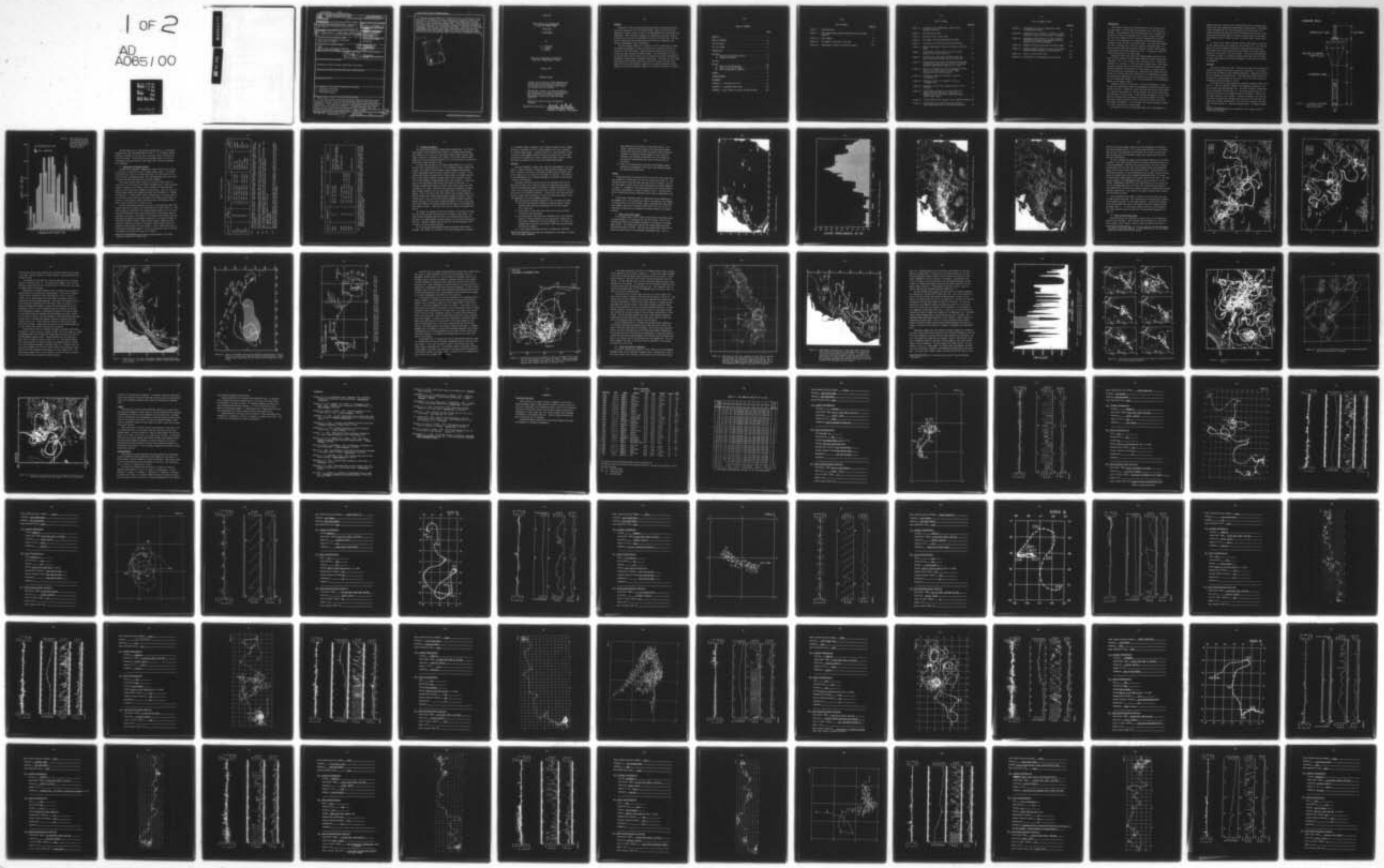
AD-A065 100 WOODS HOLE OCEANOGRAPHIC INSTITUTION MASS F/G 13/10
FREE-DRIFTING BUOY TRAJECTORIES IN THE GULF STREAM SYSTEM (1975--ETC(U)
JAN 79 P L RICHARDSON, J J WHEAT, D BENNETT N00014-74-C-0262

UNCLASSIFIED WHOI-79-4 NL

1 OF 2
AD
A065100



REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: WHOI-79-4
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): FREE-DRIFTING BUOY TRAJECTORIES IN THE GULF STREAM SYSTEM (1975-1978), A DATA REPORT.
5. TYPE OF REPORT & PERIOD COVERED: Technical rept.
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): P. L. Richardson, J. J. Wheat and D. Bennett
8. CONTRACT OR GRANT NUMBER(s): N00014-74-C-0262; NSF-OCE 75-08765; OCE 77-08045
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Woods Hole Oceanographic Institution, Woods Hole, MA 02543
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NR 083-004
11. CONTROLLING OFFICE NAME AND ADDRESS: NORDA, National Space Technology Laboratory, Bay St. Louis, MS 39529
12. REPORT DATE: January 1979
13. NUMBER OF PAGES: 158
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 170p.
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
    1. Satellite tracked buoy
    2. Trajectories at buoys
    3. Gulf Stream System
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

From 1975 to 1978, thirty-one satellite-tracked free-drifting surface buoys were launched in the Gulf Stream system. Most of these buoys were launched in cyclonic rings, as part of an interdisciplinary Gulf Stream ring experiment. Other buoys were launched in anticyclonic rings and the Gulf Stream itself; one buoy was launched in a cyclonic Kuroshio ring. The basic data set consists of buoy trajectories and sea surface temperature and velocity measurements along trajectories. ~~(Cont. on back)~~ Cont'

381 000

CONT →

The main results consist of a series of 19 buoy trajectories in rings from which the movement of rings is inferred and a series of 20 buoy trajectories in the Gulf Stream. Rings frequently coalesced with the Gulf Stream; and some reformed as modified rings. The trajectories of buoys in the Stream reveal that at times surface currents are strongly influenced by topographic features such as seamounts and ridges. Most buoys in the Stream continued to move eastward until they reached the vicinity of the Grand Banks (50°W) where they rapidly fanned out, some moving northward, others eastward across the mid-Atlantic Ridge, still others southward and westward.

(50 deg W)

WHOI-79-4

FREE DRIFTING BUOY TRAJECTORIES IN THE GULF STREAM SYSTEM

(1975-1978)

A DATA REPORT

by

P. L. Richardson
J. J. Wheat
D. Bennett

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts 02543

January 1979

TECHNICAL REPORT

Prepared for the Office of Naval Research under Contract N00014-74-C-0262; NR 083-004 and for the National Science Foundation under Grants OCE 75-008765 and OCE 77-08045.

Approved for Distribution: [signature]
Valentine Worthington, Chairman
Department of Physical Oceanography

ABSTRACT

From 1975 to 1978, thirty-one satellite-tracked free-drifting surface buoys were launched in the Gulf Stream system. Most of these buoys were launched in cyclonic rings, as part of an interdisciplinary Gulf Stream ring experiment. Other buoys were launched in anticyclonic rings and the Gulf Stream itself; one buoy was launched in a cyclonic Kuroshio ring. The basic data set consists of buoy trajectories and sea surface temperature and velocity measurements along trajectories.

The main results consist of a series of 19 buoy trajectories in rings from which the movement of rings is inferred and a series of 20 buoy trajectories in the Gulf Stream. Rings frequently coalesced with the Gulf Stream, and some reformed as modified rings. The trajectories of buoys in the Stream reveal that at times surface currents are strongly influenced by topographic features such as seamounts and ridges. Most buoys in the Stream continued to move eastward until they reached the vicinity of the Grand Banks (50°W) where they rapidly fanned out, some moving northward, others eastward across the mid-Atlantic Ridge, still others southward and westward.

TABLE OF CONTENTS

	Page
ABSTRACT	i
TABLE OF CONTENTS	ii
LIST OF TABLES	iii
LIST OF FIGURES	iv
INTRODUCTION	1
THE BUOYS	2
I. Temperature and Drogue Sensors	5
II. Drogues and Tethers	8
THE DATA	9
RESULTS	10
I. Buoys in the Gulf Stream	10
II. Buoys in Gulf Stream Rings	15
III. Buoys Influenced by Seamounts	24
SUMMARY	33
ACKNOWLEDGEMENTS	33
REFERENCES	35
APPENDIX A - Individual Buoy Data	37
APPENDIX B - Supplemental Buoy Data	133
APPENDIX C - Buoy Position Accuracy and Data Editing	148

LIST OF TABLES

		Page No.
Table 1.	Recovered Buoys.	6
Table 2.	Buoys whose drogue sensors indicated that the drogues came off.	7
Table A-1.	Buoy Summary.	38
Table A-2.	The number of each day of the year.	39
Table C-1.	Subdivision of Fixes into Quality Classes.	155

LIST OF FIGURES

Page No.

Figure 1. A drawing of the COSRAMS Buoy, made by Polar Research Laboratory. 3

Figure 2. The lifetime of buoys. 4

Figure 3. Location of buoy launch sites. 11

Figure 4. The number of buoys simultaneously tracked. 12

Figure 5. Trajectories of thirty-six free-drifting buoys. 13

Figure 6. Monthly displacement vectors of thirty-six drifting buoys. 14

Figure 7. Trajectories of three buoys in the Gulf Stream beginning near 64°W in May 1977. 16

Figure 8. Trajectories of four buoys launched across the width of the Gulf Stream near 57°W in July 1977. 17

Figure 9. Trajectories of all rings continuously tracked with free-drifting buoys plus one, just west of Bermuda, tracked by SOFAR float (Cheney *et al.*, 1976). 19

Figure 10. Ring Al in December 1976 and the subsequent trajectories of the two pieces as it split apart, measured with free-drifting buoys. 20

Figure 11. Trajectory of buoy 162 launched in ring Art, 14 December 1976. 21

Figure 12. Trajectory of buoy 215 launched in ring Al, 4 December 1976. 23

Figure 13. Trajectory of buoy 731A, launched 14 April 1977 in ring Bob. 25

Figure 14. Simultaneous trajectories of three rings, Bob, Charlie and Dave (dark lines) from April to November 1977 and portions of four buoy trajectories (light lines). 26

Figure 15. A North-South section through the New England Seamounts. 28

Figure 16. Trajectories of six buoys which were caught in strong eddy motion near the New England Seamounts. 29

LIST OF FIGURES (Contd)

		Page No.
Figure 17.	Superposition of the six trajectories shown in the previous figure.	30
Figure 18.	Trajectory of buoy 1076A as it passed in a small anticyclonic loop over the Atlantis II Seamount.	31
Figure 19.	Trajectory of buoy 0113B as it first stopped at the edge of the Corner Rise Seamounts and then began to loop over the seamounts.	32
Figure C-1.	Examples of buoy position data provided by NASA.	150
Figure C-2.	Satellite elevation angle vs. great circle angle between satellite subpoint and buoy position.	152
Figure C-3.	Error vs. great circle angle.	154
Figure C-4.	Distribution of the magnitude of fix errors.	156

INTRODUCTION

This report contains the free-drifting buoy data obtained from two experiments, a Gulf Stream ring experiment and a Gulf Stream experiment. The objectives of the ring experiment were to measure the movement of rings in the Sargasso Sea in order to learn where rings go, what their eventual fate is, and what influences their motion. The work is one component of a cooperative and interdisciplinary experiment to study cyclonic Gulf Stream rings. Two rings were followed over their lifetimes and a series of cruises to them were made. On these cruises we measured the rings' physical, chemical and biological characteristics and their changes with time. In addition we have obtained trajectories of ten other rings.

Rings are formed from large Gulf Stream meanders which pinch off from the main current and form intense eddies of swiftly flowing water (Fuglister, 1972, 1977; Saunders, 1971; Gotthardt, 1973). During the formation of a cyclonic or cold core ring a sizable mass of Slope Water, originally located north of the Stream and containing biological and chemical components characteristic of that region, is carried south of the Stream and into the Sargasso Sea. Rings are large eddies with diameters up to 300 km; they occur frequently in the Northwestern Atlantic and have primary importance to that region and to the size and shape of the Gulf Stream gyre (Parker, 1971; Lai and Richardson, 1977; Richardson, Cheney and Worthington, 1978).

Fuglister (1972, 1977) was first to follow the movement of rings. He used ship observations (XBTs and hydrographic stations) and also buoys tracked from ship. Fuglister's study indicated that surface buoys stayed in a ring for long periods of time (six months) and thus they provided a good technique to follow rings. These results encouraged us to try using satellite tracked buoys to measure the continuous movement of rings. Richardson, Cheney and Mantini (1977) describe the first of our buoys that worked successfully. At the present time we have obtained a series of 19 buoy trajectories in twelve rings.

The purpose of the Gulf Stream experiment was to investigate the general problem of where the Gulf Stream goes and how it disperses and recirculates after passing the Grand Banks of Newfoundland. Worthington (1976) contended that the Gulf Stream returns to the southwest in a relatively tight gyre while Mann (1967) maintained that the Gulf Stream branches near the Grand Banks, one branch turning toward the northeast and forming the North Atlantic current, the other branch flowing southward.

In order to help resolve the near surface flow pattern of the Gulf Stream, several buoys were launched in the Stream in 1977. In addition, many of the buoys originally launched in rings became entrained into the Stream as the rings coalesced with the Stream; these buoys provide additional trajectories in the Gulf Stream. We have also obtained data from buoys in rings, the Stream and nearby areas kindly made available by other investigators; these data complement our data and are included in Appendix B.

THE BUOYS

Two types of buoys were used. The first was made by Nova University (hull)* and American Electronics Laboratory (electronics). The second type of buoy was made by Polar Research Laboratory. Beginning in October 1975 we launched six Nova/AEL buoys. They had a short mean lifetime of 50 days; two of them worked for four days, one for 132 days (1151A, see Richardson, Cheney and Mantini, 1977).

In October 1976 we began using Polar Research Laboratory (PRL) buoys (Fig. 1). They are smaller, lighter, less expensive and proved to be more reliable than the Nova/AEL buoys. The mean lifetime of twenty PRL buoys is presently 228 days (Fig. 2). This value includes the life of five buoys recovered at sea (mean lifetime of 300 days). Three of the PRL buoys worked for over 400 days. Lifetime is defined to be the time from which the buoys were launched until the time of the last good fix before they stopped transmitting or, in the case of recovery, the time when they were picked up. None was recovered after it stopped transmitting.

*Three of these buoys had hulls constructed of PVC tubing, three of reinforced fibreglass.

