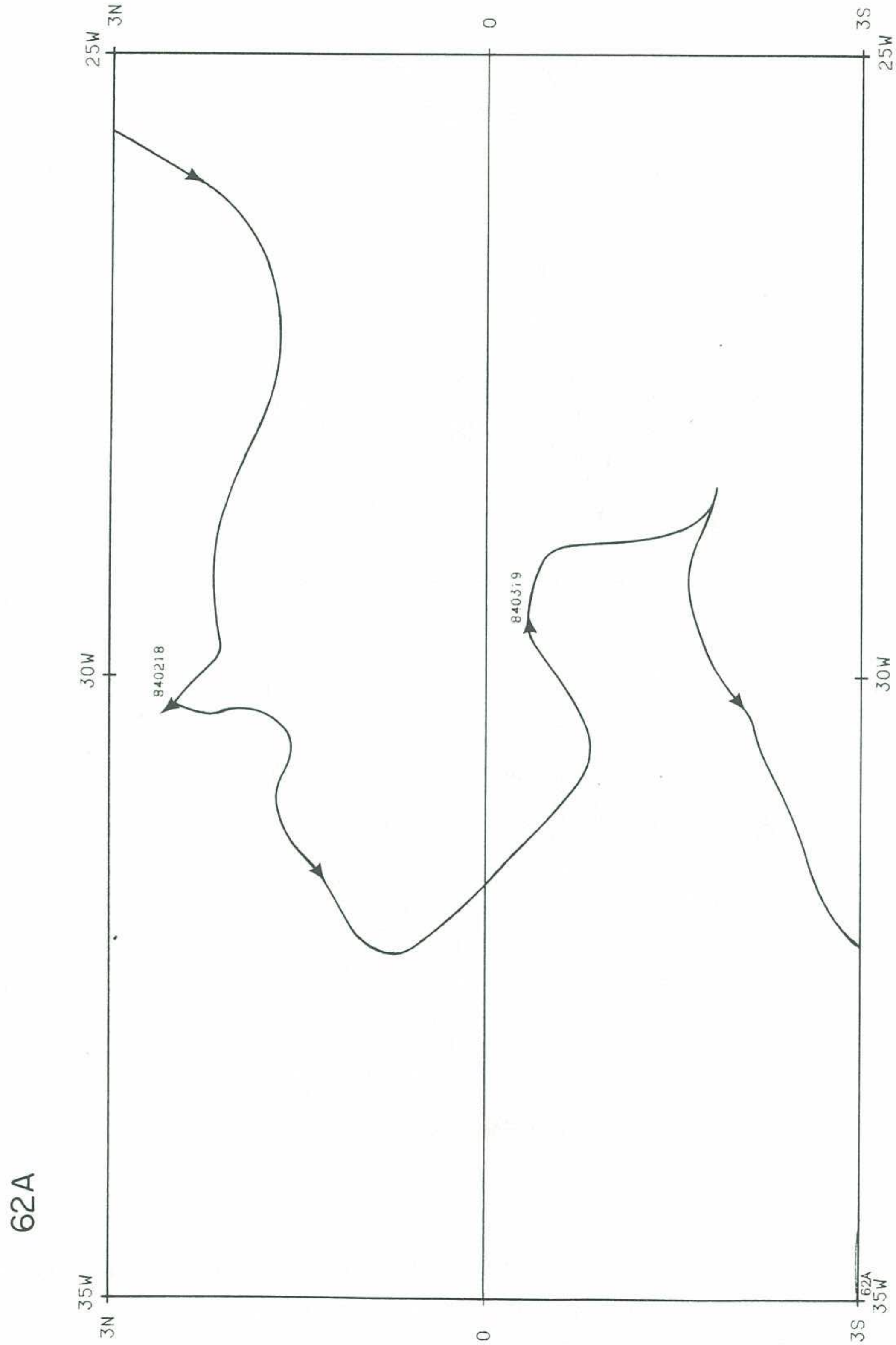


Figure 100: Eastward drift along the equator from March 8 to 27, 1984, of buoy 62A.

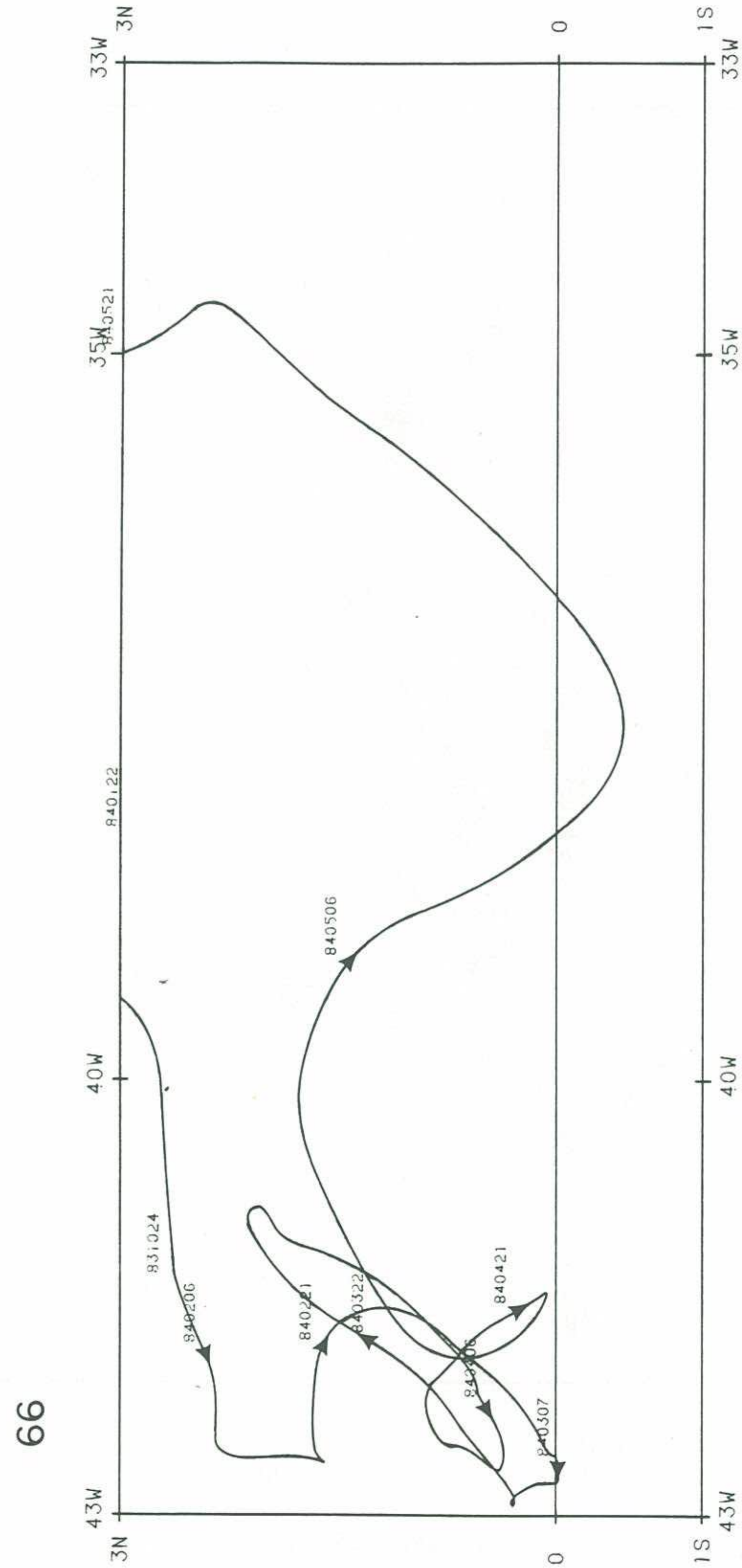


Figure 101: Eastward drift along the equator from April 28 to May 19, 1984, of buoy 66.

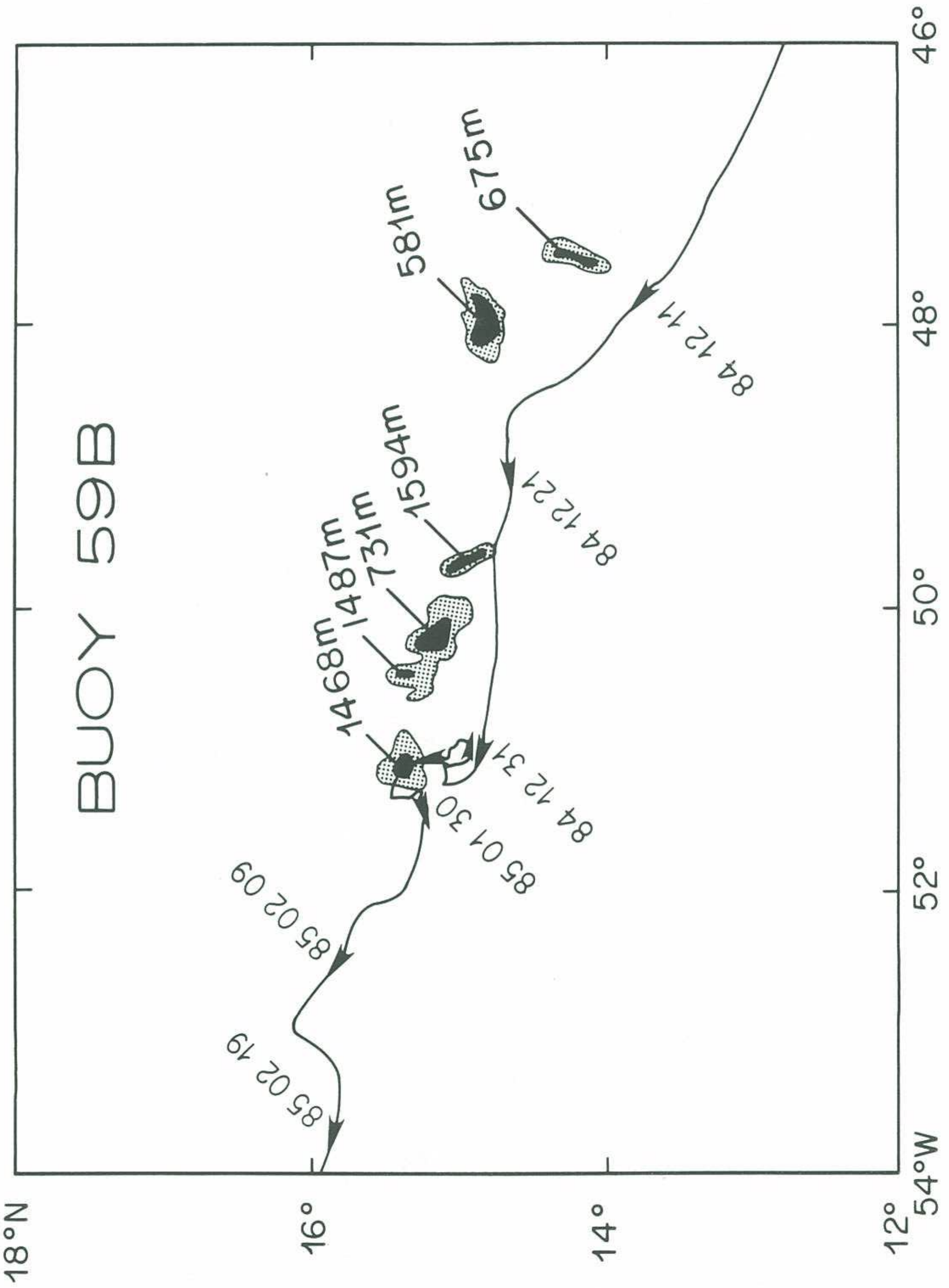


Figure 102: Trajectory of buoy 59B that was drifting in the North Equatorial Current but stalled for a month near some seamounts. Depths less than 2000 m are black and between 2000 m and 3000 m are stippled (of the prominent seamounts). Other buoys in the NEC and also this one when it was not near the seamounts drifted westward quite steadily (see Figure 24).

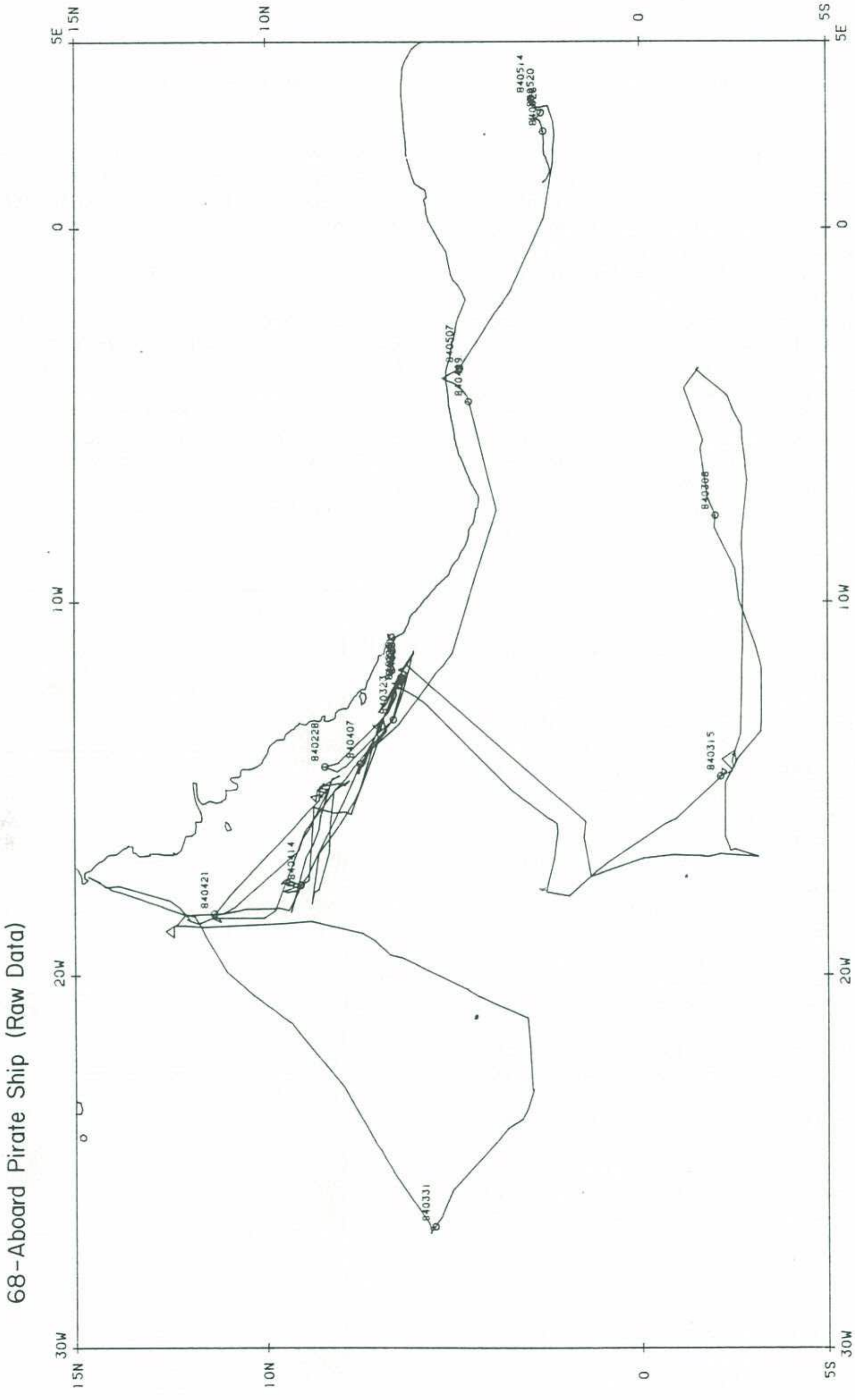


Figure 103: The trajectory (unsmoothed) of buoy 68 after it was stolen.

GEOPHYSICAL RESEARCH LETTERS, VOL. 11, NO. 8, PAGES 745-748, AUGUST 1984

DRIFTING BUOY TRAJECTORIES IN THE ATLANTIC NORTH EQUATORIAL COUNTERCURRENT DURING 1983

P. L. Richardson

Physical Oceanography Department, Woods Hole Oceanographic Institution

Abstract. During 1983, 21 freely drifting buoys measured trajectories in the vicinity of the Atlantic North Equatorial Countercurrent. These provide a visualization of the flow field and the first direct measure of the seasonal variation of the velocity during a single year. From February to May the buoys moved gradually westward. From June to December the buoys moved swiftly eastward with maximum speeds of 90 cm sec^{-1} located in the western Atlantic. The seasonal variation in current was similar to that measured by historical ship drifts except that the onset of the Countercurrent in 1983 was about a month earlier than usual. Of the buoys that drifted eastward in the Countercurrent, three went into the North Equatorial Current, two into the South Equatorial Current and seven into the Guinea Current.