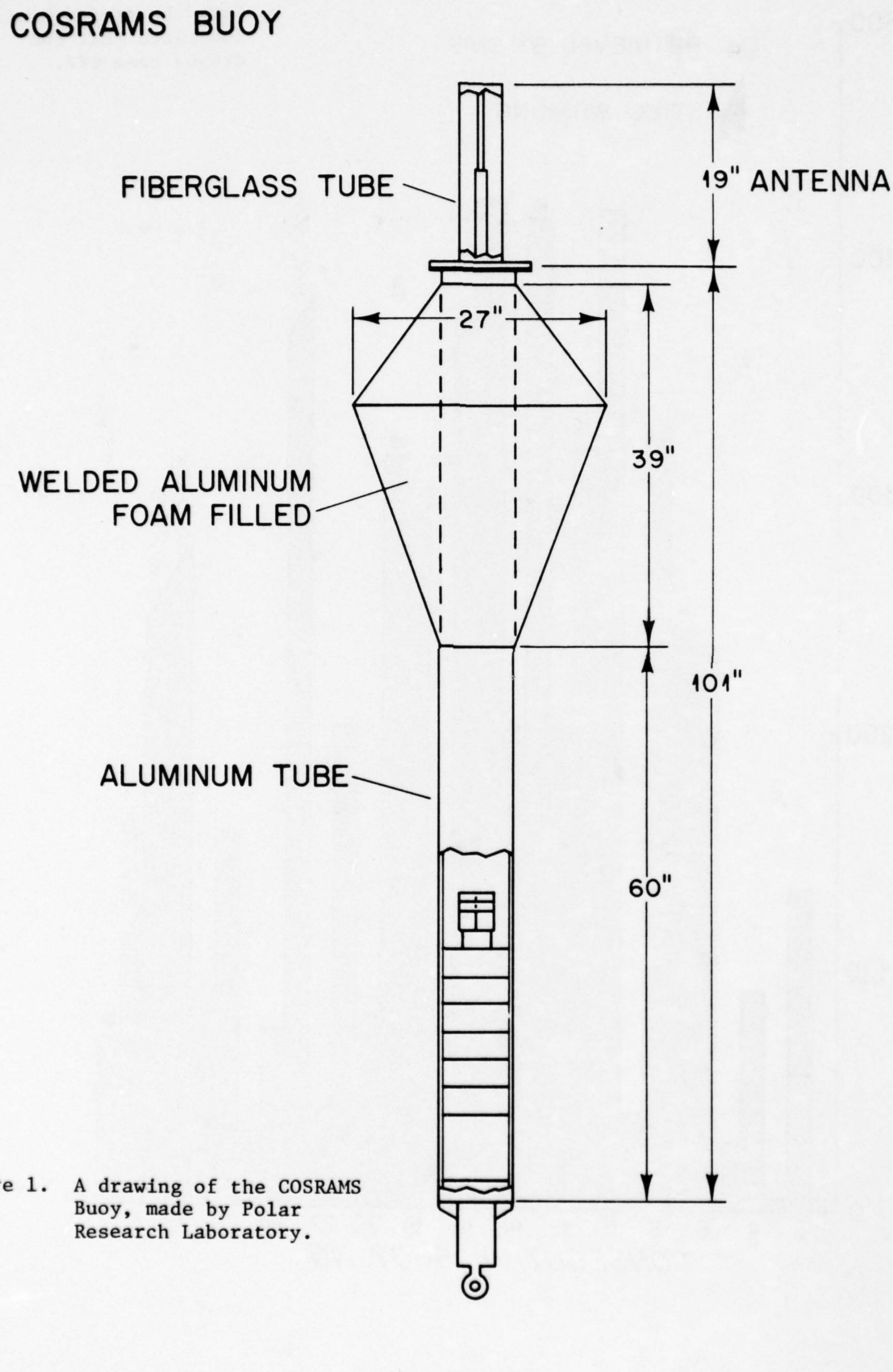
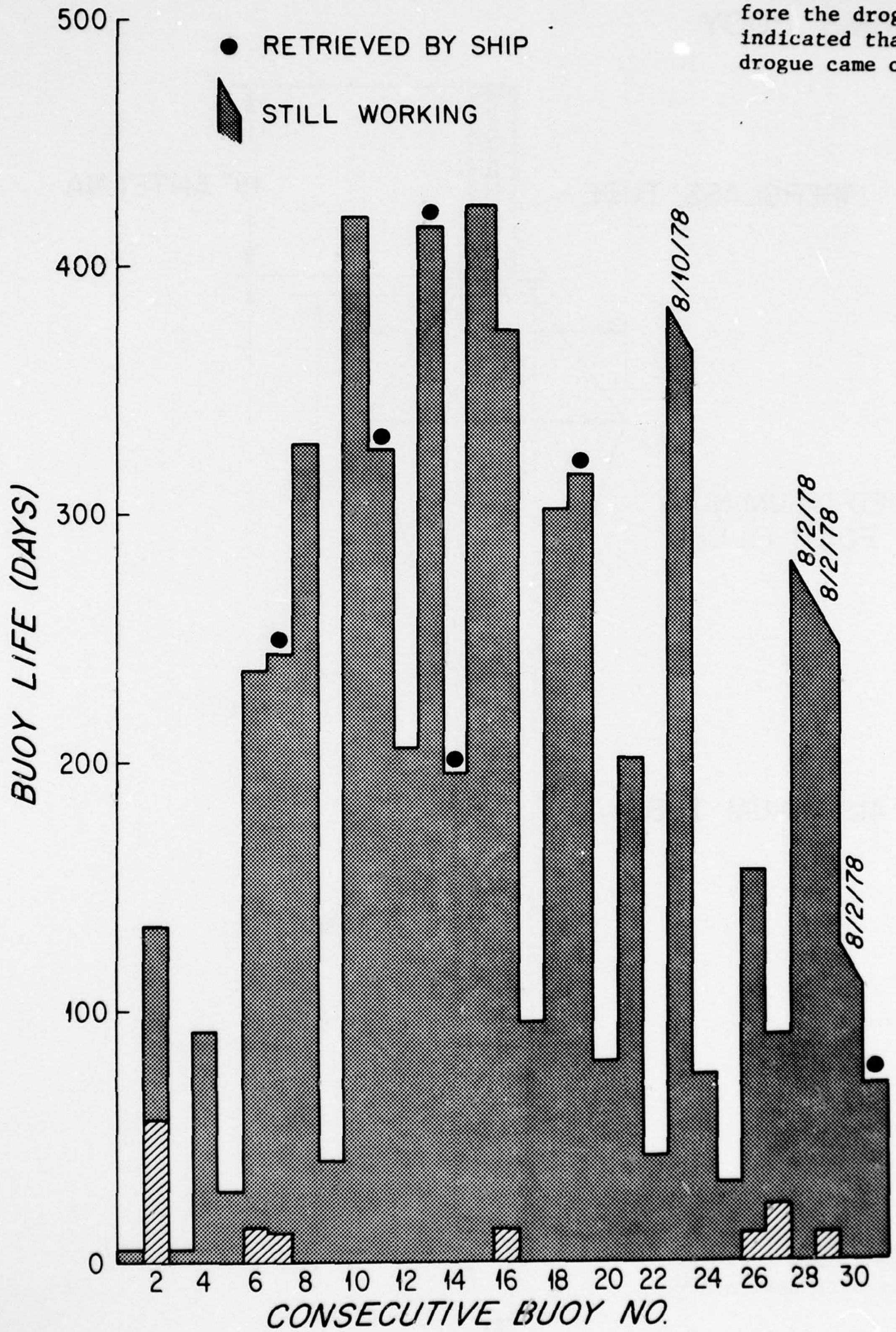


Figure 1. A drawing of the COSRAMS Buoy, made by Polar Research Laboratory.

Figure 2. The lifetime of buoys. The crosshatched area indicates the time before the drogue sensor indicated that the drogue came off.



The PRL buoys are 3 m long and are constructed of a .32 cm welded aluminum hull; they each weigh 200 lbs (Fig. 1). A fibreglass antenna housing is attached to the top, and a flotation collar is located just below the antenna. Six PRL buoys were recovered (Table 1); all were structurally sound and three of them (264B, 731B, 437B) were repowered and relaunched.

I. Temperature and Drogue Sensors

The PRL buoys contained a temperature sensor located near the base of the buoy at a depth of 2 m and a drogue tension sensor. The temperature data from the first few buoys were noisy, but the problem was corrected by PRL on subsequent buoys. The buoy temperature data were found to agree with XBTs taken when the buoys were launched.

The drogue tension sensor consists of an on/off switch which is activated by a 50 lb load to the tether attachment point. When sufficient tension is applied to the tether, rubber toroids are compressed and a magnet is pulled away from a magnetic on/off switch. Four of the six recovered drogue sensors had become overloaded and had jammed in a "drogue on" position.* A fifth sensor (0437A) indicated that the drogue came off after being at sea 12 days and this sensor was working properly when recovered. A sixth sensor (731B), modified by PRL, was working properly when it was recovered after 71 days at sea.

Of all the PRL buoys launched, only six of them indicated that their drogues came off; all within a 23 day period after launch (Table 2). Thus after 23 days we think most of the drogue sensors jammed in an "on" position and therefore we do not know how long most of the drogues remained attached to the buoys. The failure of the drogue tension sensor may have been caused by high shock loadings transmitted to the sensor through the relatively unelastic tethers. PRL has made a design change that they think will eliminate failures of the drogue tension sensors and we are presently testing three of the new sensors. One of these (731B) was recovered and was working properly. We are also exploring ways to decouple the movement of the buoy from that of the drogue.

*Only one of six Nova/AEL drogue sensors worked properly, the others failed to transmit any tension data.

Table 1 - Recovered Buoys

Buoy ID[a]	Time at Sea (days)	Original tether/drogue[d]	Recovered hardware	Last Failure[e]
113B	326	5 m, 3/8" chain; 200 m, 1.50" pp/WS	Chain only	Shackle
264A	326	5 m, 3/8" chain; 200 m, 1.50" pp/WS	Chain only	Shackle
437A[b]	244	400 m, 1/4" dacron/WS	Thimble only	Line
707A	416	5 m, 3/8" chain; 200 m, 1.25" pp/WT	Chain only	Shackle
731A	196	5 m, 3/8" chain; 200 m, 1.50" pp/WS	Chain, thimble	Line
731B[c]	71	5 m, 3/8" chain; 200 m, 1.25" pp/WT	All recovered	None

(a) These buoys (except for 437) were recovered using an OAR automatic radio direction finder loaned to us by the NOAA Data Buoy Office. The direction finder first received the buoys' signal at a distance of 8-9 miles.

(b) The drogue sensor indicated that the drogue came off after 12 days at sea. Four of the other drogue sensors failed due to overloading and indicated that the drogues were on (see text).

(c) Buoy 731B was retrieved after 71 days at sea in the vicinity of the Grand Banks of Newfoundland. This buoy contained a modified drogue sensor which was working properly when recovered.

(d) WS - window shade drogue, 25 m^2, 100 lbs.
WT - 100 lb weight.
pp - Polypropylene.

(e) From the visual inspection of the recovered 3/8" safety shackles it appears that the ones that failed had become so corroded that either the bolt broke or the stainless steel cotter pin and nut dropped off and the bolt worked its way out of the shackle.

Table 2 - Buoys whose drogue sensors indicated that the drogues came off

Buoy ID	Time(days) [a]	Tether/drogue	Comments
0401A	14	200 m, 3/8" nylon/WS	Kuroshio ring
0437A	12	400 m, 1/4" dacron/WS	recovered with bare thimble and no tether after 244 days at sea
0557A	11	50 m, 3/8" nylon/WS	air launched buoy
1076A	13	5 m, 3/8" chain; 200 m, 1.25" pp/WS	
1370A	11	5 m, 3/8" chain; 200 m, 1.25" pp/WT	
1406A	23	5 m, 3/8" chain; 200 m, 1.50" pp/WT	
1511A	56	200 m, 5/8" nylon/WS	Nova/AEL buoy

(a) Time at sea before drogue came off as indicated by drogue sensor. After about 23 days the PRL drogue sensors became jammed in an "on" position and thus we do not know how long most of the drogues stayed attached to the buoys. Only one Nova/AEL drogue sensor functioned; it indicated the drogue stayed on for 56 days.

II. Drogues and Tethers.

We tried several different drogue-tether combinations. Our conclusions based on the recovered buoys (Table 1) and drogue tension sensor data (Table 2) are 1) that our thin tethers parted rather quickly, sometimes as early as a few weeks after launch, 2) the thick tethers lasted longer but we do not know how long and 3) the safety shackles corroded and parted after about 300 days at sea.

On nine buoys we used a 25 m^2 window shade drogue (1.7 m x 14.5 m, 100 lbs) and a relatively thin (1.4 - 5/8" diameter) tether, usually 200 m long. The evidence from the drogue sensors suggests these drogue/tether combinations came off after a period from 11 to 56 days. To alleviate the problem of drogue-tether failures which we thought could be due to chafe and/or fishbite we began using a 200 m section of thick (1.25"-1.50" diameter) polypropylene tether, and we added a 5 meter section of 3/8" galvanized chain between the tether and the buoy. We attached a window shade drogue to seven of the thick tethers and a 100 lb weight to 15 others. When the thick line was used without a window shade drogue attached to it the line itself (area $\sim$ 6 m^2) became the drogue. Five of the buoys with thick tethers were recovered (Table 1). Only one (731B) had a window shade drogue or weight attached; it was recovered after 71 days at sea with line and hardware in good condition. Another buoy had the chain and a thimble attached to it but no line was around the thimble; the shackles connecting the chain to the thimble had been highly corroded. Three buoys had only the chain; the shackles had parted.

In summary the drogues did not stay attached to the buoys very long. The thin tethers parted after periods of two weeks to two months. The thick tethers sometimes parted as early as two weeks after launch but because of the jammed drogue tension sensors we do not know how long they did last. Evidence suggests that the one buoy recovered complete after 71 days at sea was in good condition.

We are presently experimenting with two different drogue tether systems. One consists of 5 meters of 3/8" chain connected to 10 meters of 1" diameter rubber (stretches to 20 m under the static load of drogue and wire), connected to 175 m of nylon jacketed 3/32" wire, connected to a window shade drogue. A second consists of a 100 m section of stiff (to keep it from wrapping around the buoy) line which lies on the water surface and is attached to a float, slightly positively buoyant. Below the float is attached a 100 m wire and a window shade drogue.

THE DATA

The buoy transmits a signal (401.2 mHz) for approximately 1 sec each minute. Signals consist of a NASA buoy identification number and sensor data. The buoy's position is calculated by NASA from the Doppler shift of the signal as it is received by the Nimbus 6 satellite. The Nimbus 6 is sun-synchronous; has a high-noon passage, an altitude of 1100 km and a period of 108 minutes.

Typically five fixes per buoy per day are obtained; they have an RMS error of about 5 km. Position errors are introduced from several sources including weak signals, low number of signal transmissions received, low or high angle of satellite pass, unknown velocity of the buoy, and errors of the satellite position. In practice it was found that the errors of fixes could be reduced to 1-2 km by eliminating suspect fixes (see Appendix C for a more complete discussion).

Data editing and processing consisted of the following five steps.

1) The data were obtained from NASA on computer printout sheets. Obviously bad fixes were eliminated; the rest were entered into a buoy file.
2) Trajectories of each buoy were plotted and velocity between successive fixes calculated.
3) Two good-quality fixes per day, a half-day apart, were selected based on a visual inspection of the trajectory, velocity and the quality parameters of each fix (Appendix C). At times, for example when a buoy ran low on power, fewer than two good fixes per day were retained.
4) A cubic spline function* was used to compute buoy positions

*The spline function was developed and programmed for the Sigma 7 by Glenn Flierl and Roger Goldsmith.

and velocities evenly spaced in time (two per day). The spline function filled in gaps in the data and provided a uniform time series with which we could do further analysis. A benefit of using data evenly spaced in time is that by looking at the spacing of semi-daily dots on trajectories, one can get a good feeling for a buoy's velocity and its variations.

5) Plots of the trajectories, velocity-stick diagrams, speed, direction and temperature time series were generated using the edited and splined data.

RESULTS

During the period from October 1975 to June 1978, thirty-one buoys were launched in various parts of the Gulf Stream system (Fig. 3). Two records are short, only four days long, and are not included. In mid-1977 the number of buoys that we were simultaneously tracking peaked at 17 (Fig. 4). A summary of the trajectories plus seven others obtained from other investigators is shown on Figures 5 and 6. Detailed plots of the trajectories and buoy velocities can be seen in Appendices A and B.

Several very different types of trajectories can be identified on the summary plots. The trajectories reflect the different flow regimes in features such as the Gulf Stream, rings, topographic and other meso-scale eddies, and also in different geographical areas such as near the mid-Atlantic ridge and in the Western and Eastern Basins of the North Atlantic.

I. Buoys in the Gulf Stream

In the region west of 60°W, buoys located outside the Stream showed a strong tendency to be entrained into the Gulf Stream. Once in the Stream buoys usually moved rapidly eastward to the region of the Grand Banks (50°W). The trajectories indicate the Stream reaches its maximum latitude between 55-60°W. From here the Stream flows southeastward along the western side of the southeast Newfoundland Rise. East of

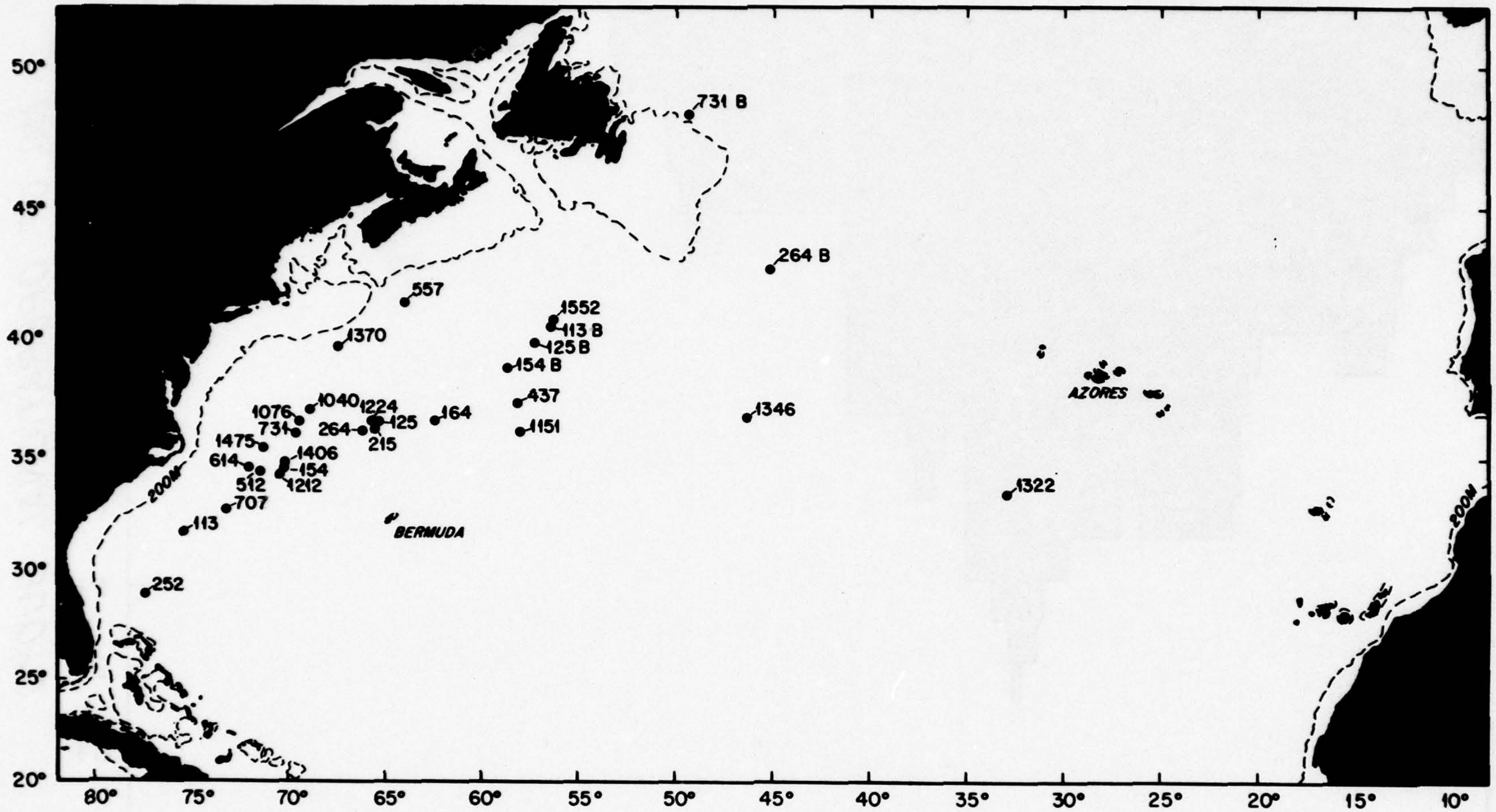


Figure 3. Location of buoy launch sites.