Introduction

Historical ship drifts and subsurface temperatures show that the Atlantic North Equatorial Countercurrent undergoes an enormous seasonal change [Schumacher, 1940; Richardson and McKee, 1984; Garzoli and Katz, 1983]. In summer and fall the Countercurrent flows swiftly eastward across the Atlantic (between 5-10N approximately) and into the Guinea Current. In winter and spring the Countercurrent disappears west of 20W and the velocity becomes westward. Aside from ship drifts, the only direct current measurements in the Countercurrent are some short time current meter series during GATE [Bubnov and Egorikhin, 1979; Halpern, 1980] and a few drifting buoys [Cochrane, personal communication; Molinari, 1983]. No direct measurements exist that give current variations over a single year.

The purpose of the present experiment is to directly measure the seasonal variation in the Countercurrent and to relate this to the variation of wind forcing. During 1983 drifters were launched at several sites and times and current meters were moored in the Countercurrent. The preliminary drifter trajectories described here give a visualization of the velocity field during 1983 and its seasonal variation.

Measurements

Twenty-one satellite tracked freely drifting buoys were deployed -- seven in February and early March, two in April, three in July and nine in September. The buoys were made by Polar Research Laboratory, had partially floating tethers, window shade drogues at 20 m, and sea surface thermometers; thirteen had anemometers. Approximately five positions per day per buoy are being obtained. Weekly positions are used here in order to present recent results concerning the large scale and long time character of the currents.

Results

Trajectories are displayed three different ways. Figure 1 shows clusters of trajectories of buoys launched together with a few additional ones that passed near the launch locations and times. Figure 2 shows monthly summaries of all trajectories. Figure 3 shows time-longitude trajectories of buoys located in the Countercurrent region 4-9N.

Seven buoys were launched in February and

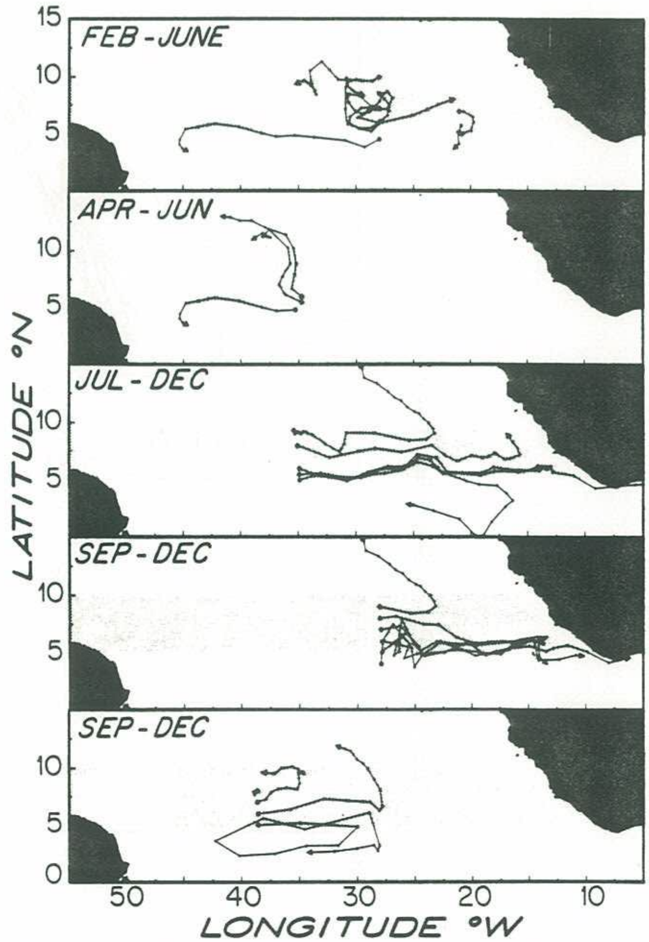


Fig. 1. Trajectories of 21 freely drifting satellite-tracked buoys launched in the vicinity of the North Equatorial Countercurrent during February, April, July and September 1983. Dots are spaced at approximately weekly intervals. Shading indicates the general location of the Countercurrent during summer and fall.

Paper number 4L6091.
0094-8276/84/004L-6091$03.00

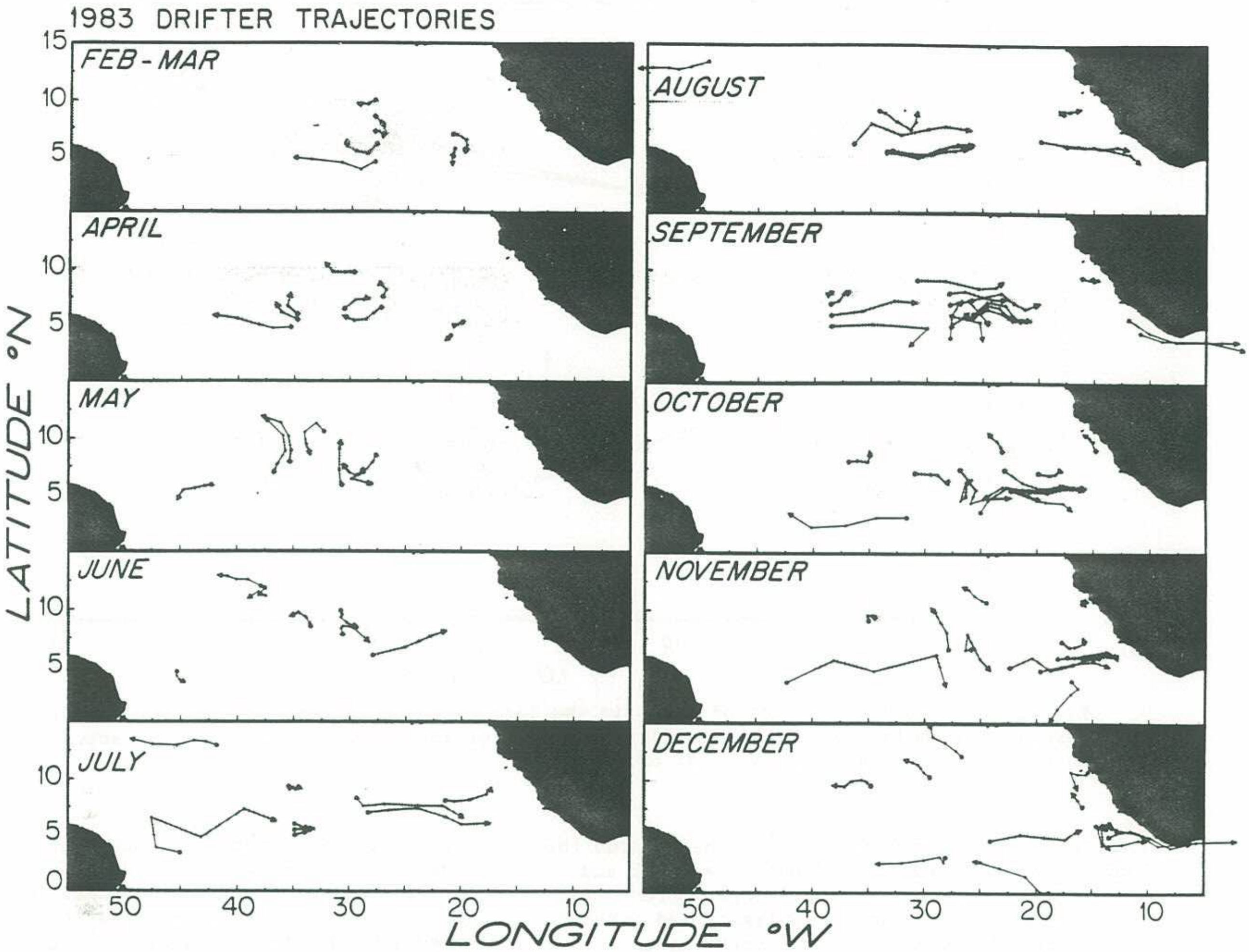


Fig. 2. Monthly trajectories during 1983 of 21 drifting buoys. In May and June buoys began to move eastward in the Countercurrent. Some buoys continued eastward through December.

March (Figure 1, panel 1). The northern buoy drifted westward at 10 cm sec^{-1} in the North Equatorial Current (NEC), and the southern buoy drifted westward at 30 cm sec^{-1} in the South Equatorial Current (SEC). Both buoys subsequently entered the Countercurrent in July. Two buoys near 20W went southward toward the SEC but both died prematurely. From February to May the three middle buoys launched in the vicinity of the Countercurrent at 28W drifted gradually westward at 1-3 cm sec^{-1}, more slowly than the buoys in the NEC and SEC. The three trajectories are dominated by mesoscale eddy motions. An inspection of trajectories (and velocities) shows fluctuations that have a characteristic speed of 10-20 cm sec^{-1}, diameter of a few hundred km, and period of a few months. In May and June these three buoys began to drift eastward as the Countercurrent accelerated. All three continued into the Gulf of Guinea, two in September, and one in 1984.

In April two buoys were launched along 35W (Figure 1, panel 2); they drifted northward through the Countercurrent region and turned westward in the NEC north of 10N. One drifted westward and went aground on Martinique in September; the other died prematurely. The southern buoy (Figure 1, panel 2) entered the Countercurrent in July and reappears as the second to northernmost buoy in Figure 1, panel 3.

In May the trajectories in the vicinity of the Countercurrent had a strong meridional component -- southward at 28W, northward at 31W, southward at 34W, northward at 36W. This suggests spatially periodic motion with a wavelength of about six degrees of longitude (Figure 2, panel 3).

In July eight buoys drifted eastward in the Countercurrent. The western one was fastest and meandered eastward with a speed up to 90 cm sec^{-1} and wavelength of about 6-7 degrees of longitude. This meandering may be caused by an instability associated with the strong shear between the Countercurrent and SEC. Three buoys were launched in July along 35W at 5.0N, 5.5N, and 6.0N. These three drifted eastward together at 30 cm sec^{-1} for two months without diverging from each other. One peeled off southward in October and entered the SEC; the other two continued eastward together into December. Of the five that drifted eastward across 35W in July (Figure 1, panel 3), two went into the NEC, one went into the Guinea Current, one went into the SEC, and one slowed near the Coast of Africa.

In September five buoys were launched along 28W and a sixth, the northern one in Figure 1, panel 4, was there by chance. All six moved

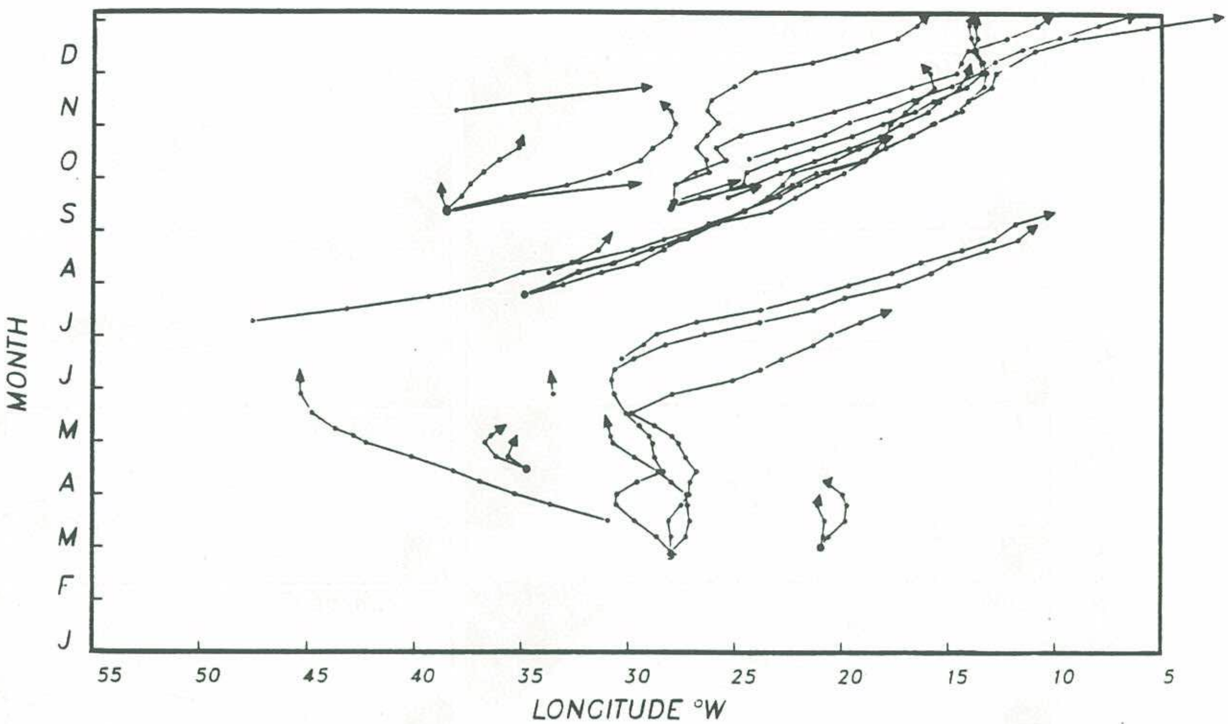


Fig. 3. Time-longitude plot of buoys in the latitude band of the Countercurrent, 4-9N. The zonal velocity is indicated by the direction and slope of the trajectories. The trajectories most nearly horizontal are the swiftest ones.

eastward in the Countercurrent. One entered the NEC, one died, one stalled near the coast and the other three entered the Guinea Current (two of them in 1984). During September and October one buoy was trapped for two months in an anticyclonic eddy centered near 6N, 27W. Three other buoys were deflected around it. The buoy in the eddy looped with a swirl of speed of 20 cm sec^{-1}, period of a month and diameter of 150 km.

Four buoys were launched in September along 38W (Figure 1, panel 5). The northern one was very slow and died prematurely. The next one south drifted slowly northeastward and entered the NEC. The two southern buoys drifted rapidly eastward with (weekly) average speeds up to 90 cm sec^{-1}. These two buoys left the Countercurrent near 25-30W. The northern one entered the NEC, and the southern one entered the SEC, drifted westward, entered the Countercurrent and repeated its earlier trajectory. The circulation time for the Countercurrent-SEC loops was about two months.

My interpretation of these trajectories and Figure 3 is that from September to November the eastward flow in the Countercurrent slowed or was blocked near 25-30W and that the Countercurrent was divided into a western and eastern region. The eastern Countercurrent continued to flow eastward at least through December, and the western Countercurrent continued at least through November, the last months that buoys were in the vicinity of the Countercurrent. Historical ship drifts agree with this result in that they show that the average monthly eastward velocity in the Countercurrent decreases to zero first near 25-30W (in December). The eastern Countercurrent (east of 20W) continues throughout the year, but the western Countercurrent has eastward flow only from July to January [Richardson and McKee, 1984].

The seasonal variation of zonal velocity in the Countercurrent centered near 6N, 28W measured with drifters is similar to that measured with a current meter at 20 m during 1983 and to that calculated from historical ship drifts (Figure 4). All three data sets show westward velocity during spring and eastward velocity during summer and fall. In comparison to the historical ship drifts, both drifters and the current meter have slower westward velocity in spring, faster velocity in summer, and an earlier onset of the Countercurrent (by about a month). The early onset of the Countercurrent is in accord with the onset of the winds near the equator and upwelling in the Gulf of Guinea both of which were 1-2 months earlier than usual in 1983 [Garzoli and Katz, 1984; Houghton, 1984]. The differences in velocity between drifters and current meter are mainly due to differences of the space-time averages of drifters in a 3 by 10 degree box versus the time average of current meter values at a point. When a drifter passes close to the current meter their velocities agree closely.

Summary and Conclusions

The trajectories show that the Countercurrent had disappeared from February to May and that generally westward velocity occurred. At this time the central region of the Countercurrent had a slower westward velocity than the nearby NEC and SEC. In May and June the buoys drifted eastward as the Countercurrent accelerated. From September to at least November the eastward drift of buoys in the Countercurrent was disrupted near

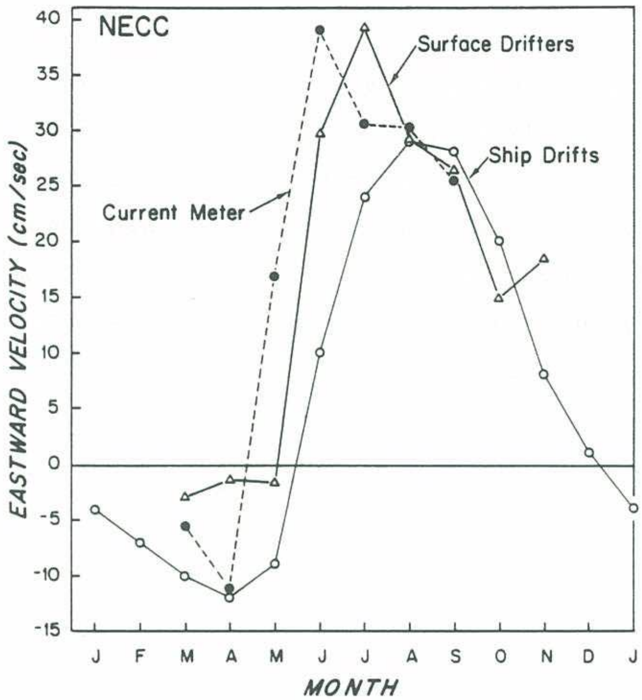


Fig. 4. Seasonal variation of near-surface zonal velocity in the Countercurrent during 1983. Monthly averages are from a current meter at 20 m near 6N, 28W, drifting buoys located in a box whose limits are 5-8N, 23-33W. Also shown is the long-term average zonal velocity from historical ship drifts in a box bounded by 5-8N, 25-30W.