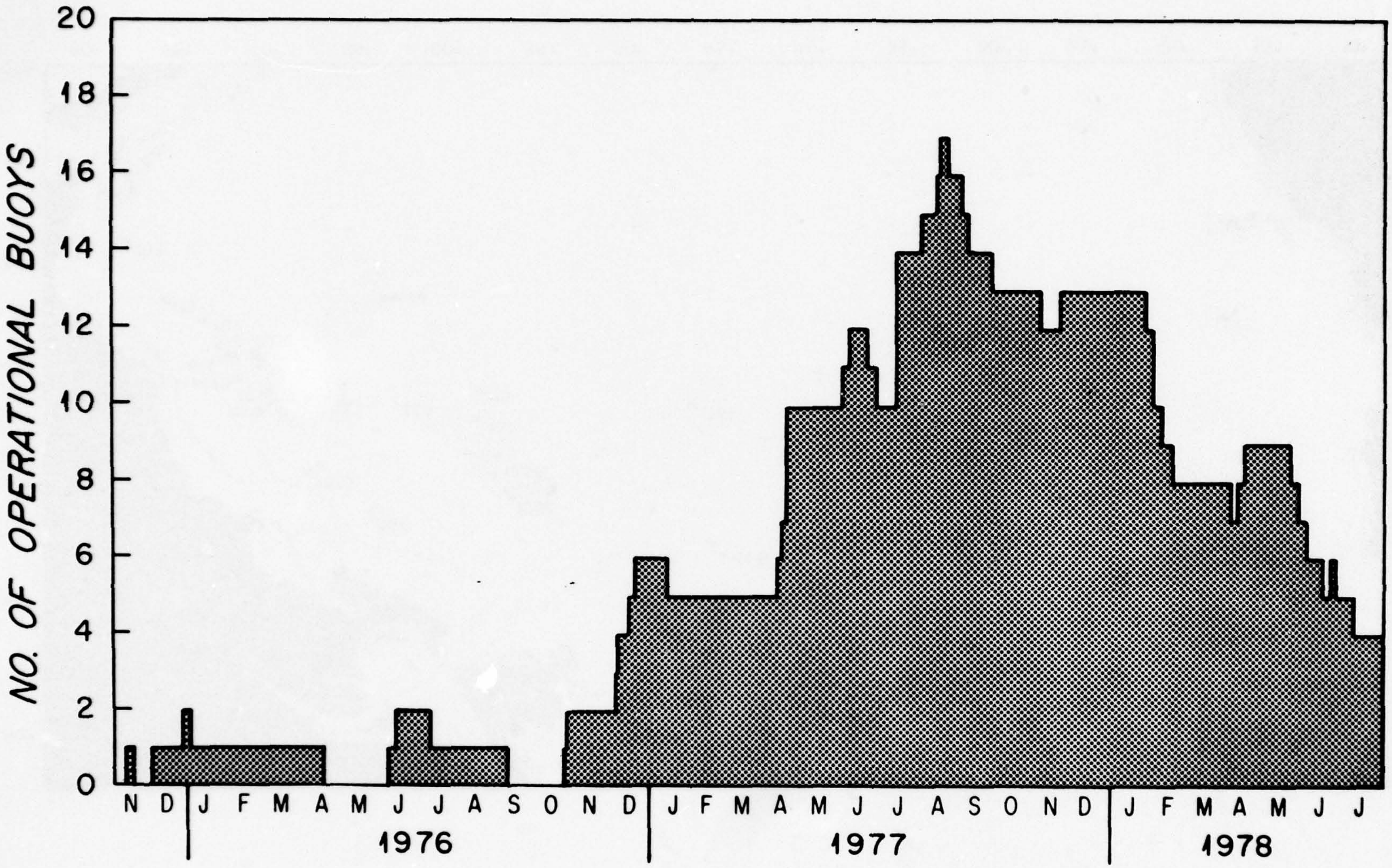


Figure 4. The number of buoys simultaneously tracked.

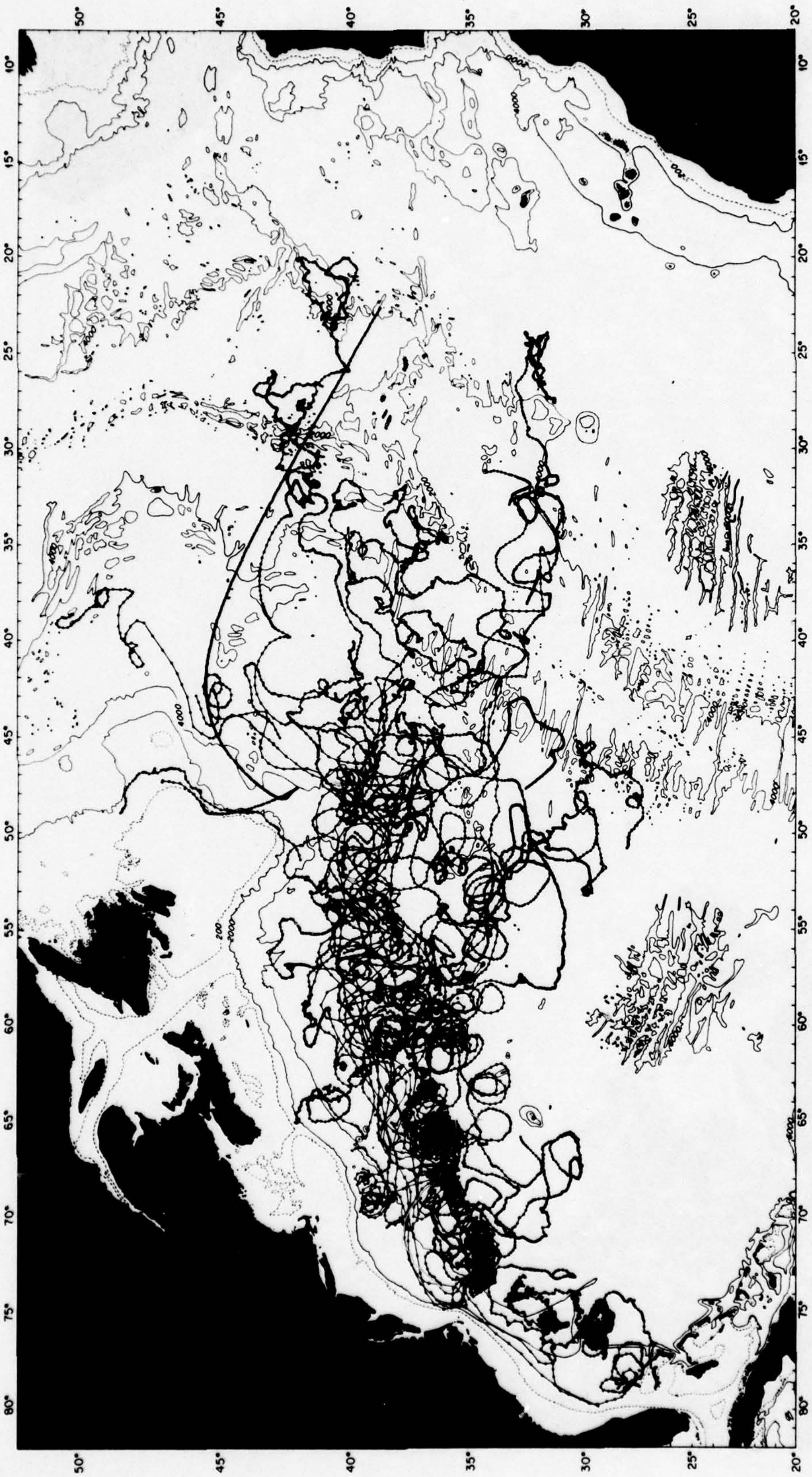


Figure 5. Trajectories of thirty-six free-drifting buoys. Two positions per day are shown by dots.

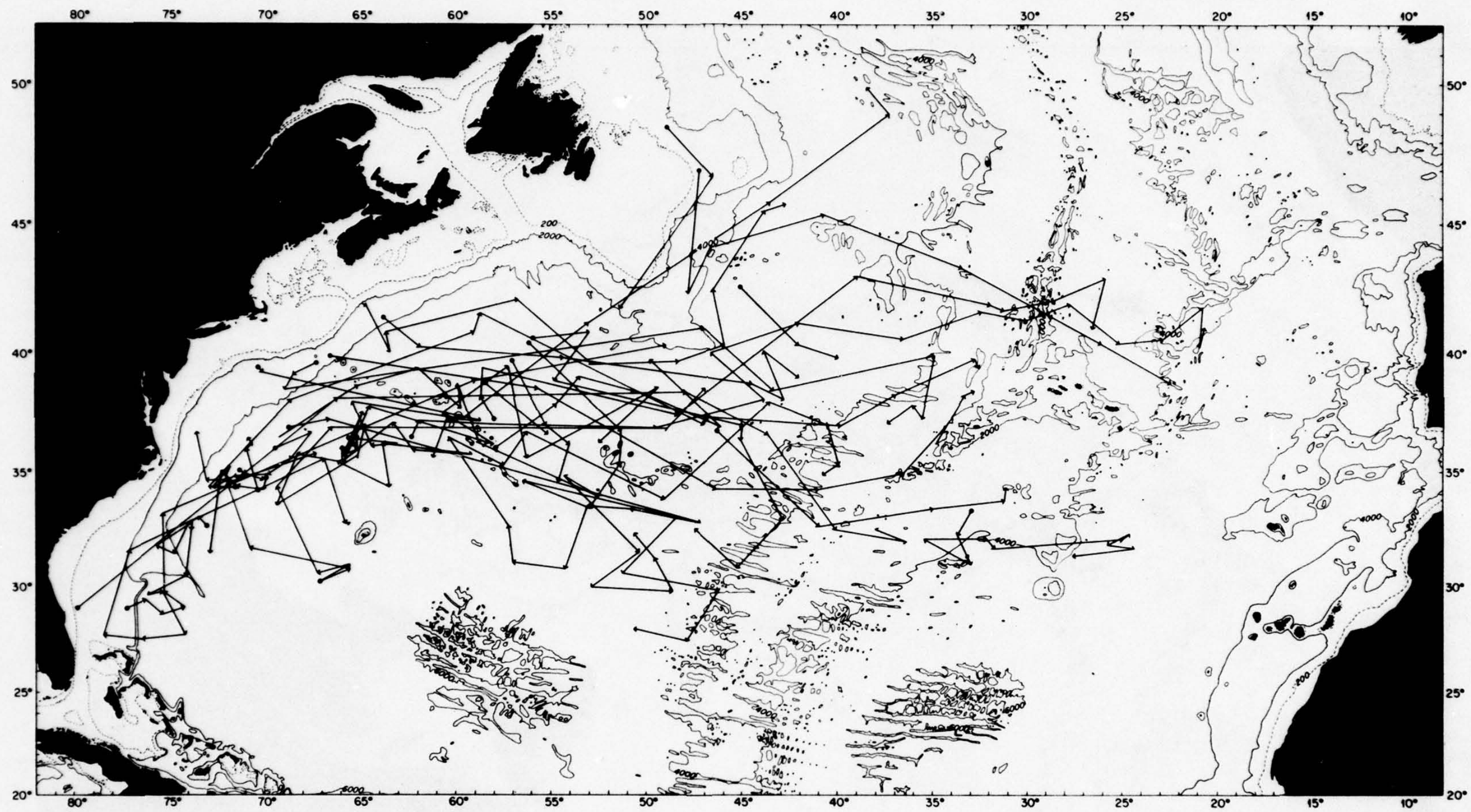


Figure 6. Monthly displacement vectors of thirty-six drifting buoys.

60°W the buoy trajectories spread out and the spreading is increased in the region between 40-50°W. It is interesting that none of the drifters spun off into the Slope Water on the north, or at least that any buoys that did move into the Slope Water region were quickly entrained into the Gulf Stream again.

The buoy trajectories suggest three possible branches of the surface currents.* One branch swings around the Southeast Newfoundland Rise and turns northeastward. From here the current divides, one part continues northeastward and the other part moves eastward across the mid-Atlantic Ridge, north of the Azores, near latitude 42-43°N. A second branch of the Stream continues to flow southeastward from the main current, running along the western side of the Southeast Newfoundland Rise; it crosses the mid-Atlantic Ridge south of the Azores, near latitude 33°N. The third branch consists of a southwestward flow on the south side of the Gulf Stream. Approximately one-half of the buoys moved out of the Stream and into the southwestward flow; the other half continued moving eastward. The westward flow is difficult to resolve because it is dominated by highly energetic eddy motion. The energy of the eddies decreases quite rapidly with decreasing latitude.

On two occasions buoys began to drift in the Gulf Stream from near the same location and time. The trajectories of the buoys give a measure of how rapidly particles in the Stream disperse. On the first occasion, three buoys passed very close to one another near 64°W longitude purely by chance (Fig. 7). On the second occasion four buoys were launched at four sites located across the width of the Stream near longitude 57°W (Fig. 8).

II. Buoys in Gulf Stream rings.

Twenty-one buoys were launched in rings as part of the interdisciplinary ring experiment. When launched near the center of a ring these buoys tended to move radially outward toward the high velocity part of

* The effect of wind and waves on the buoys both with and without drogues is presently being investigated. In this discussion of the preliminary results the wind effect will be ignored.

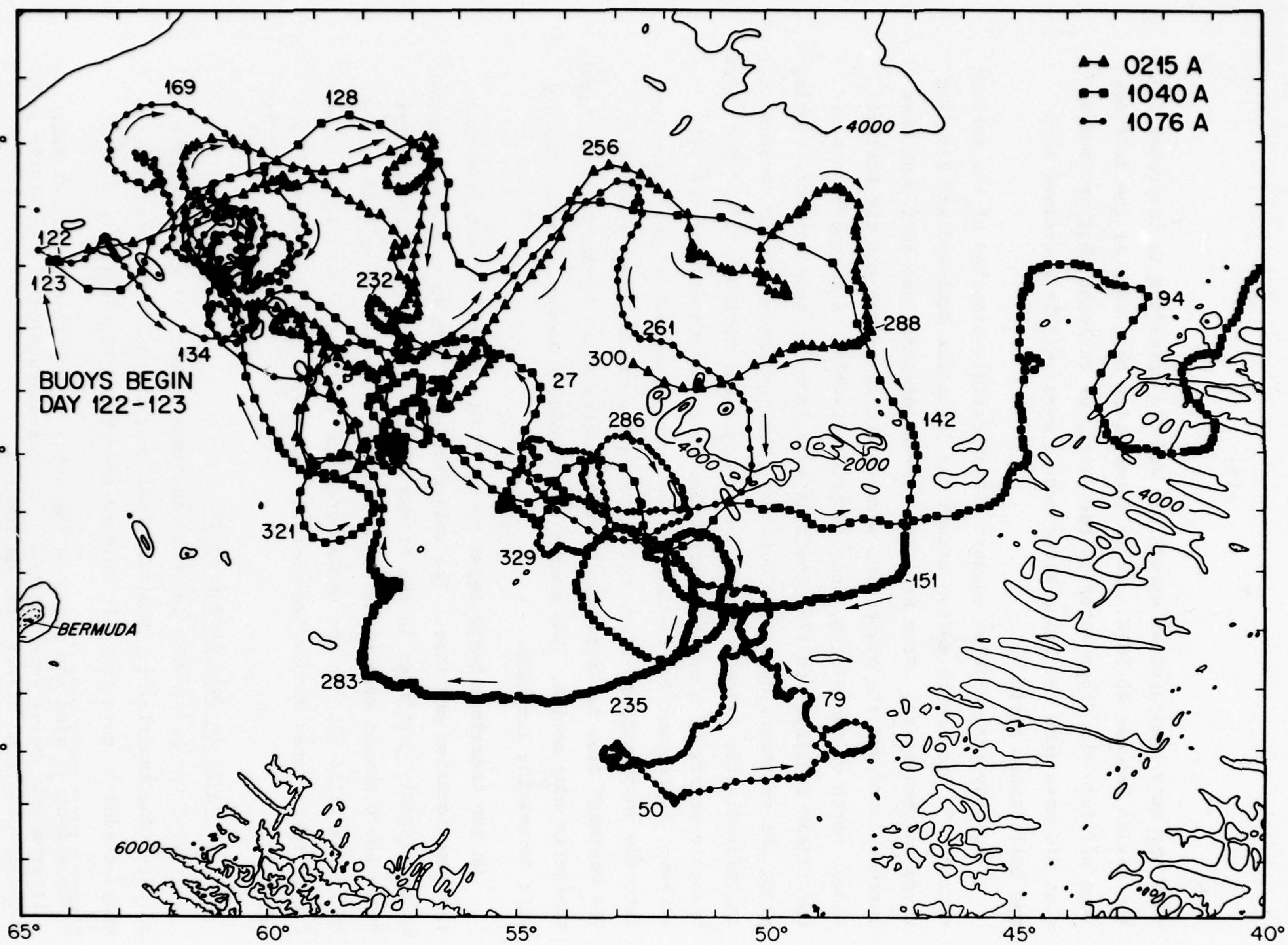


Figure 7. Trajectories of three buoys in the Gulf Stream beginning near 64°W in May 1977.