25-30W. Both east and west of this location the Countercurrent continued to flow eastward. The western Countercurrent was fastest with drift velocities up to 90 cm sec^{-1}.

During the period February-May when the Countercurrent had disappeared and the mean zonal velocity was weak, the trajectories were dominated by mesoscale eddy motion. Eddy motion was also observed near 25-30W as the Countercurrent decayed during the fall (September-November). During the period June-August the mean eastward velocity in the Countercurrent was 30-40 cm sec^{-1}, larger than the mesoscale velocity, and trajectories were more nearly linear.

Acknowledgements. This is Contribution Number 5624 from the Woods Hole Oceanographic Institution. Funds were provided by National Science Foundation Grant OCE82-08744. Many SEQUAL and FOCAL participants helped to launch the buoys from the R/V CAPRICORNE, R/V CONRAD and R/V KNORR. Chief Scientists were E. Katz, P. Hisard and C. Henin. T. K. McKee made calculations and plotted trajectories, D. Carson drafted the figures, and M. A. Lucas typed the manuscript.

References

Bubnov, V. A. and V. D. Egorikhin, Study of water circulation in the tropical Atlantic, Deep-Sea Res., GATE Suppl. II to V, 26, 125-136, 1979.

Garzoli, S. L. and E. J. Katz, The forced annual reversal of the Atlantic North Equatorial Countercurrent, J. Phys. Oceanogr., 13, 2082-2090, 1983.

Garzoli, S. L. and E. J. Katz, Winds at St. Peter and St. Paul rocks during the first SEQUAL year, Geophys. Res. Lett. (this issue), 1984.

Halpern, D., Variability of near-surface currents in the Atlantic North Equatorial Countercurrent during GATE, J. Phys. Oceanogr., 10, 1213-1220, 1980.

Houghton, R. W., Seasonal variation of Gulf of Guinea thermostructure, Geophys. Res. Lett. (this issue), 1984.

Molinari, R. L., Satellite-tracked drifting buoy observations of near-surface currents and temperature in the central and western tropical Atlantic Ocean, J. Geophys. Res., 88, 4433-4438, 1983.

Richardson, P. L. and T. K. McKee, Average seasonal variation of the Atlantic Equatorial Currents from historical ship drifts, J. Phys. Oceanogr., in press, 1984.

Schumacher, A., Monatskarten des oberflachenstromungen im Nordatlantischen Ozean, Annalen der Hydrographie und Maritimen Meteorologie, 68, 109-123, 1940.

P. L. Richardson, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543

(Received February 24, 1984;
revised May 23, 1984;
accepted May 25, 1984.)

APPENDIX 2

The following figures show data after March 1, 1985, the cut-off date for most plots in this data report. Figure 104 shows all SEQUAL trajectories from March 1 to June 30, 1985. Values were smoothed with a two-day filter. Figures 105-108 show monthly summaries of trajectories. Values were smoothed with a two-day filter. Figure 109 shows a reversal of the Guinea Current from April 11 to May 11, 1985, as measured by buoy 73. This is the only buoy that drifted westward in the Guinea Current. Figure 110 shows time series from buoy 73.

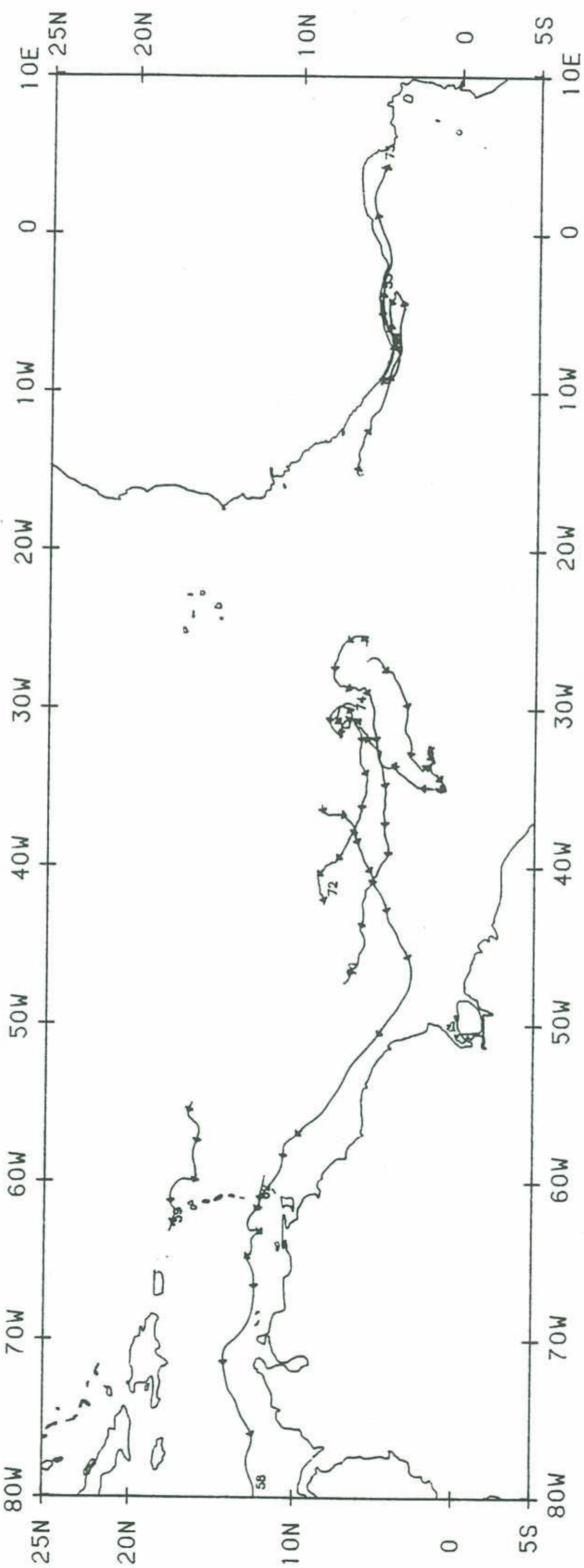


Figure 104: Trajectories, March 1-June 30, 1985.