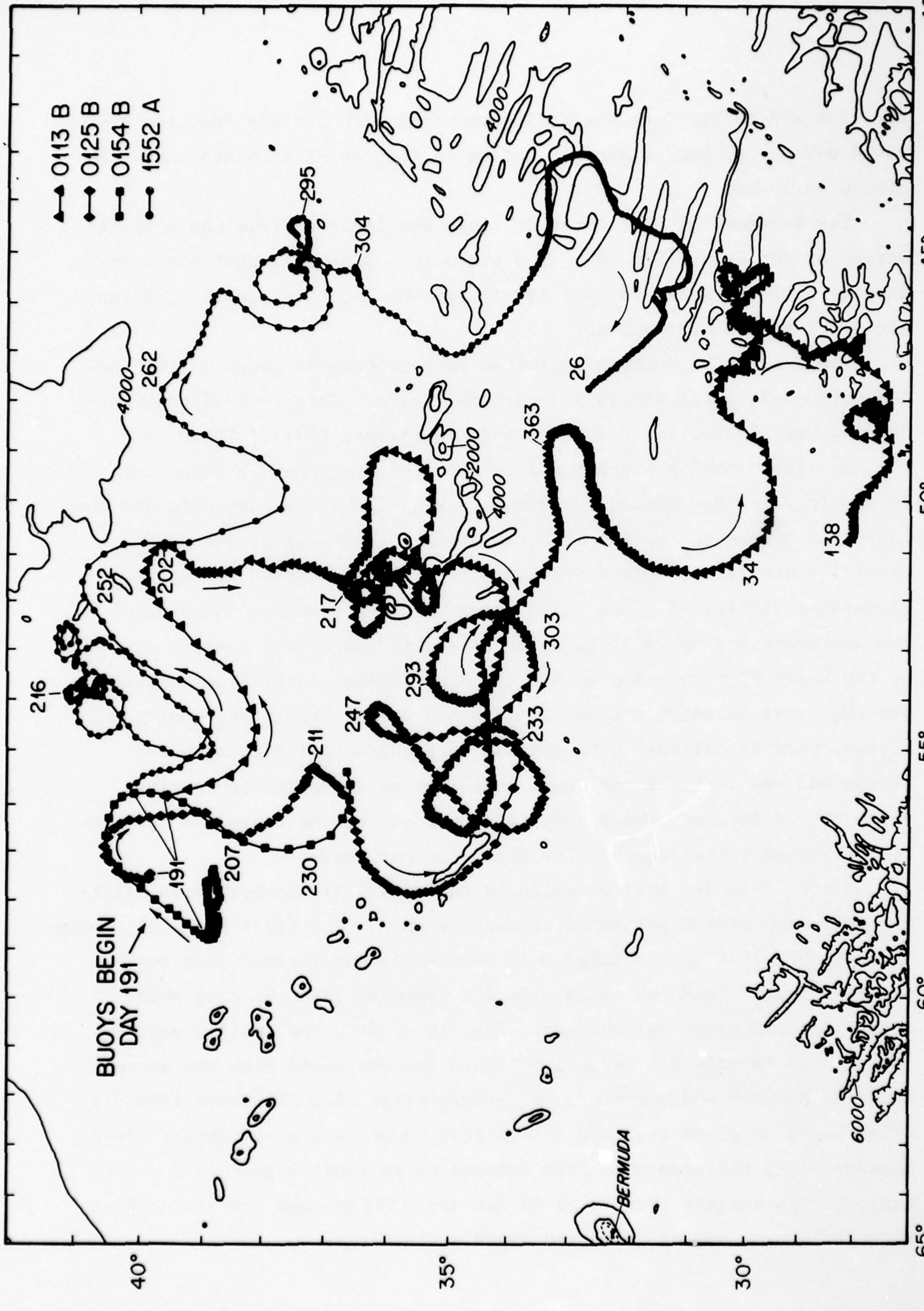


Figure 8. Trajectories of four buoys launched across the width of the Gulf Stream near 57°W in July 1977.

the ring and to stay there circling the ring with periods from two days to 10 days. One buoy stayed in a ring as long as eight months and completed 86 loops.

The movement of the center of rings was inferred from the looping motion of the buoys (Fig. 9). The trajectories suggest that rings frequently coalesce with the Gulf Stream and that as this occurs, the buoys are swept away in the Stream.

Rings north of Bermuda exhibited large clockwise loops as they became attached to the Stream and reformed again. This type of movement is also seen in Fuglister's 1967 ring (Fuglister, 1977). There is evidence for a semi-permanent and complicated ring/meander structure lying along the New England Seamounts. Rings near the seamounts did not last long before coalescing with the Stream. There is evidence of a general southwestward movement, similar to that described by Lai and Richardson (1977), of those rings which were not touching the Stream. The southwestward movement is apparently affected by the shallow depth of the Blake Plateau and possibly the Blake Bahama Outer Rise. There are two cases in which a ring was attached to the Stream and moving downstream, when it collided with another ring which coalesced with the Stream and was lost. Three buoys were located in anticyclonic rings north of the Stream. These buoys all came out of the rings and went into the Stream rather quickly (typically in one month).

During 1976 and 1977 we followed two rings, Al and Bob, with drifting buoys and made a series of cruises to them. The first ring, Al, formed in September 1976 from a large Gulf Stream meander located just west of the New England Seamount chain. During December 1976 the ring split apart into two rings, Al and Art, (Fig. 10). Art, the smaller eastern part, moved rapidly (10 cm/sec) eastward and coalesced with the Stream over the New England Seamounts in January (Fig. 11). Evidence from six other buoys suggests that the Gulf Stream formed a semi-permanent ring/meander along the seamounts from January to at least August 1977. The trajectories suggest that by early January 1977 Art had come in contact with the Stream and was advected rapidly eastward.

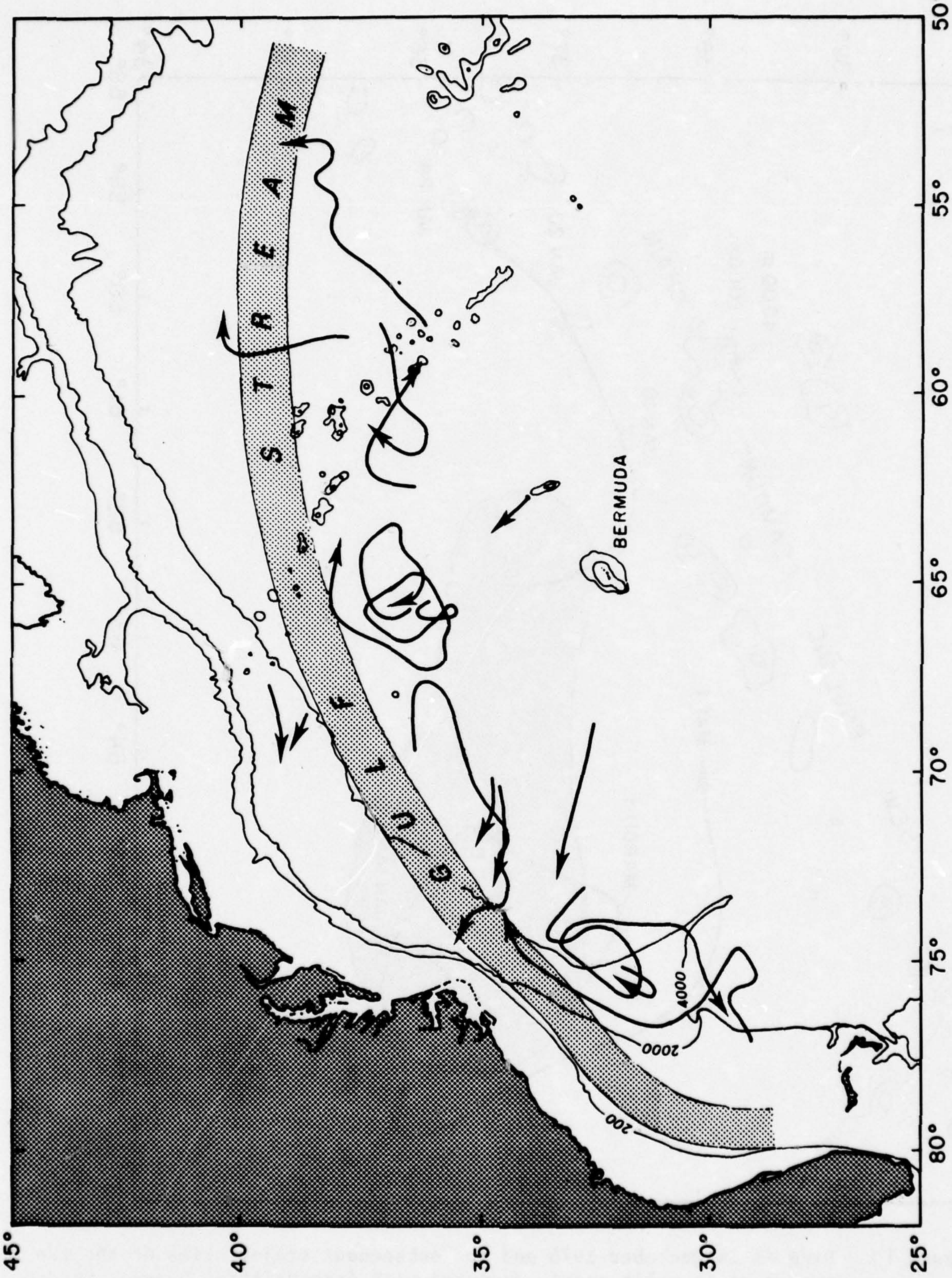


Figure 9. Trajectories of all rings continuously tracked with free-drifting buoys plus one, just west of Bermuda, tracked by SOFAR float (Cheney *et al.*, 1976).

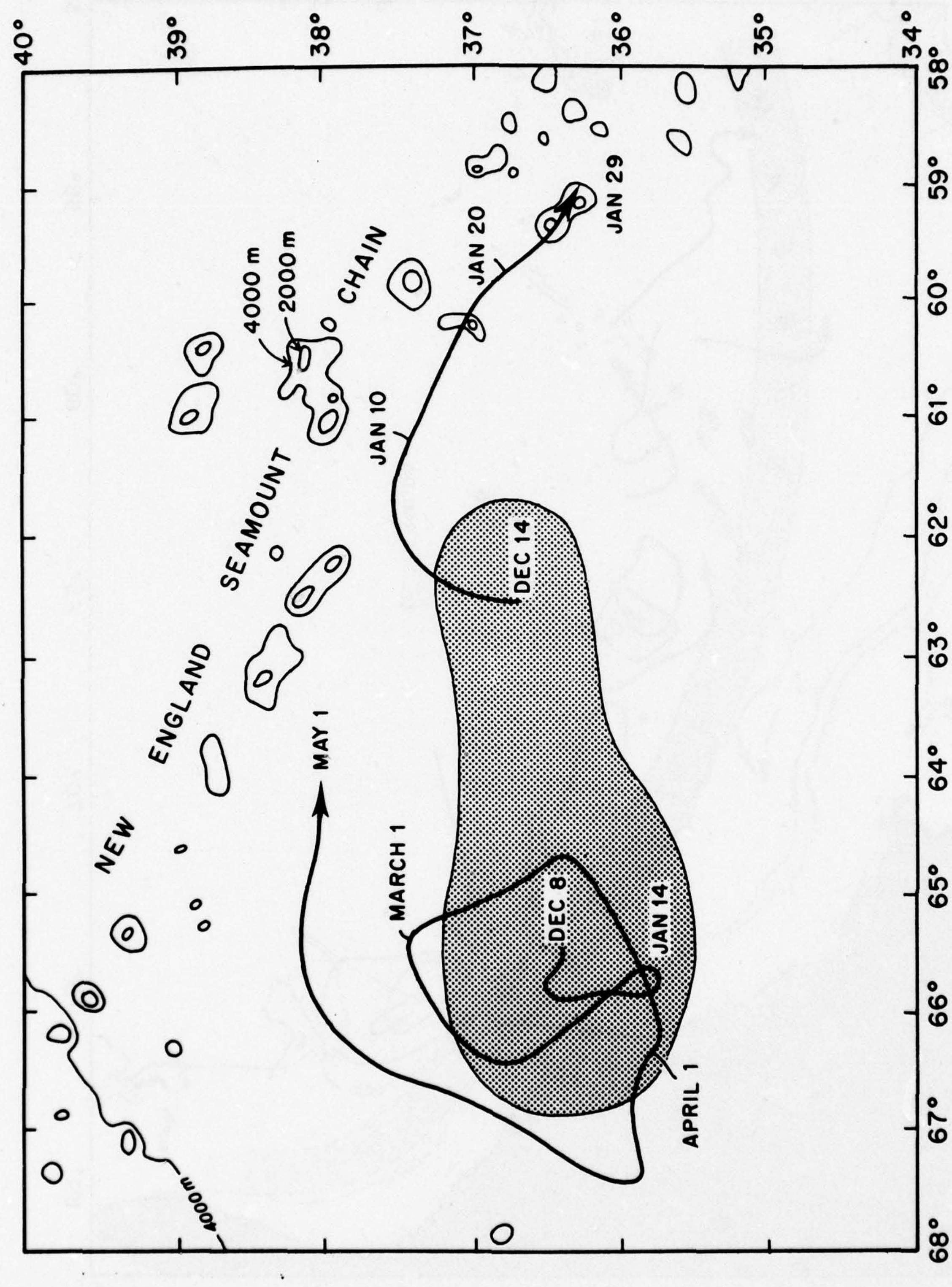


Figure 10. Ring A1 in December 1976 and the subsequent trajectories of the two pieces as it split apart, measured with free-drifting buoys. Shaded area is water colder than 15°C at a depth of 600 m based on an XBT survey.

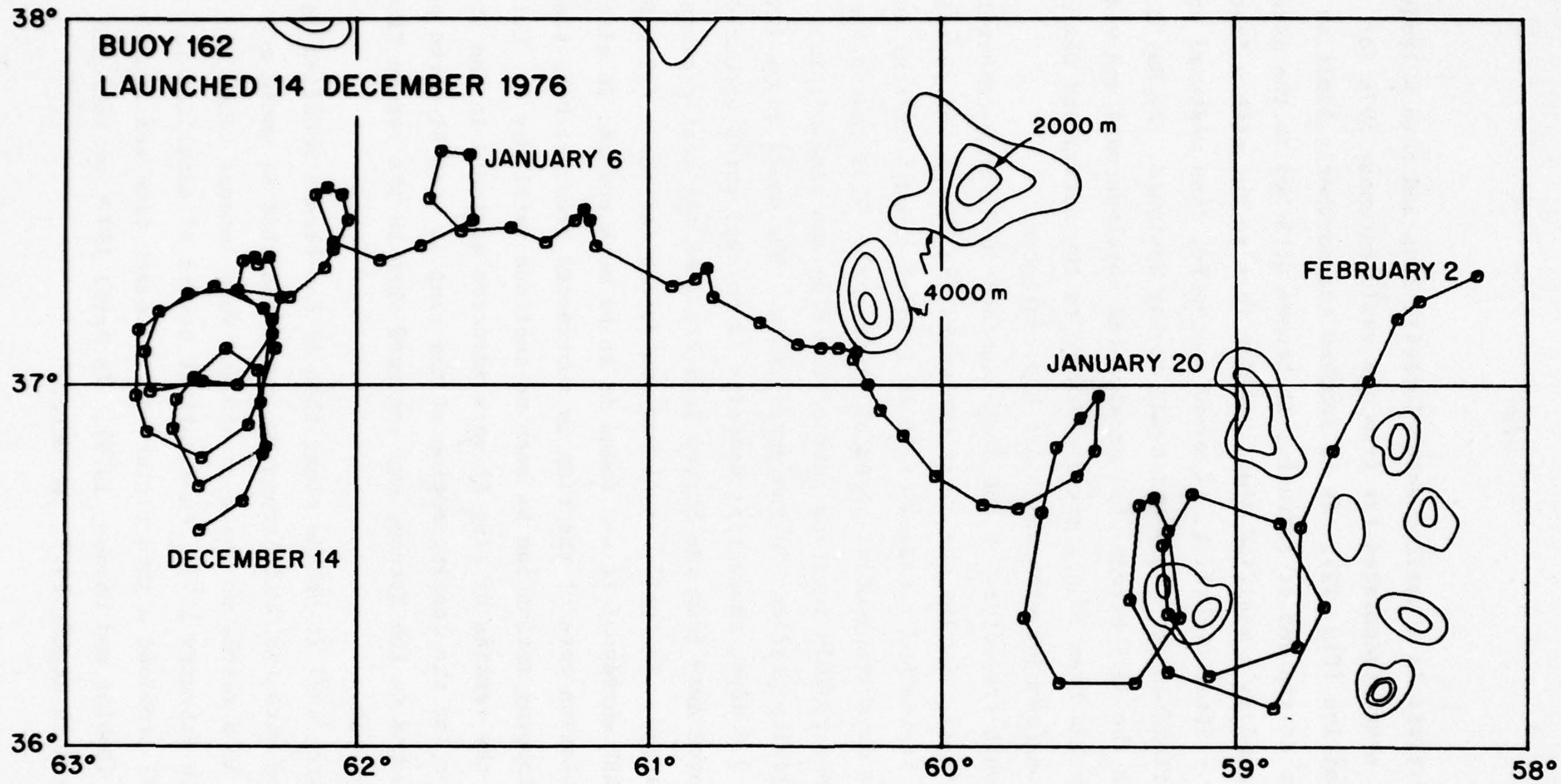


Figure 11. Trajectory of buoy 162 launched in ring Art, 14 December 1976. Two fixes per day are shown by closed circles. Ring Art coalesced with the Gulf Stream in January 1977 and the buoy moved eastward in the Stream.

A1 moved first in a small counterclockwise loop and then a large clockwise loop; it never translated far from its early December 1976 (or September) position (Fig. 12). As A1 reached its northerly limit on the clockwise loop at the end of February, it became attached to the Stream and then reformed as a modified ring, smaller in size but with a faster rotation rate. After reforming, A1 moved southward, then westward and collided with a ring/meander (Bob) which was moving eastward. By May 2 A1 had coalesced with the Gulf Stream, had accelerated northeastward and was lost. The buoy which had been in A1, moved eastward in the Stream and was caught by the same ring/meander with which Art had coalesced.

A five month trajectory of the buoy launched in A1 in December 1976 is shown in Figure 12. During the first two weeks the buoy moved radially outward until it reached a radius of 35 km (radial speed 6 cm/sec) and a period of five days (tangential speed of 51 cm/sec). This radius was located within the rapidly rotating part of the ring and also within a strong horizontal salinity gradient in the upper 200 m. The small loops (radius 20 km, period 2.0 days, tangential velocity 73 cm/sec) which occurred in March as A1 moved away from the Stream indicate that the ring's characteristics had changed. In April, as A1 was coalescing for the final time we made a short XBT survey of it and found it to be much reduced in size. When the translation rate of the ring is subtracted from the buoy trajectory, the looping motion can be seen to continue until May 1. Evidence suggests that the remains of ring A1 were advected eastward in the Stream. One explanation for the looping motion of the ring is that A1 moved eastward when attached to the Stream, and westward when in the return flow south of the Stream.

During March 1977 it became clear that A1 had become modified through its interaction with the Gulf Stream; we suspected that A1 would not last much longer. As a result we chose to study a very intense ring, Bob, which formed in February 1977. An excellent series of satellite infrared images (NOAA 5) provided a good picture of the exact time and location of its formation (Doblar and Cheney, 1977). In April 1977, we launched three buoys in Bob and in August 1977 two more.

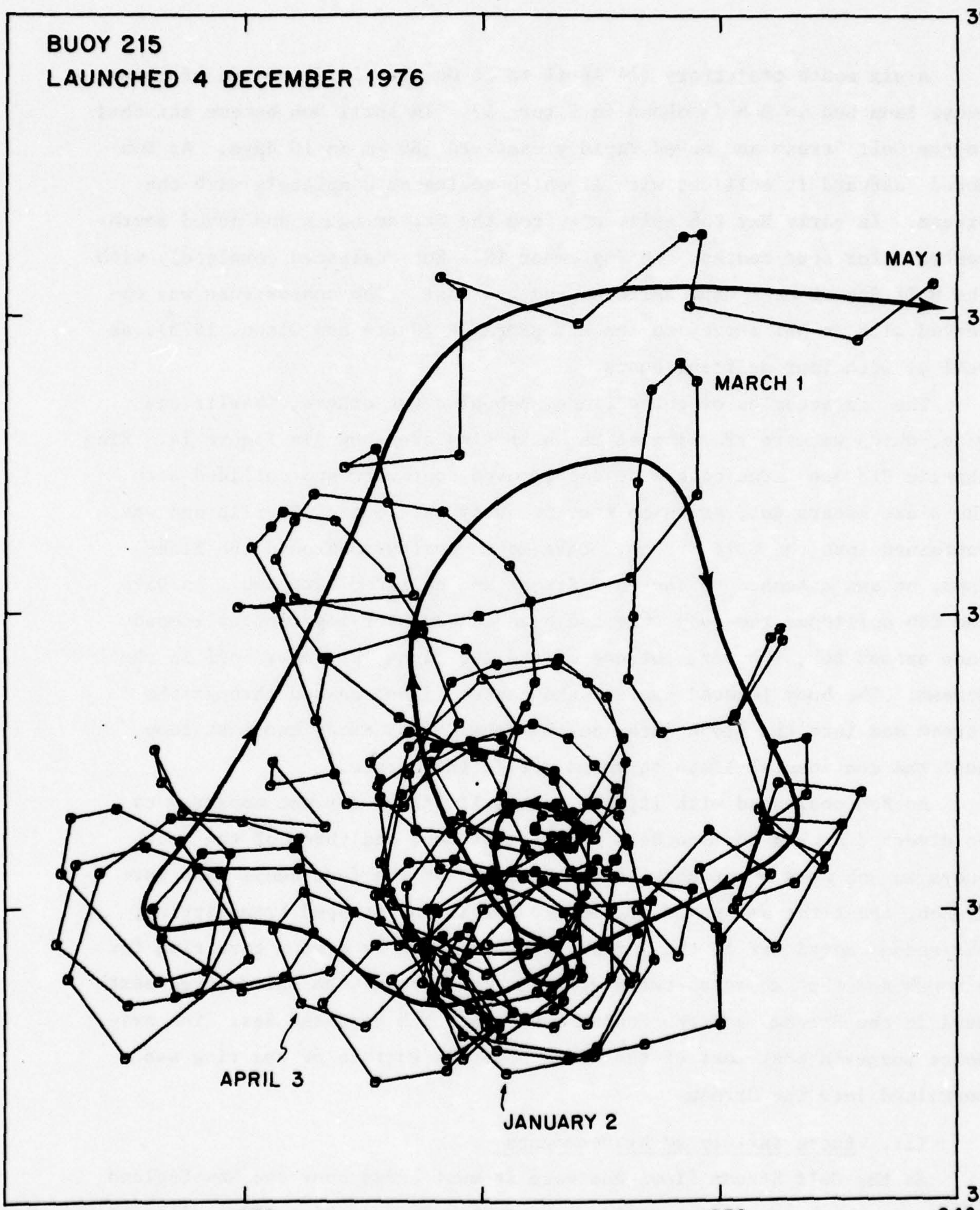


Figure 12. Trajectory of buoy 215 launched in ring A1, 4 December 1976. Dark line is inferred path of the center of ring A1. Ring A1 coalesced with the Gulf Stream at the end of April 1977 as the Stream formed another, more intense ring, Bob, to the west of A1.

A six month trajectory (14 April to 26 October 1977) of one of three buoys launched in Bob is shown in Figure 13. In April Bob became attached to the Gulf Stream and moved rapidly eastward 180 km in 10 days. As Bob moved eastward it collided with Al which coalesced completely with the Stream. In early May Bob split off from the Stream again and moved southwestward for four months. In September 1977 Bob coalesced completely with the Gulf Stream near Cape Hatteras and was lost. The coalescence was observed with an XBT survey on the R/V ENDEAVOR (Watts and Olson, 1978), as well as with four drifting buoys.

The trajectories of three rings, Bob plus two others, Charlie and Dave, which we were tracking at the same time are shown in Figure 14. Ring Charlie did one large clockwise loop, moved southward and collided with the Blake Escarpment, at which time the buoy came out of Charlie and was entrained into the Gulf Stream. Dave moved northward around the Blake Spur, became attached to the Gulf Stream and collided with Bob. As Dave and Bob collided, the buoy that had been in Dave for five months looped once around Bob, the more intense of the two rings, and moved off in the Stream. The buoy located nearest the center of Bob passed through the Stream and into the Slope Water on the other side; after one last loop near the continental slope it moved off in the Stream.

As Bob coalesced with it, the main Gulf Stream current appeared to be diverted around the southeastern side of Bob, and three of the four buoys in Bob were swept away in the Stream. Of the four buoys that were in Bob, the first one moved off in the Stream and stopped transmitting, the second moved off in the Stream, was entrained by a warm core ring for a month and then moved eastward again in the Stream, the third moved eastward in the Stream, and the fourth moved into the Sargasso Sea. The evidence suggests that most of the water near the surface of the ring was entrained into the Stream.

III. Buoys influenced by seamounts.

As the Gulf Stream flows eastward it must cross over the New England Seamounts which are an impressive mountain chain, reaching quite close to the ocean surface and occupying a large portion of the deep water region

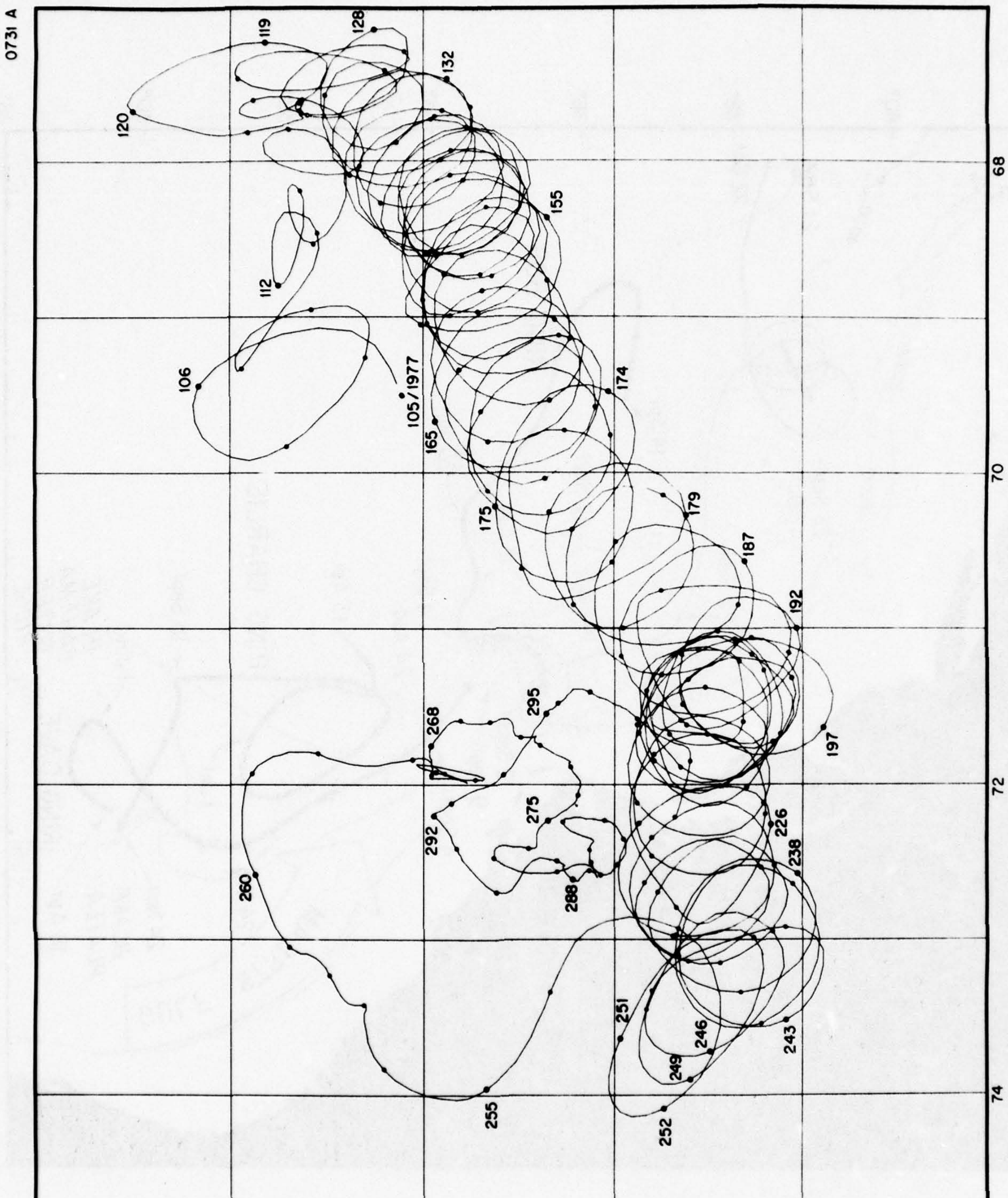


Figure 13. Trajectory of buoy 731A, launched 14 April 1977 in ring Bob. The trajectory was calculated with a cubic spline. The straight lines are three hour segments; one dot per day is shown and the numbers represent the consecutive day of the year beginning with January 1 (see Table A-2, page 39).

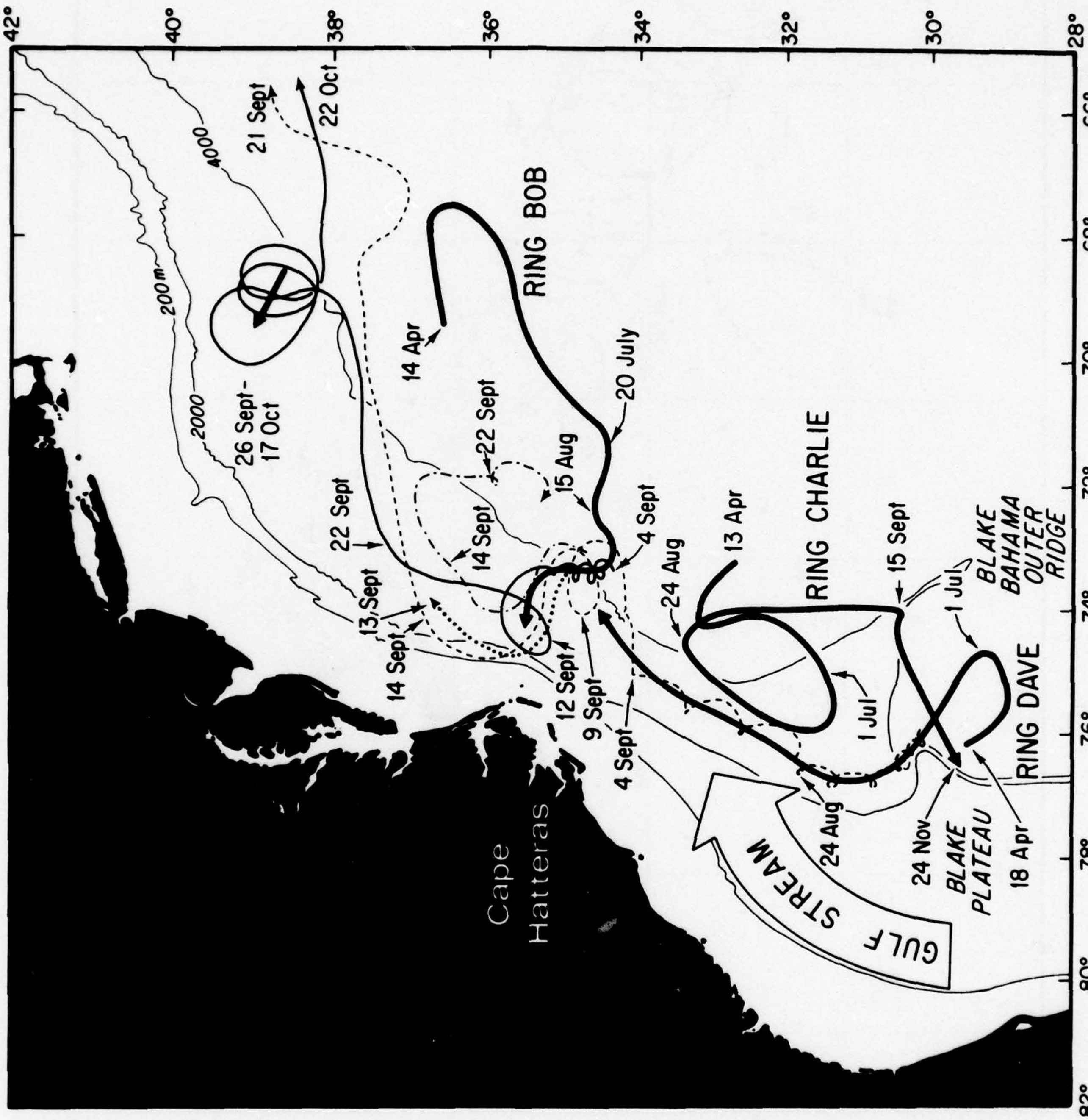


Figure 14. Simultaneous trajectories of three rings, Bob, Charlie and Dave (dark lines) from April to November 1977 and portions of four buoy trajectories (lighter lines). In August two additional buoys were launched in Bob bringing the total to three buoys. All three plus a fourth that had been in Dave but had become entrained into Bob were swept away in the Gulf Stream as Bob coalesced with the Stream.

(Fig. 15). The deep water of the Stream must pass either over the seamounts or between them. Several buoys that moved eastward in the Gulf Stream showed that surface currents can be strongly influenced by individual seamounts as well as clusters of seamounts. Approximately half of all the buoys in the Stream passing the New England Seamounts became trapped in a complicated meander/ring/eddy structure lying near the seamounts (Figs. 16 and 17). This region is also one in which rings frequently form and also coalesce with the Stream (Fig. 9).

One buoy (1076A) which passed over the Atlantis II Seamount suggests the presence of a Taylor (1917) column (Fig. 18). This buoy moving eastward in the Gulf Stream with speeds of 100-150 cm/sec, slowed to 5-10 cm/sec as it passed over the top of the seamount in a partial anticyclonic* (clockwise) loop and then speeded up again to 100 cm/sec. The buoy remained near the seamounts caught in strong eddy motion for four months. The motion of the buoy as it passed over the seamount is very similar to that suggested by McCartney (1975, Fig. 4; 1976, Fig. 5) who modelled the formation of Taylor columns over seamounts by an impinging flow. McCartney shows a small trapped region of anticyclonic flow over a seamount and a meandering wake downstream (eastward) of the seamount. Under certain circumstances the wake forms a train of cyclonic and anticyclonic eddies. Vastano and Warren (1976) have reported finding warm-core and cold-core eddies in the lee of the Atlantis II Seamount in agreement with McCartney's model.

Additional evidence for the presence of Taylor columns over seamounts is given by buoy 113B, which looped over the Corner Rise Seamounts (Fig. 19). This buoy, launched in the Gulf Stream, moved eastward then southward, and as it approached the Corner Rise it stopped. After it reached what looks like a stagnation point in the flow, the buoy began to loop (anticyclonic loops) over the seamounts. The buoy looped four times (period $\sim$ 12 days, diameter 40-100 km, mean speed $\sim$ 35 cm/sec) over the seamounts and then once more as the eddy in which it was embedded was swept away to the southwest. Two other buoys (1040A, 1076A) also made anticyclonic loops in the

*Note that rings south of the Stream have cyclonic (counterclockwise) circulation.