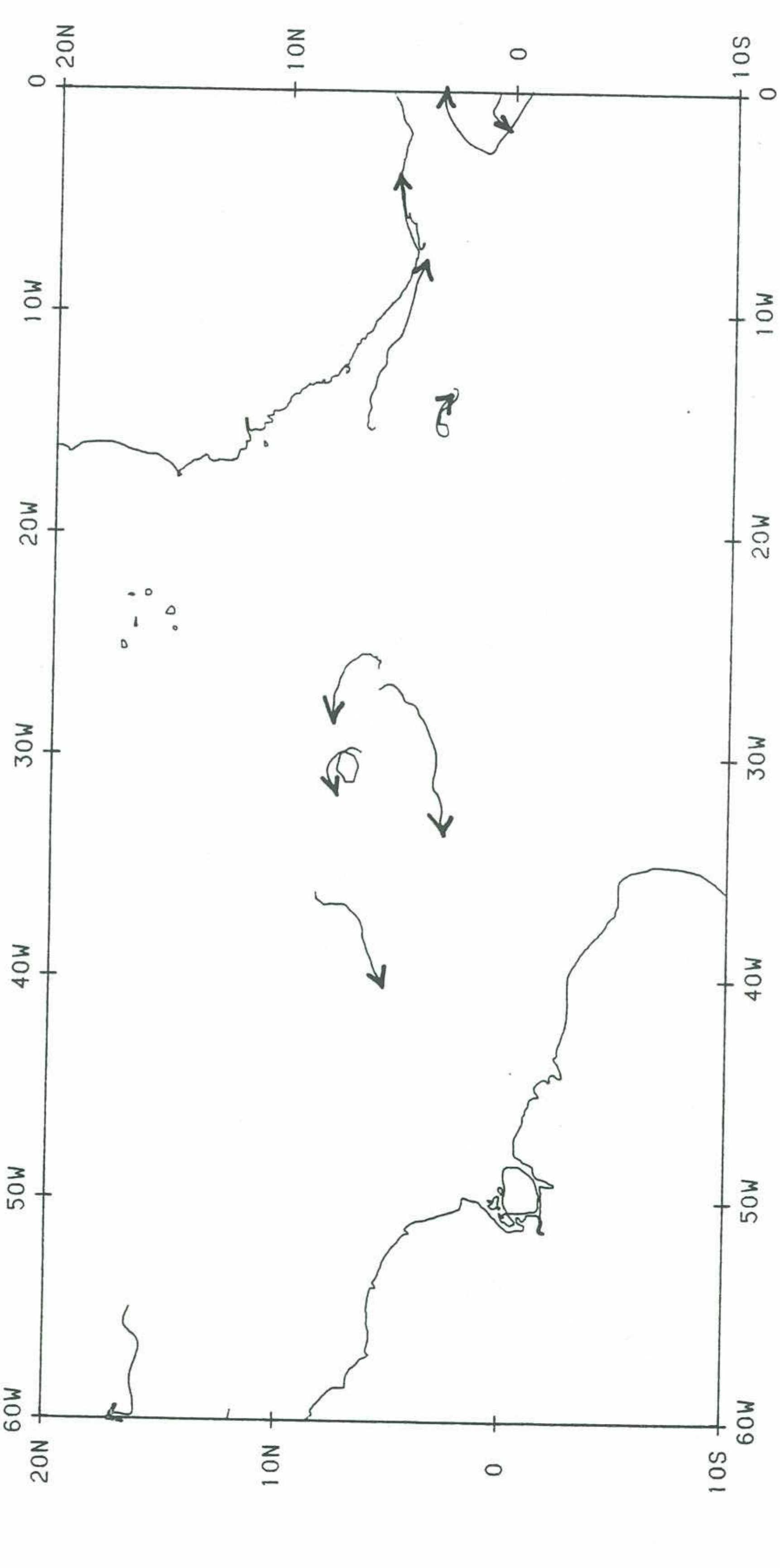


Figure 105: March 1985 trajectories.

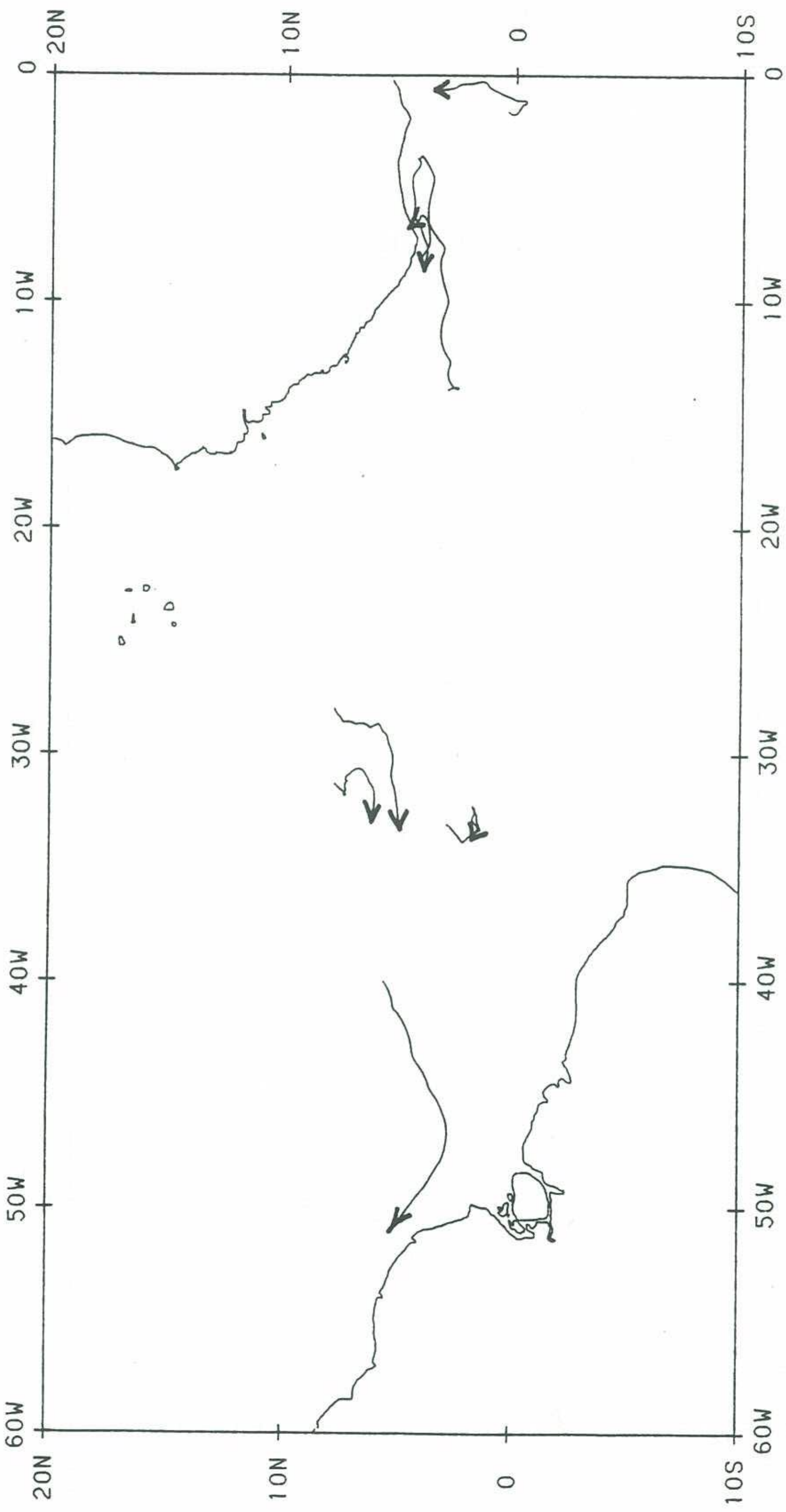


Figure 106: April 1985 trajectories.