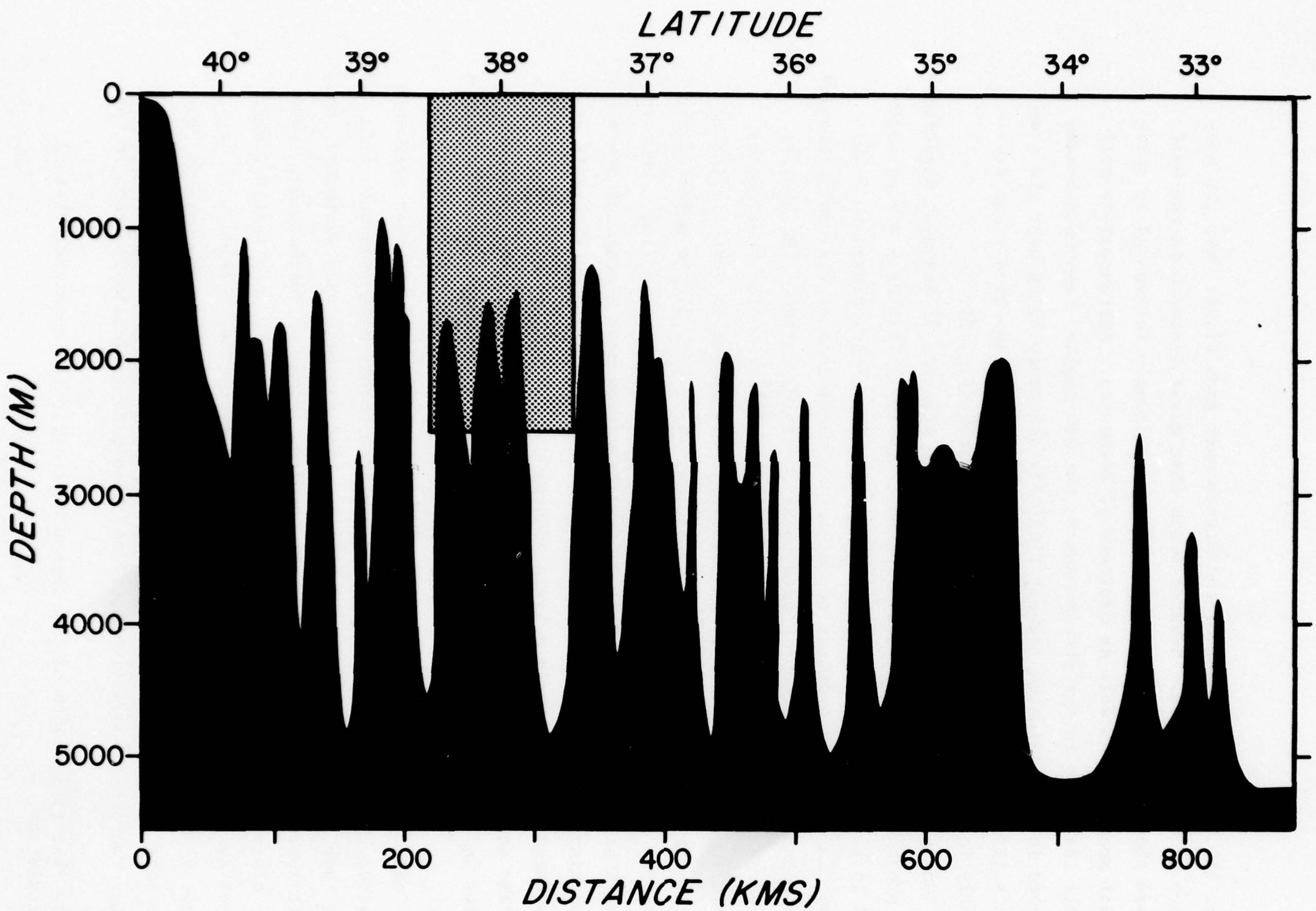


Figure 15. A North-South section through the New England Seamounts. The Gulf Stream is shown schematically by the stippled region. In this figure the Stream is 110 km wide and 2.5 km deep.

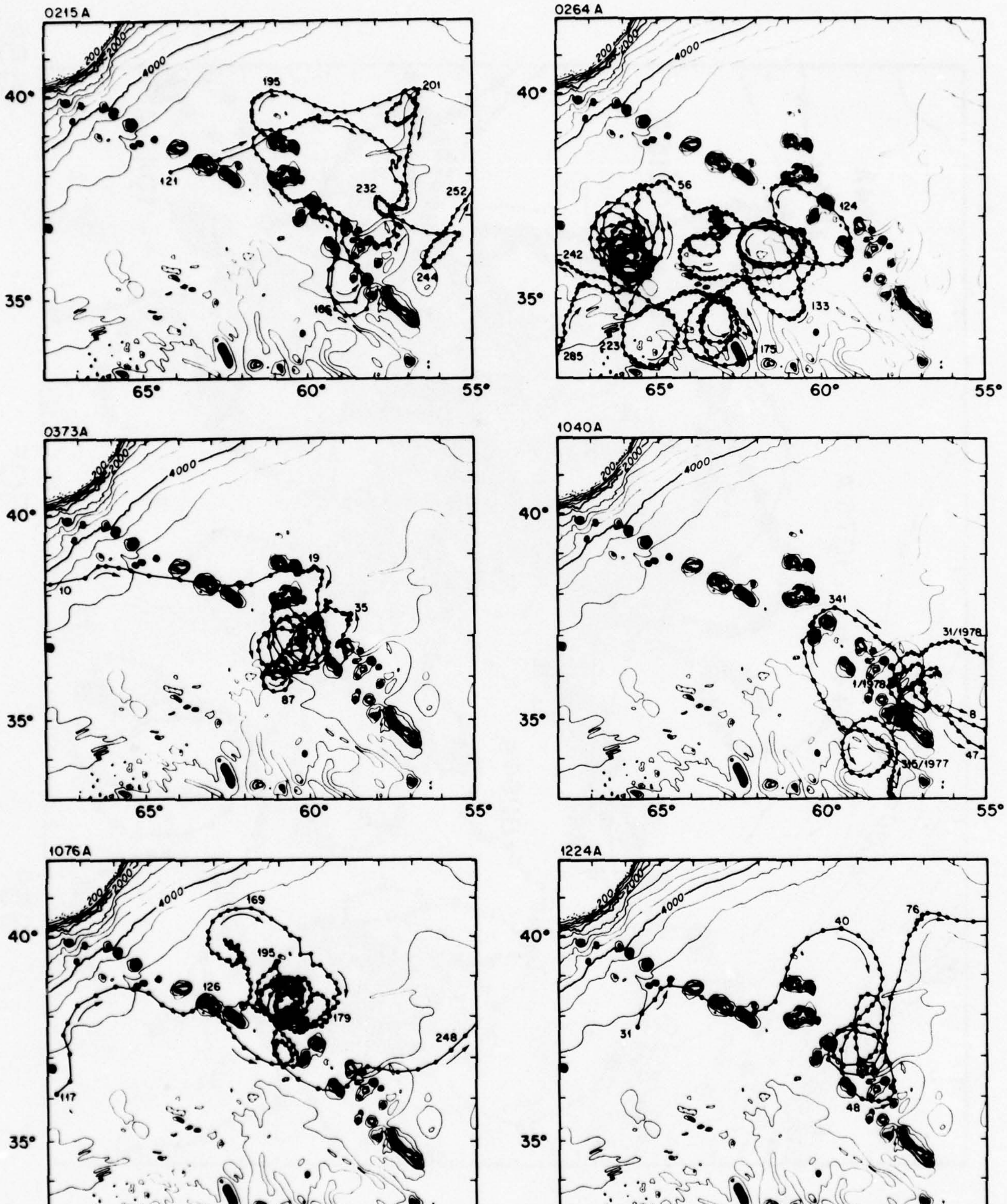


Figure 16. Trajectories of six buoys which were caught in strong eddy motion near the New England Seamounts.

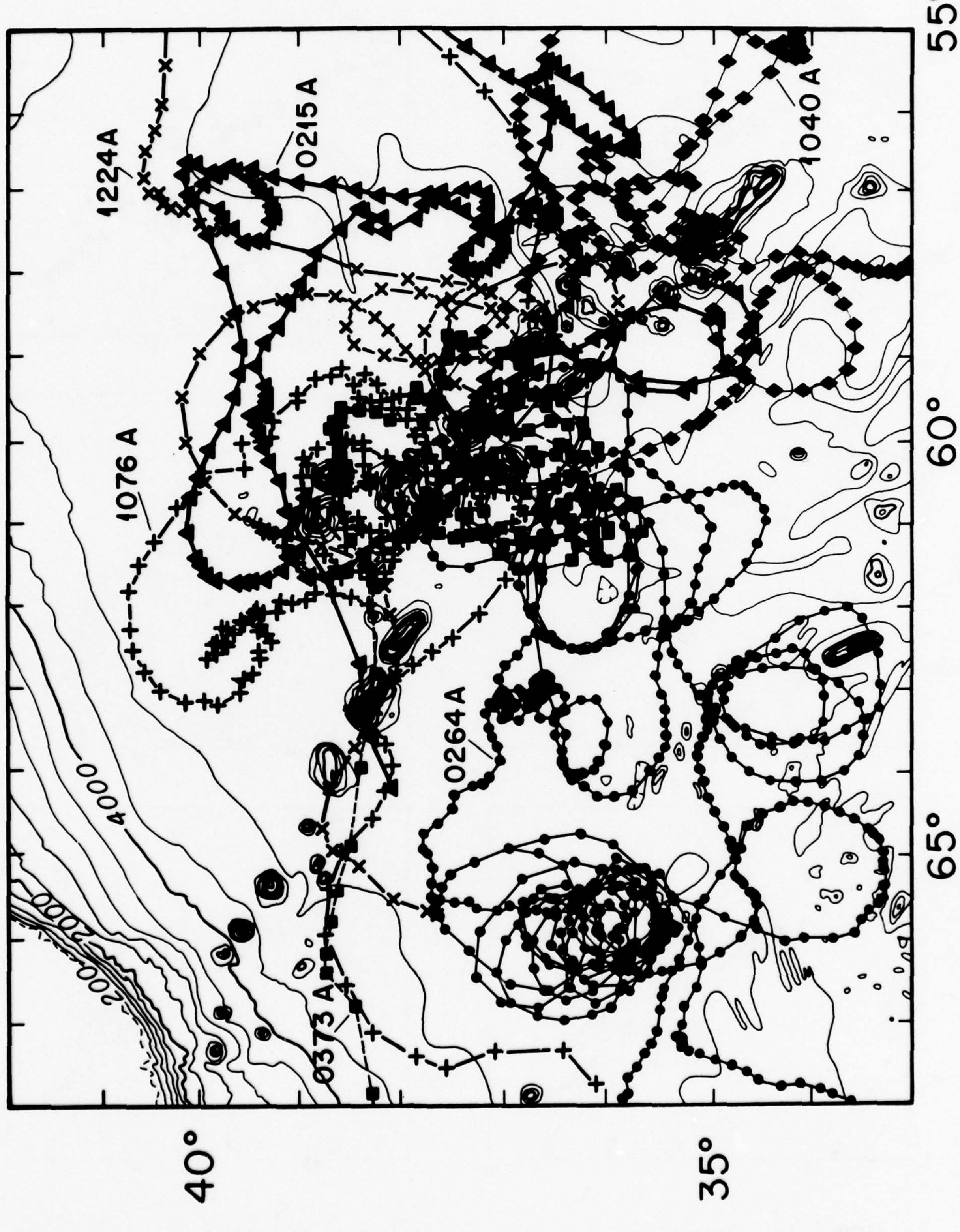


Figure 17. Superposition of the six trajectories shown in the previous figure.

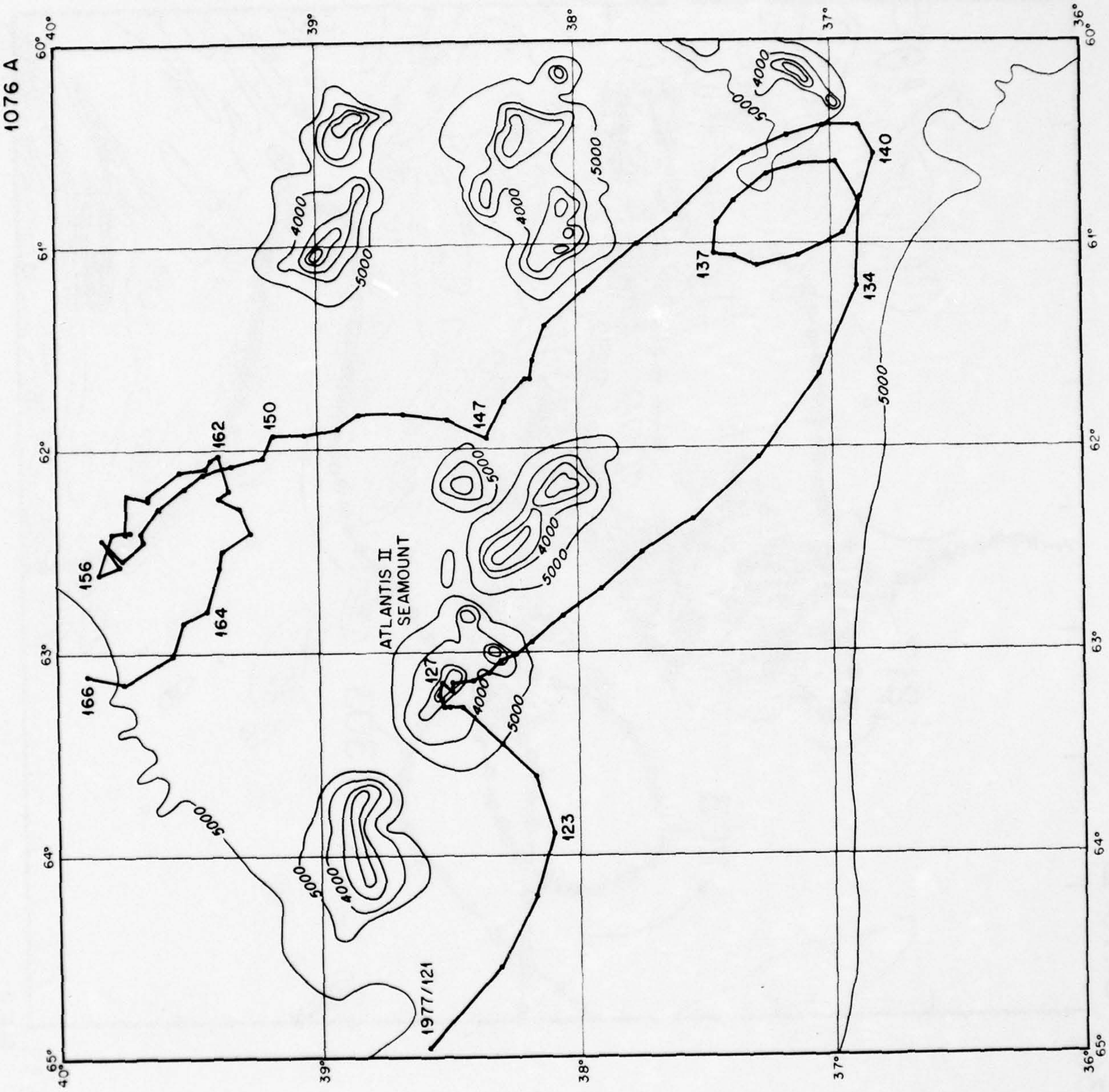


Figure 18. Trajectory of buoy 1076A as it passed in a small anticyclonic loop over the Atlantis II Seamount.

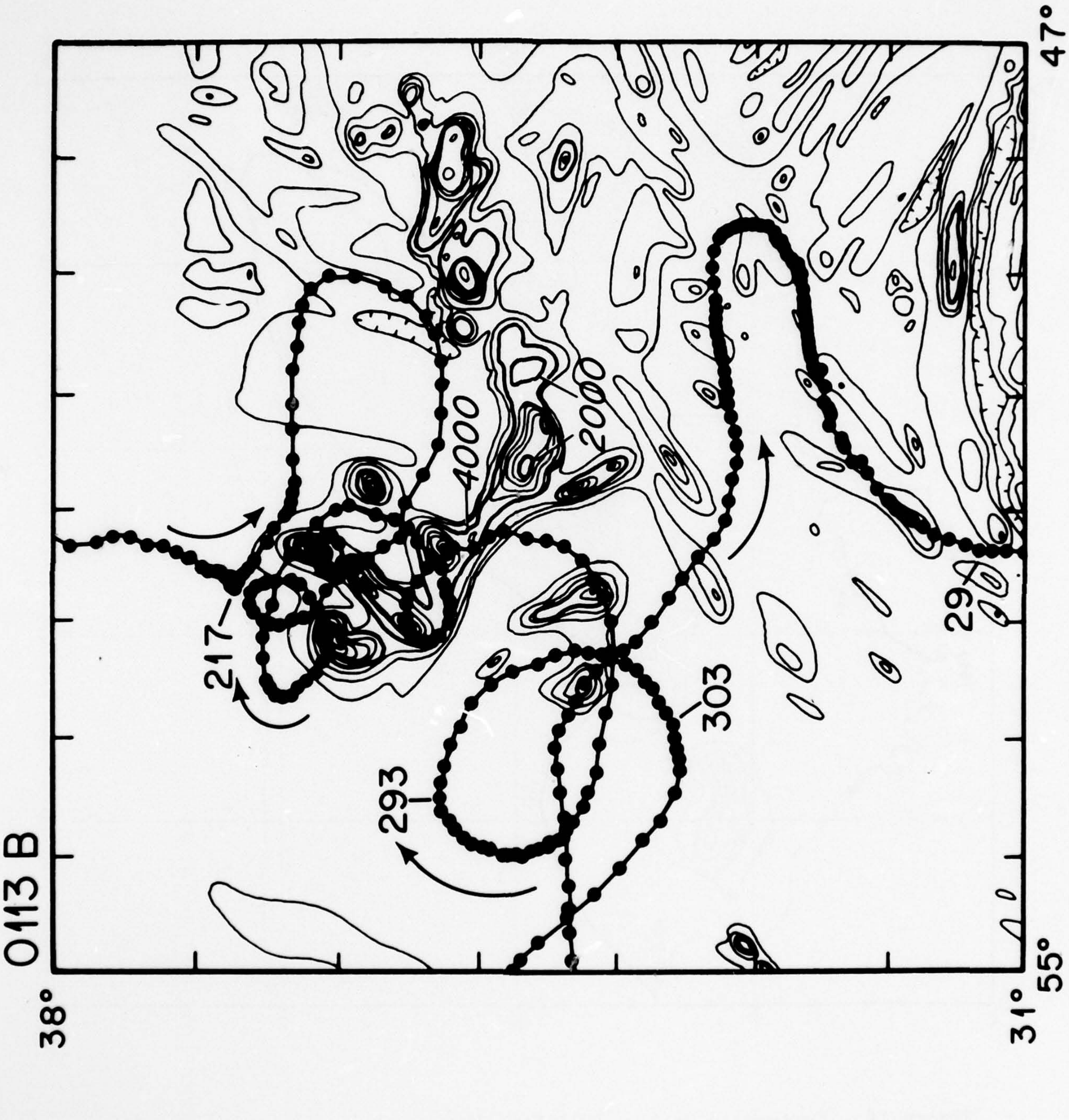


Figure 19. Trajectory of buoy 0113B as it first stopped at the edge of the Corner Rise Seamounts and then began to loop over the seamounts.

vicinity of the Corner Rise Seamounts. In addition, one buoy moving eastward in the Kuroshio Current was observed to make a series of anticyclonic loops over the Emperor Seamount Chain (Cheney, Richardson and Nagasaka, 1978).

SUMMARY

The buoys have revealed some interesting aspects of the ocean flow, including the movement of rings, paths of the Gulf Stream and the influence of bathymetric features such as seamounts on the surface flow. Although the buoy trajectories are a measurement of the near surface currents (very close to the surface, two meters, for the buoys without drogues), these currents frequently extend to great depths, at least in the case of rings and the Gulf Stream.

While buoys were in strong currents the influence of the wind on the buoy either directly or via surface waves and wind drift currents was probably small. One buoy stayed in a ring for eight months; the wind had little or no effect on this one, or on other buoys in rings. As the buoys moved into the eastern regions where slower currents were observed (over the mid-Atlantic Ridge for example), the wind influence on the buoy's motion may have become important and thus these trajectories need to be interpreted with caution. We are presently examining the problem of wind-induced buoy velocity.

ACKNOWLEDGEMENTS

This research was made possible with funds provided by the National Science Foundation (Grants OCE75-08765, OCE77-08045) and the Office of Naval Research (Contract N00014-74-C-0262, NR 083-004). Many people aided in this study especially those who formed the nucleus of the ring experiment, D. Kester, A. Vastano and P. Wiebe.

The buoys were launched and retrieved on a series of cruises by numerous people namely G. Cotter, G. Knapp, V. Worthington, D. Lai, D. Mountain, G. Tupper, G. Volkmann, P. LaViolette, R. Harbison, M. Briscoe, D. Moller and N. Hogg. M. Burdette (NDBO) provided the direction finder which was used to locate the buoys, D. Simoneau rigged most of the tethers

and A. Morton repowered several buoys.

NASA provided the buoy positions and telemetered data. B. Seechuck and M. McElroy assisted by sending data to us at sea so we could follow the movement of the buoys by ship. R. Goldsmith prepared the basic buoy data processing and plotting programs. G. Flierl developed the cubic spline interpolating program. S. Waskilewicz and G. Knapp assisted in the data processing and T. McKee created the final time series plots.

Unpublished data from buoys which were part of other experiments were provided by J. Fornshell, E. Kerut, D. Kirwan, A. Leetmaa and R. Weir. Some of these buoy trajectories are shown in Appendix B.

REFERENCES

Cheney, R. E., P. L. Richardson, and K. Nagasaka, 1978. Tracking a Kuroshio Cold Ring with a Free-drifting Buoy. Deep-Sea Res. (submitted).

Cheney, R. E., W. H. Gemmill, M. K. Shank, P. L. Richardson, and D. Webb. 1976. Tracking a Gulf Stream ring with SOFAR floats. J. Phys. Oceanogr. 6:741-749.

Doblar, R. A. and R. E. Cheney. 1977. Observed formation of a Gulf Stream cold core ring. J. Phys. Oceanogr. 7:944-946.

Fuglister, F. C. 1972. Cyclonic rings formed by the Gulf Stream, 1965-1966. Studies in Physical Oceanography, Vol. 1, Gordon and Breach, 137-167.

Fuglister, F. C. 1977. A cyclonic ring formed by the Gulf Stream 1967. A Voyage of Discovery, Pergamon Press, 177-198.

Gotthardt, G. A. 1973. Observed formation of a Gulf Stream anticyclonic eddy. J. Phys. Oceanogr. 3:237-238.

Greene, C. R. 1978. RAMS Position Accuracy Analysis, Technote No. 52. Polar Research Laboratory, Inc., Santa Barbara, CA.

Kirwan, A. D. Jr., G. McNally and J. Coehlo. 1976. Gulf Stream Kinematics Inferred from a Satellite-Tracked Drifter. J. Phys. Oceanogr. 6:750-755.

Lai, D. Y. and P. L. Richardson. 1977. Distribution and Movement of Gulf Stream Rings. J. Phys. Oceanogr. 7:670-683.

Mann, C. R. 1967. The termination of the Gulf Stream and the beginning of the North Atlantic current. Deep-Sea Res. 14:337-360.

Martin, P., C. R. Gillespie. 1978. Arctic Odyssey-Five years of Data Buoys in AIDJEX. AIDJEX Bulletin No. 40:7-14.

McCartney, M. S. 1975. Inertial Taylor columns on a beta plane. J. Fluid Mech. 68:71-95.

McCartney, M. S. 1976. The interactions of zonal currents with topography with application to the Southern Ocean. Deep-Sea Res. 23: 413-427.

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner and D. H. Bent. 1975. Statistical Package for the Social Sciences. McGraw-Hill. New York. 675p.

Parker, C. E. 1971. Gulf Stream rings in the Sargasso Sea. Deep-Sea Res. 18:981-993.

Richardson, P. L., R. E. Cheney and L. A. Mantini. 1977. Tracking a Gulf Stream ring with a Free-drifting Surface Buoy. J. Phys. Oceanogr. 7:580-590.

Richardson, P. L., R. E. Cheney and L. V. Worthington. 1978. A Census of Gulf Stream Rings, Spring 1975 J. Geophys. Res. (in press).

Saunders, P. M. 1971. Anticyclonic eddies formed from shoreward meanders of the Gulf Stream. Deep-Sea Res. 18:1207-1219.

Taylor, G. I. 1917. Motion of solids in fluids when the flow is not irrotational. Proc. Roy. Soc. A93, 99-113.

U. S. Coast Guard. 1978. Report of the International Ice Patrol Service in the North Atlantic Ocean. USCG Bulletin Nos. 62, 63, 64; CG-188-31, 32, 33. (in press).

Vastano, A. C. and B. A. Warren. 1976. Perturbations to the Gulf Stream by Atlantis II Seamount. Deep-Sea Res. 23:681-694.

Watts, D. R. and D. B. Olson. 1978. Gulf Stream Coalescence with the Gulf Stream off Cape Hatteras . Science 202, 971-972.

Worthington, L. V. 1976. On the North Atlantic circulation. The Johns Hopkins Oceanographic Series, Vol. 6, The Johns Hopkins University Press, Baltimore, 110pp.

APPENDIX A

Individual Buoy Data

This section of the report contains a summary of each buoy's launch position, drogue, tether and life (Table A-1) and a series for each buoy containing a buoy information sheet, a plot of the trajectory (two dots per day) and a plot of the velocity, speed, direction and temperature vs time. Note that "up" on the velocity stick diagrams corresponds to an eastward velocity. Table A-2 which converts year day to month and day, is included.

Information sheets and plots for five buoys obtained from other investigators is included in Appendix B.

Table A-1 BUOY SUMMARY

BUOY ID(a)	DATE	CRUISE	LOCATION	LAUNCH POSITION LAT.	LONG.	TETHER(b)	DROGUE(e)	LIFE (days)
0113A	7 VI 76	OCEANUS 7	Ring D	31°50'	75°27'	.62 nylon	WS	92
0113B	9 VII 77	KNORR 66	Gulf Stream	40 30	56 24	1.5 pp	WS	316(c)
0125A	5 XII 76	KNORR 62	Ring A1	36 34	65 17	.62 nylon	WS	40
0125B	9 VI 77	KNORR 66	Gulf Stream	39 48	57 15	1.5 pp	WS	80
0154A	12 VI 76	OCEANUS 7	Ring Lai	34 45	70 17	.62 nylon	WS	28
0154B	10 VII 77	KNORR 66	Gulf Stream	38 54	58 42	1.25 pp	WT	42
0162A	14 XII 76	KNORR 62	Ring Art	36 37	62 33	1.5 pp	WT	420
0215A	4 XII 76	KNORR 62	Ring A1	36 14	65 34	1.5 pp	WT	328
0252A	10 IV 77	KNORR 65	Ring Dave	29 01	77 26	1.25 pp	WT	206
0264A	17 XII 76	KNORR 62	Ring A1	36 10	66 07	1.5 pp	WS	326(c)
0264B	5 IV 78	EVERGREEN	N. Atl. Current	42 43	45 11	1.5 pp	WT	(51+)(d)
0401A	23 X 76	BARTLETT	Kuroshio Ring	33 00	143 19	.37 nylon	WS	237
0437A	26 X 76	KNORR 60	Ring Valentine	37 20	58 08	.25 dacron	WS	244(c)
0512A	31 VII 77	ENDEAVOR 11	Ring Bob	34 30	71 27	1.5 pp	WT	(298+)
0557A	13 IX 77	CG C-130	Ring/Meander	41 31	64 00	.37 nylon	WS	157
0614A	14 VII 77	ENDEAVOR 11	Ring Bob	34 39	72 02	1.5 pp	WT	31
0707A	12 IV 77	KNORR 65	Ring Charlie	32 48	73 10	1.25 pp	WT	416(c)
0731A	14 IV 77	KNORR 65	Ring Bob	36 04	69 40	1.25 pp	WS	196(c)
0731B	13 IV 78	EVERGREEN	Labrador Current	48 34	49 02	1.5 pp	WT	(44+)(c)
1040A	14 IV 77	KNORR 65	Ring Bob	37 03	68 58	1.25 pp	WS	426
1076A	15 IV 77	KNORR 65	Ring Bob	36 34	69 32	1.25 pp	WS	374
1151A	3 XII 75	TRIDENT 175	Ring George	36 10	58 00	.62 nylon	WS	133
1212A	12 VIII 77	ENDEAVOR 11	Near Ring Bob	34 17	70 26	1.5 pp	WT	75
1224A	1 XI 77	KNORR 71	Ring Franklin	36 37	65 46	1.5 pp	WT	(207+)
1322A	5 VI 77	KNORR 66	Mid-Atlantic Ridge	33 31	32 59	1.25 pp	WT	302
1346A	31 VI 77	KNORR 66	Gulf Stream	36 50	46 22	1.25 pp	WT	96
1370A	17 XI 77	KNORR 71	Ring Q	39 42	67 30	1.25 pp	WT	(190+)
1406A	27 X 77	KNORR 71	Ring Emerson	34 51	70 08	1.5 pp	WT	91
1475A	16 X 75	EASTWARD	Ring D	35 30	71 20	.62 nylon	WS	4
1552A	9 VII 77	KNORR 66	Gulf Stream	40 40	56 18	1.5 pp	WS	202
1773A	8 XII 75	TRIDENT 175	Ring	34 40	65 40	.62 nylon	WS	4

(a) A refers to first time identification number was used, B the second, etc.

(b) 200 m line except for 0437A which had 400 m and 0557A which had 50 m. The number refers to diameter in inches.

(c) Buoy was recovered.

(d) (+) buoy still working

(e) WS - window shade drogue

WT - 100 pound weight

TABLE A-2 THE NUMBER OF EACH DAY OF THE YEAR

Day of Mo.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Day of Mo.
1	1	32	60	91	121	152	182	213	244	274	305	335	1
2	2	33	61	92	122	153	183	214	245	275	306	336	2
3	3	34	62	93	123	154	184	215	246	276	307	337	3
4	4	35	63	94	124	155	185	216	247	277	308	338	4
5	5	36	64	95	125	156	186	217	248	278	309	339	5
6	6	37	65	96	126	157	187	218	249	279	310	340	6
7	7	38	66	97	127	158	188	219	250	280	311	341	7
8	8	39	67	98	128	159	189	220	251	281	312	342	8
9	9	40	68	99	129	160	190	221	252	282	313	343	9
10	10	41	69	100	130	161	191	222	253	283	314	344	10
11	11	42	70	101	131	162	192	223	254	284	315	345	11
12	12	43	71	102	132	163	193	224	255	285	316	346	12
13	13	44	72	103	133	164	194	225	256	286	317	347	13
14	14	45	73	104	134	165	195	226	257	287	318	348	14
15	15	46	74	105	135	166	196	227	258	288	319	349	15
16	16	47	75	106	136	167	197	228	259	289	320	350	16
17	17	48	76	107	137	168	198	229	260	290	321	351	17
18	18	49	77	108	138	169	199	230	261	291	322	352	18
19	19	50	78	109	139	170	200	231	262	292	323	353	19
20	20	51	79	110	140	171	201	232	263	293	324	354	20
21	21	52	80	111	141	172	202	233	264	294	325	355	21
22	22	53	81	112	142	173	203	234	265	295	326	356	22
23	23	54	82	113	143	174	204	235	266	296	327	357	23
24	24	55	83	114	144	175	205	236	267	297	328	358	24
25	25	56	84	115	145	176	206	237	268	298	329	359	25
26	26	57	85	116	146	177	207	238	269	299	330	360	26
27	27	58	86	117	147	178	208	239	270	300	331	361	27
28	28	59	87	118	148	179	209	240	271	301	332	362	28
29	29	*	88	119	149	180	210	241	272	302	333	363	29
30	30		89	120	150	181	211	242	273	303	334	364	30
31	31		90		151		212	243		304		365	31

* In leap years, after February 28, add 1 to the tabulated number.

Buoy Identification Number 0113A

Project Gulf Stream Rings

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise OCEANUS 7

Date/Time (GMT) June 7, 1976, 2209 z (JD 159)

Position 31°50' 75°27'

Depth of 15° 292m

Comments Ring D, Launched by David Lai

(2) Buoy Configuration

Hull FG (Nova U)

Electronics AEL

Drogue WS (window shade, 1.8 x 13.7 m)

Tether 5/8" dia. nylon line, 200 m

Temperature Sensor yes, did not work

Drogue Tension Sensor yes, did not work

Anemometer yes, did not work

Comments

(3) Buoy Recovery/Last Position

Date/Time (GMT) Sept. 8, 1976 (JD252)

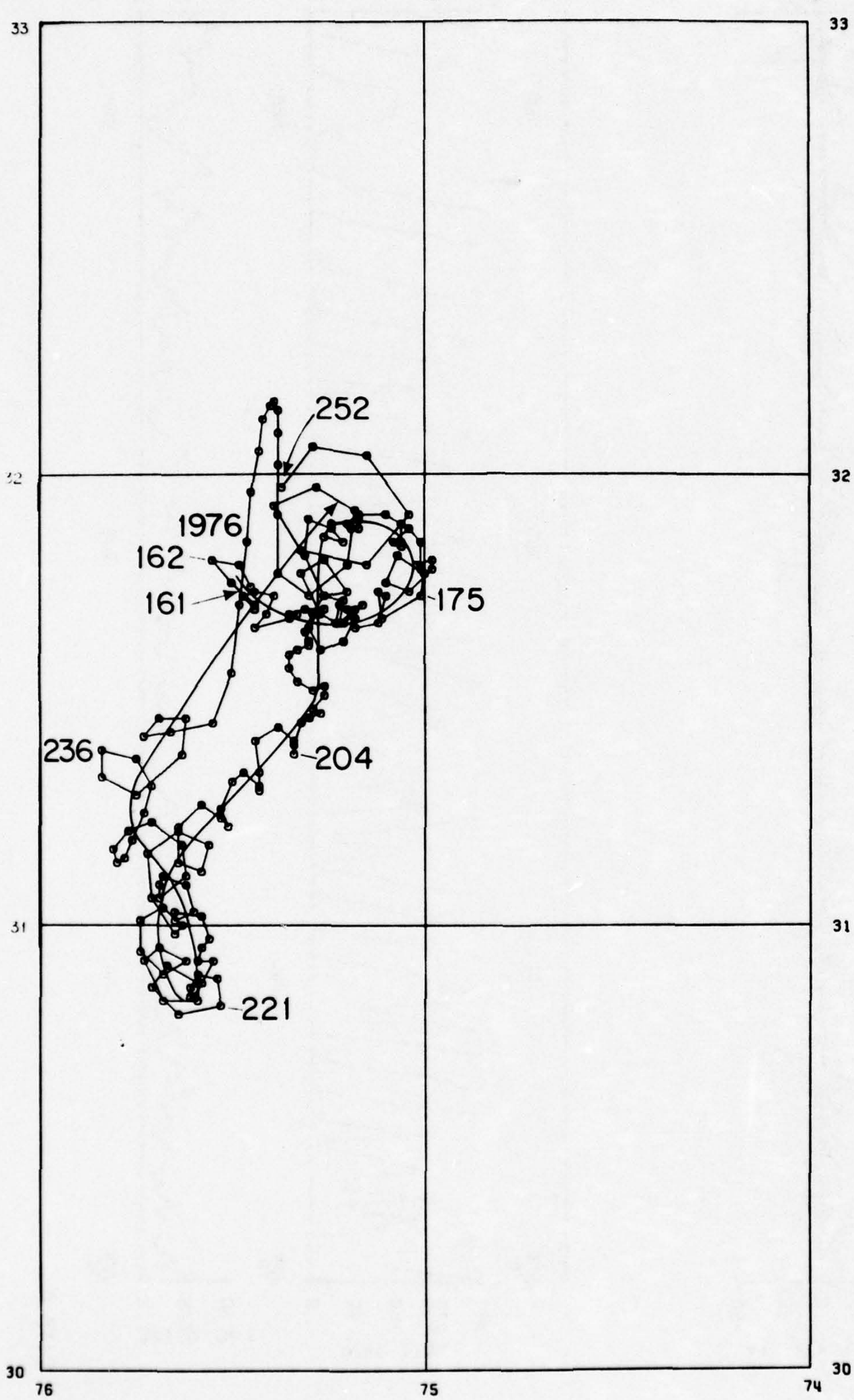
Position 31°56' 75°23'