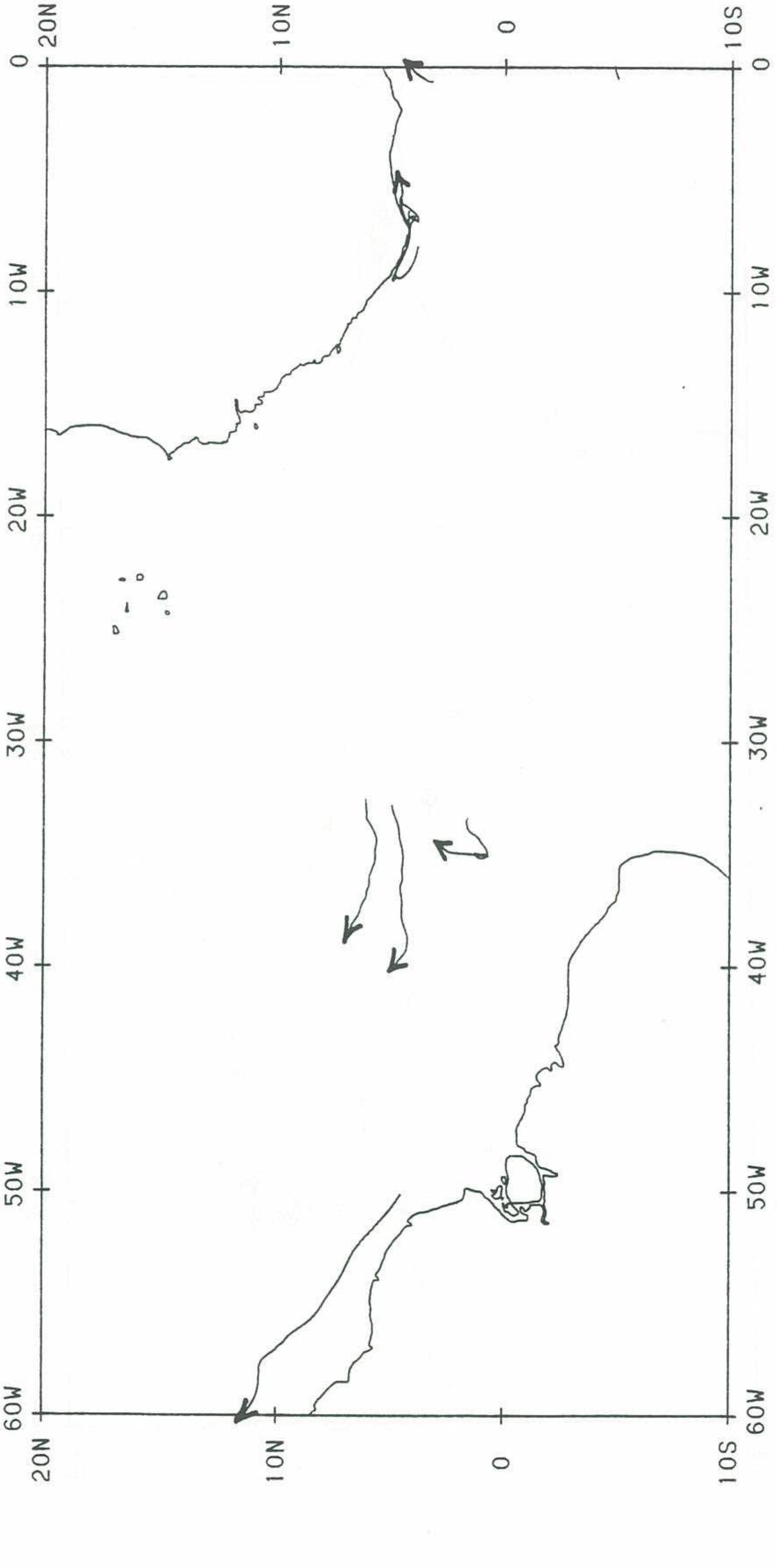


Figure 107: May 1985 trajectories.

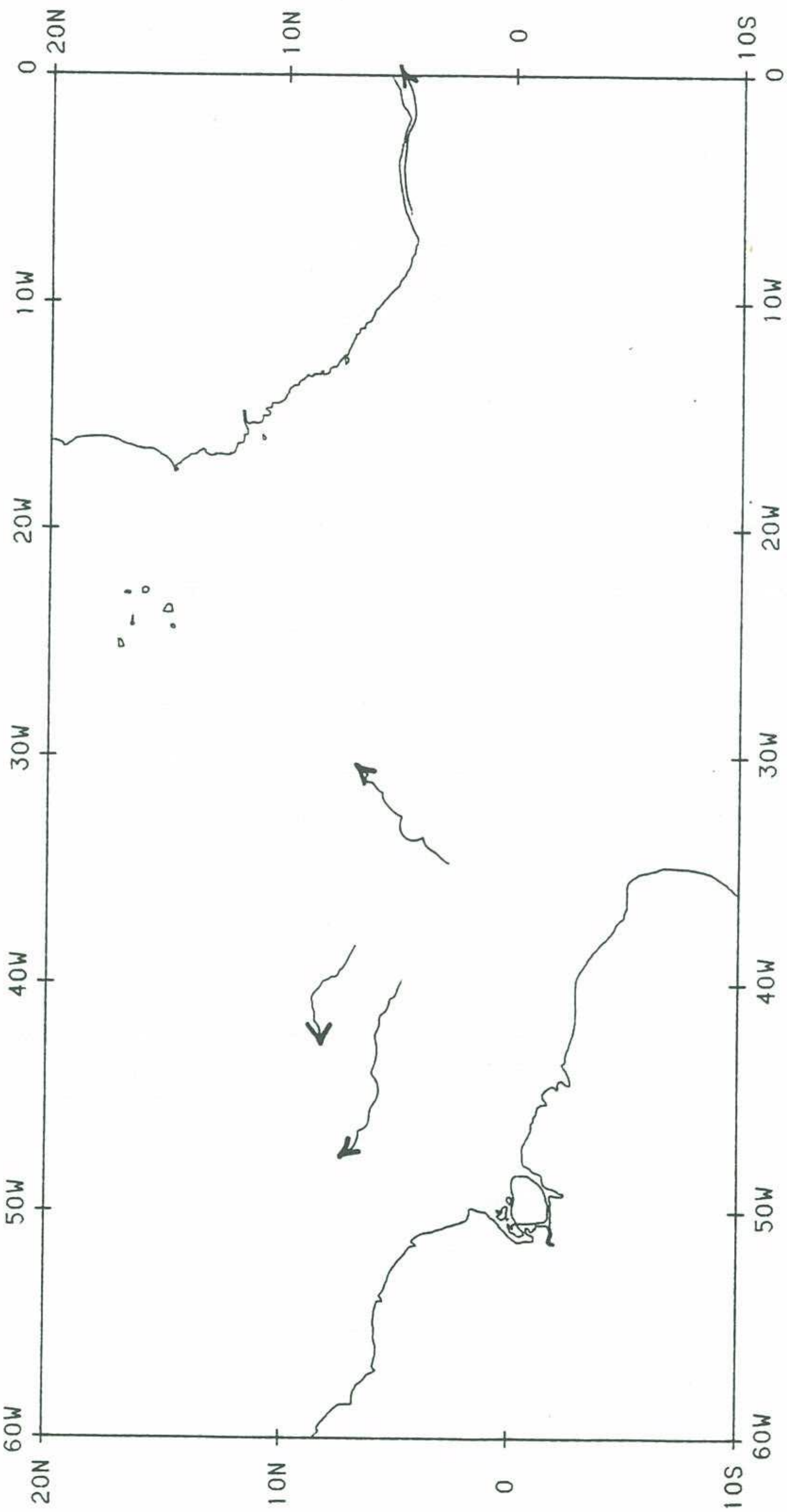


Figure 108: June 1985 trajectories.

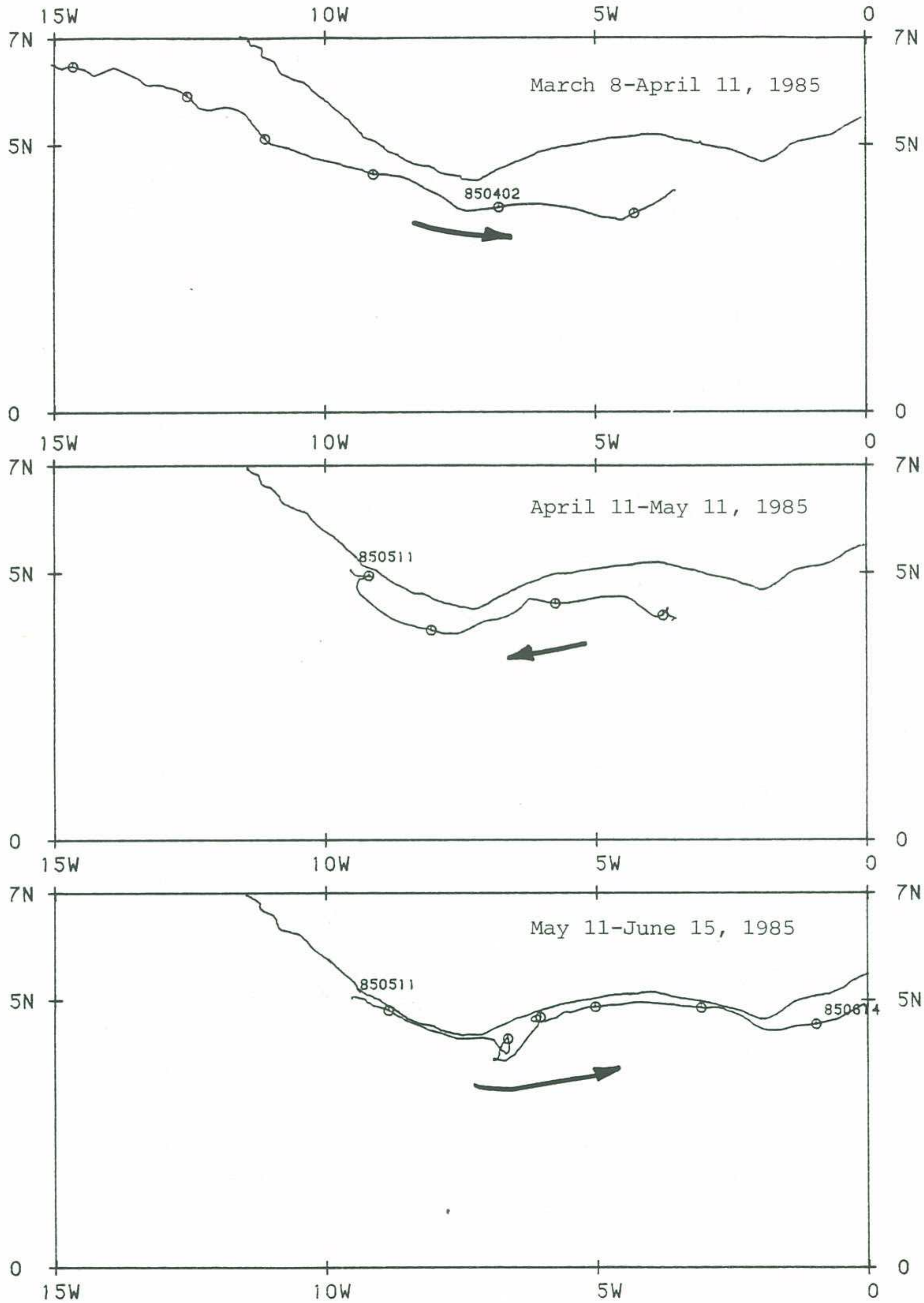


Figure 109: Buoy 73, Guinea Current Reversal.

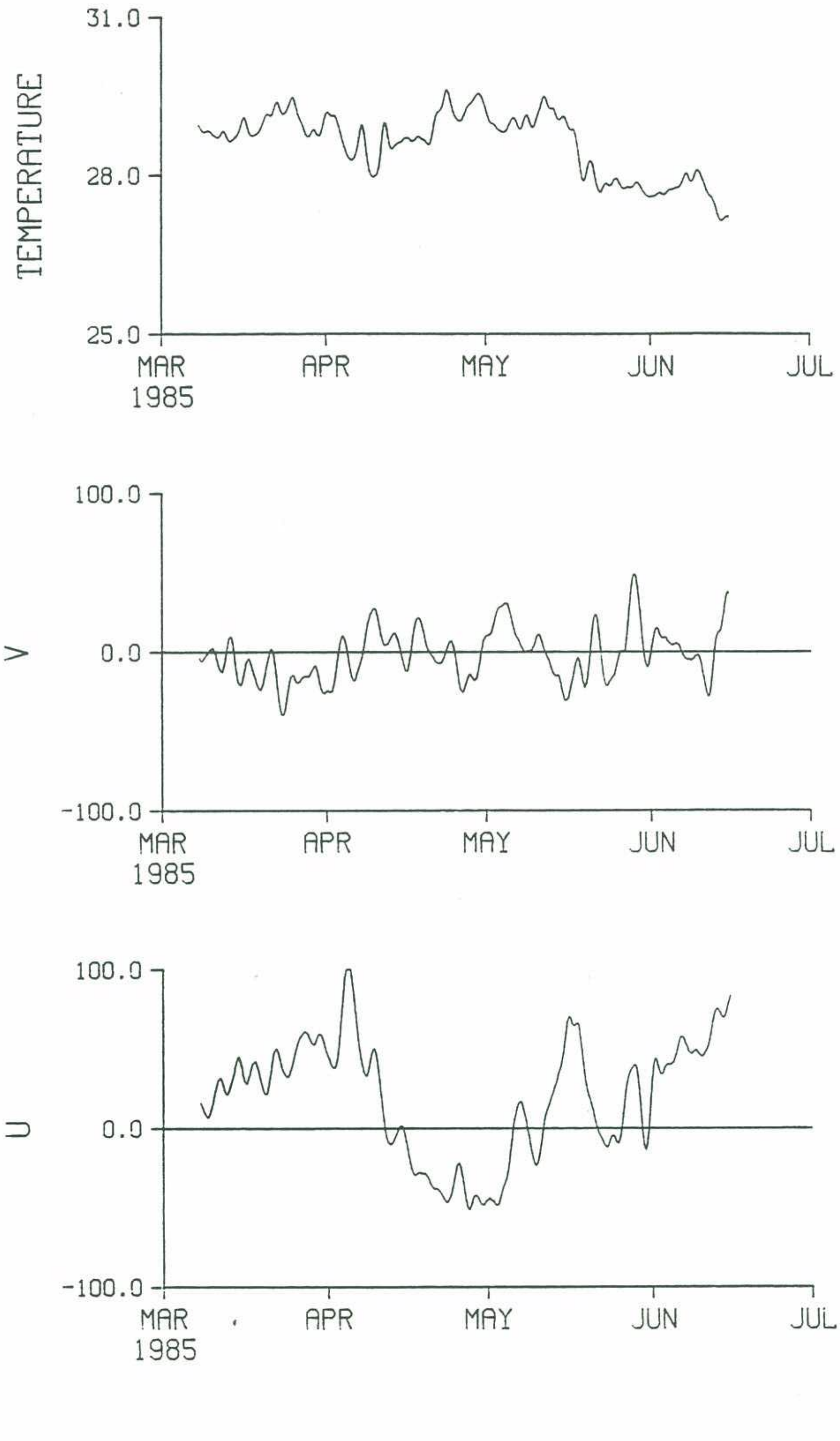


Figure 110: Time series, buoy 73.

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. WHOI-85-31	2.	3. Recipient's Accession No.

4. Title and Subtitle	5. Report Date
Surface Drifter Measurements in the Atlantic North Equatorial Countercurrent 1983-1985	September 1985
	6.
7. Author(s) Philip L. Richardson, Christine M. Wooding	8. Performing Organization Rept. No. WHOI-85-31
9. Performing Organization Name and Address Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543	10. Project/Task/Work Unit No.
	11. Contract(C) or Grant(G) No. (C) (G) OCE 82-08744
12. Sponsoring Organization Name and Address National Science Foundation	13. Type of Report & Period Covered Technical
	14.

15. Supplementary Notes

This report should be cited as: Woods Hole Oceanog. Inst. Tech. Rept. WHOI-85-31.

16. Abstract (Limit: 200 words)

Thirty freely drifting drogued surface buoys were tracked by satellite in the vicinity of the Atlantic North Equatorial Countercurrent from February 1983 to February 1985 as part of the SEQUAL (Seasonal Equatorial Atlantic) Experiment. Buoys were launched at several different times of the year in order to sample the Countercurrent in different seasons. The purpose was to measure the seasonal variation of the Countercurrent in relation to wind forcing.

The basic data set consists of buoy trajectories, and sea surface temperature, velocity, and wind speed along the trajectories. A comparison is made between the data from the buoys and from a current meter mooring near 6N, 28W. The main results presented here consist of the collection of figures which show trajectories and time series data along the Countercurrent, and in the North and South Equatorial Currents, Guinea Current and North Brazil Current.

17. Document Analysis a. Descriptors

1. Drifters
2. Currents
3. North Equatorial Countercurrent

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement:	19. Security Class (This Report)	21. No. of Pages
Approved for publication; distribution unlimited.	UNCLASSIFIED	129
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

DOCUMENT LIBRARY

April 9, 1985

DISTRIBUTION LIST FOR TECHNICAL REPORT EXCHANGE

Institute of Marine Sciences Library
University of Alaska
O'Neill Building
905 Koyukuk Ave., North
Fairbanks, AK

Attn: Stella Sanchez-Wade
Documents Section
Scripps Institution of Oceanography
Library, Mail Code C-075C
La Jolla, CA 92093

Hancock Library of Biology & Oceanography
Alan Hancock Laboratory
University of Southern California
University Park
Los Angeles, CA 90089-0371

Gifts & Exchanges
Library
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, NS, B2Y 4A2, CANADA

Office of the International
Ice Patrol
c/o Coast Guard R & D Center
Avery Point
Groton, CT 06340

Library
Physical Oceanographic Laboratory
Nova University
8000 N. Ocean Drive
Dania, FL 33304

NOAA/EDIS Miami Library Center
4301 Rickenbacker Causeway
Miami, FL 33149

Library
Skidaway Institute of Oceanography
P.O. Box 13687
Savannah, GA 31416

Institute of Geophysics
University of Hawaii
Library Room 252
2525 Correa Road
Honolulu, HI 96822

Library
Chesapeake Bay Institute
4800 Atwell Road
Shady Side, MD 20876

MIT Libraries
Serial Journal Room 14E-210
Cambridge, MA 02139

Director, Ralph M. Parsons Laboratory
Room 48-311
MIT
Cambridge, MA 02139

Marine Resources Information Center
Bldg. E38-320
MIT
Cambridge, MA 02139

Library
Lamont-Doherty Geological Observatory
Colombia University
Palisades, NY 10964

Library
Serials Department
Oregon State University
Corvallis, OR 97331

Pell Marine Science Library
University of Rhode Island
Narragansett Bay Campus
Narragansett, RI 02882

Working Collection
Texas A&M University
Dept. of Oceanography
College Station, TX 77843

Library
Virginia Institute of Marine Science
Gloucester Point, VA 23062

Fisheries-Oceanography Library
151 Oceanography Teaching Bldg.
University of Washington
Seattle, WA 98195

Library
R.S.M.A.S.
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149