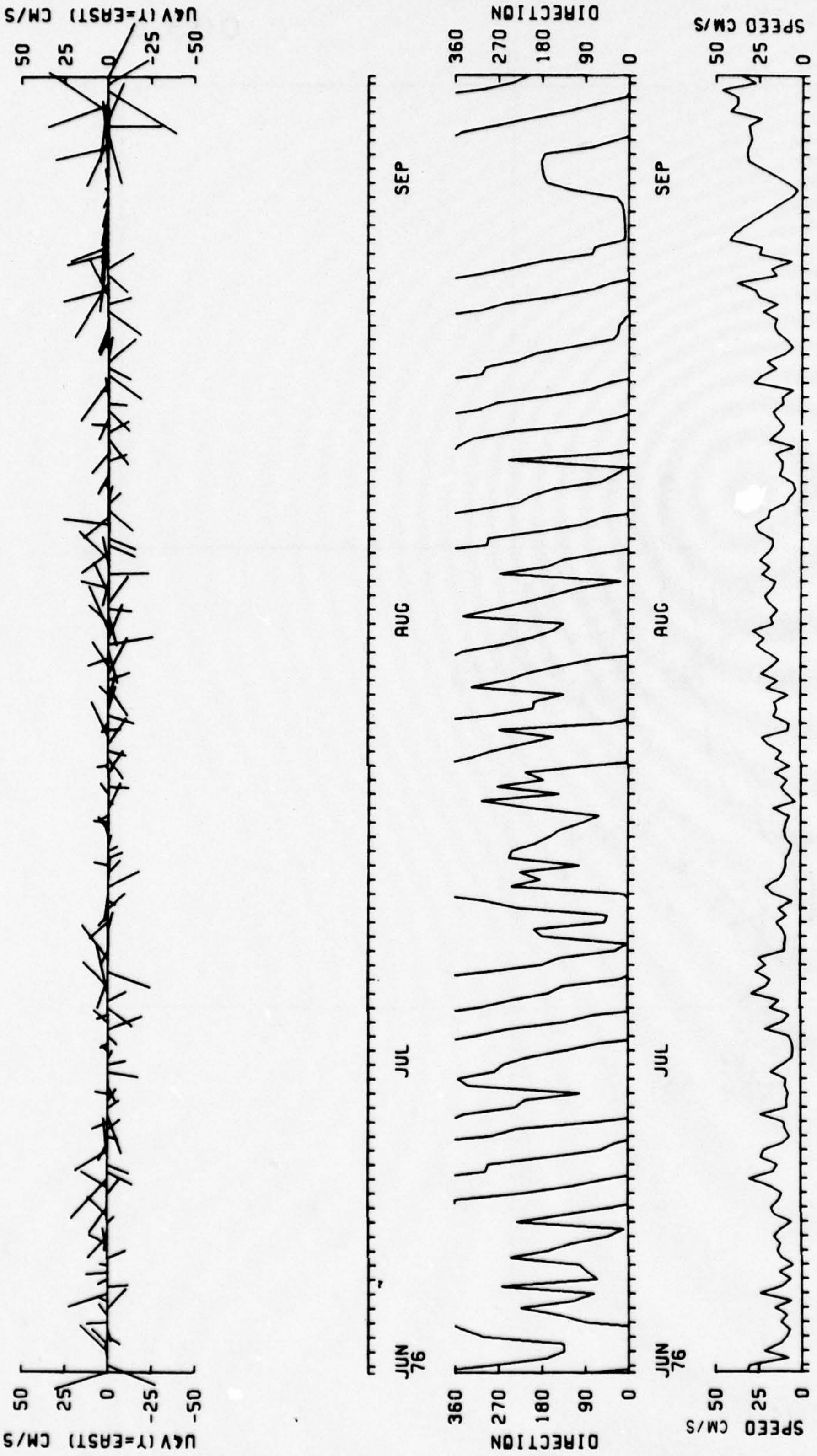
Life of Buoy (days) 92

Depth 15°C

Date Drogue came off

0113 A


75
74
33
33
32
32
31
31
30
30
76
75
74
252
1976
162
161
175
236
204
221


U&V(Y=EAST) CM/S
50
25
0
-25
-50
DIRECTION
360
270
180
90
0
SPEED CM/S
50
25
0
JUN 76
JUL
AUG
SEP

0113 A

Buoy Identification Number 0113B (reused ID)

Project Gulf Stream

Funding NSF OCE77-08045

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 66

Date/Time (GMT) 9 July 1977, 1555 z (JD 190)

Position 40°30' 56°24'W

Depth of 15° 390

Comments Gulf Stream

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue WS

Tether 600 ft. 1-1/2 in dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

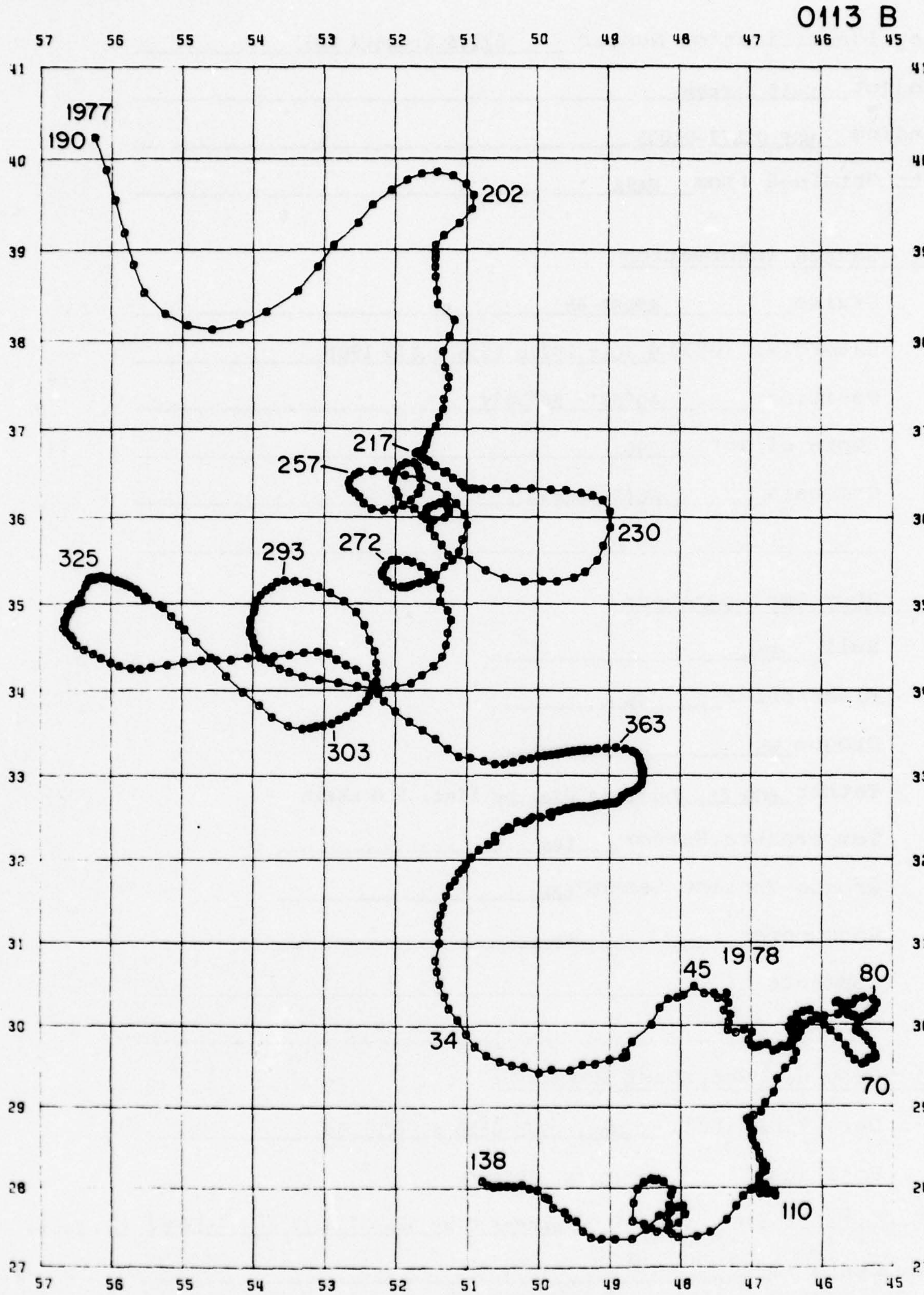
Date/Time (GMT) 20 May, 1978 0610 z, (JD 140)

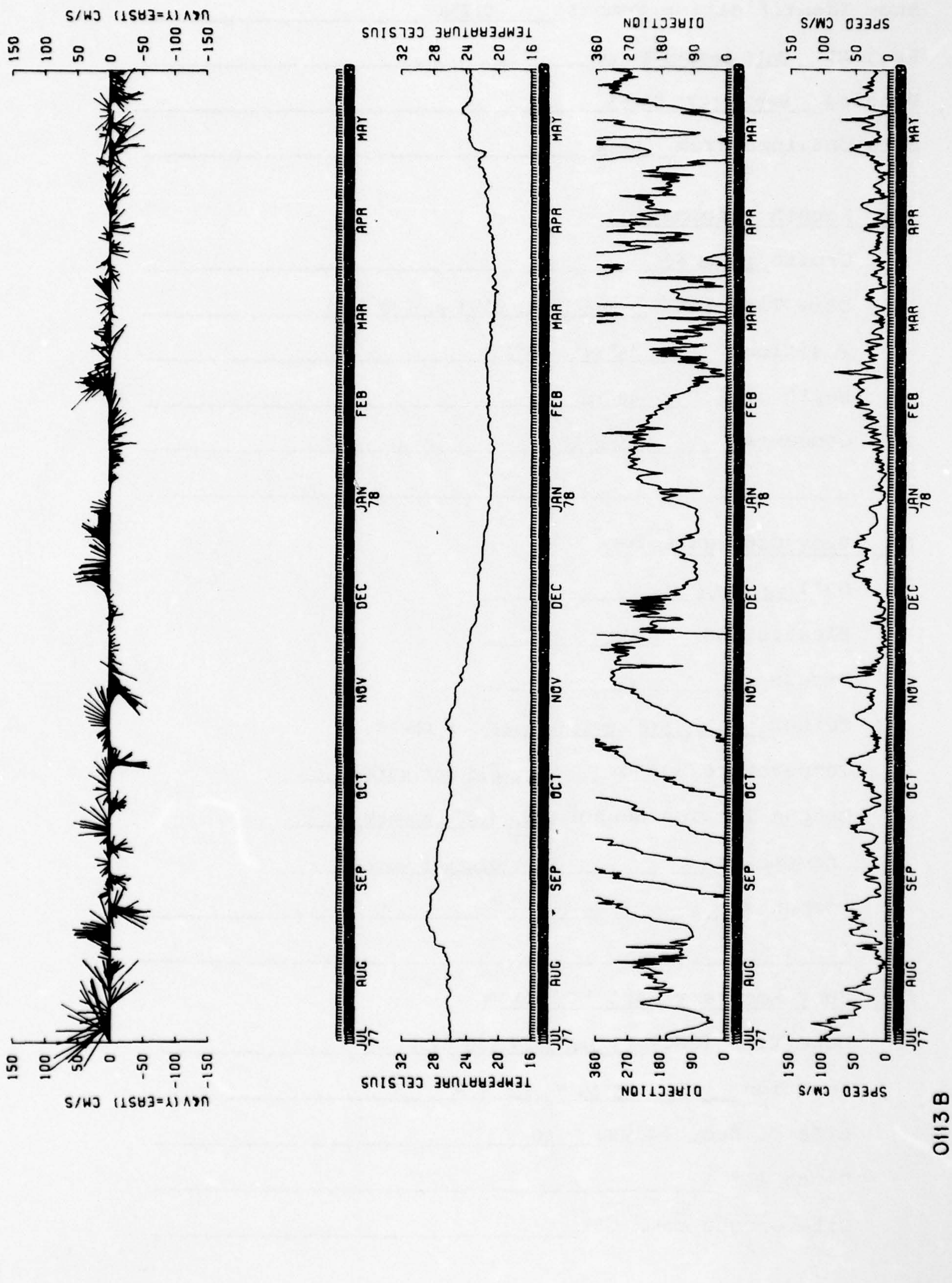
Position 28° 07'N 50°49'W

Life of Buoy (days) Recovered by ATLANTIS II (G. Tupper), 316 days

Depth 15°C

Date Drogue came off Drogue off when recovered, chain only, shackle corroded and parted.


0113 B
57
56
55
54
53
52
51
50
49
48
47
46
45
41
40
39
38
37
36
35
34
33
32
31
30
29
28
27
1977
190
202
217
257
230
272
293
325
303
363
45
19 78
80
34
70
138
110


U&V(Y=EAST) CM/S
150
100
50
0
-50
-100
-150
TEMPERATURE CELSIUS
32
28
24
20
16
DIRECTION
360
270
180
90
0
SPEED CM/S
150
100
50
0
JUL 77
AUG
SEP
OCT
NOV
DEC
JAN 78
FEB
MAR
APR
MAY

0113B

Buoy Identification Number 0125A

Project Gulf Stream Rings

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 62

Date/Time (GMT) 5 Dec 1976, 0107 z, (JD 240)

Position 36°34' 65°17'

Depth of 15° 406 m

Comments Ring A1

(2) Buoy Configuration

Hull FG (Nova U)

Electronics AEL

Drogue WS

Tether 200 m, 5/8" nylon line, 5 m chain

Temperature Sensor Yes, did not work

Drogue Tension Sensor Yes, did not work

Anemometer Yes, did not work

Comments

(3) Buoy Recovery/Last Position

Date/Time (GMT) 13 Jan 1977 (JD 013)

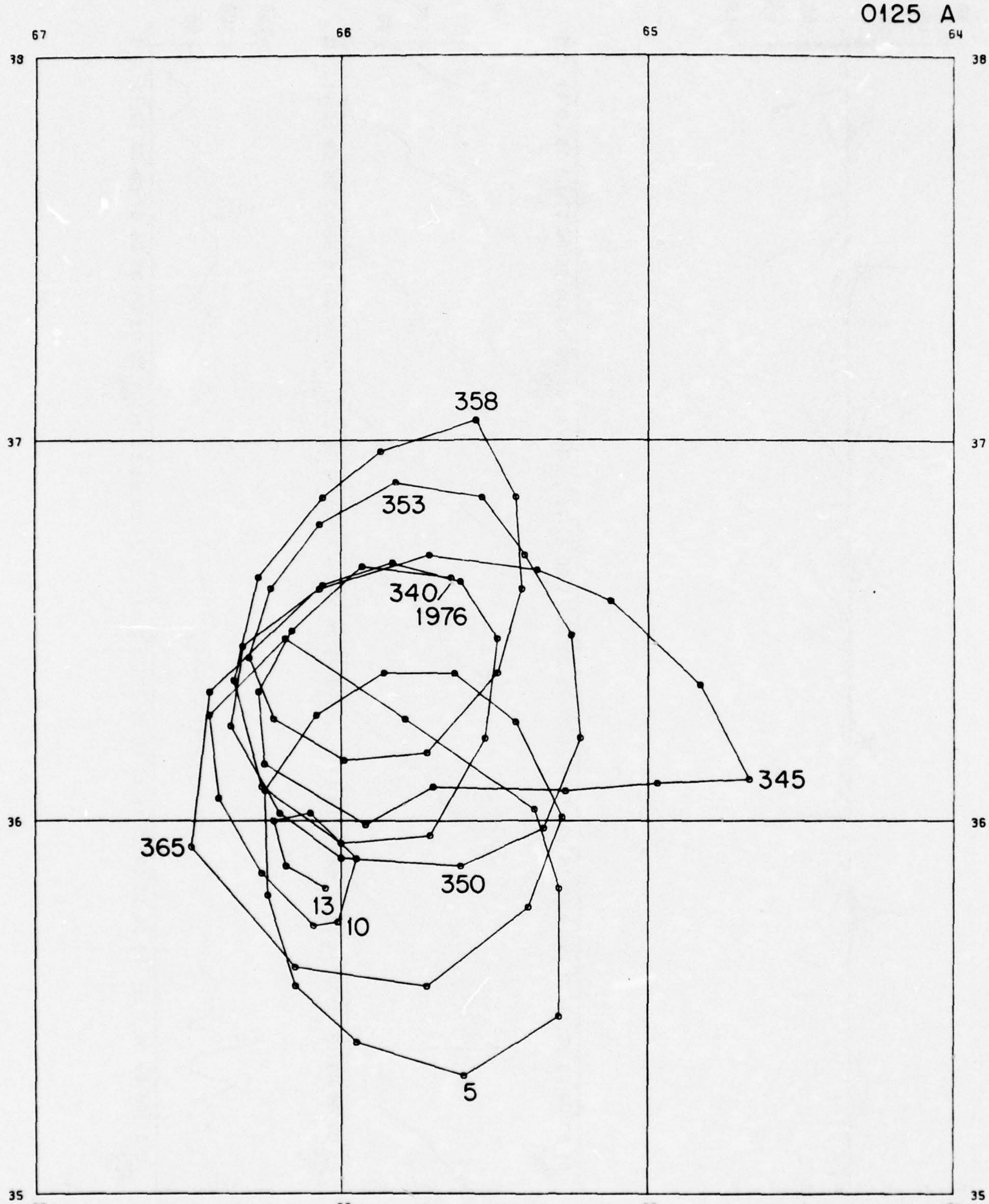
Position 35°49'N 65°59'W

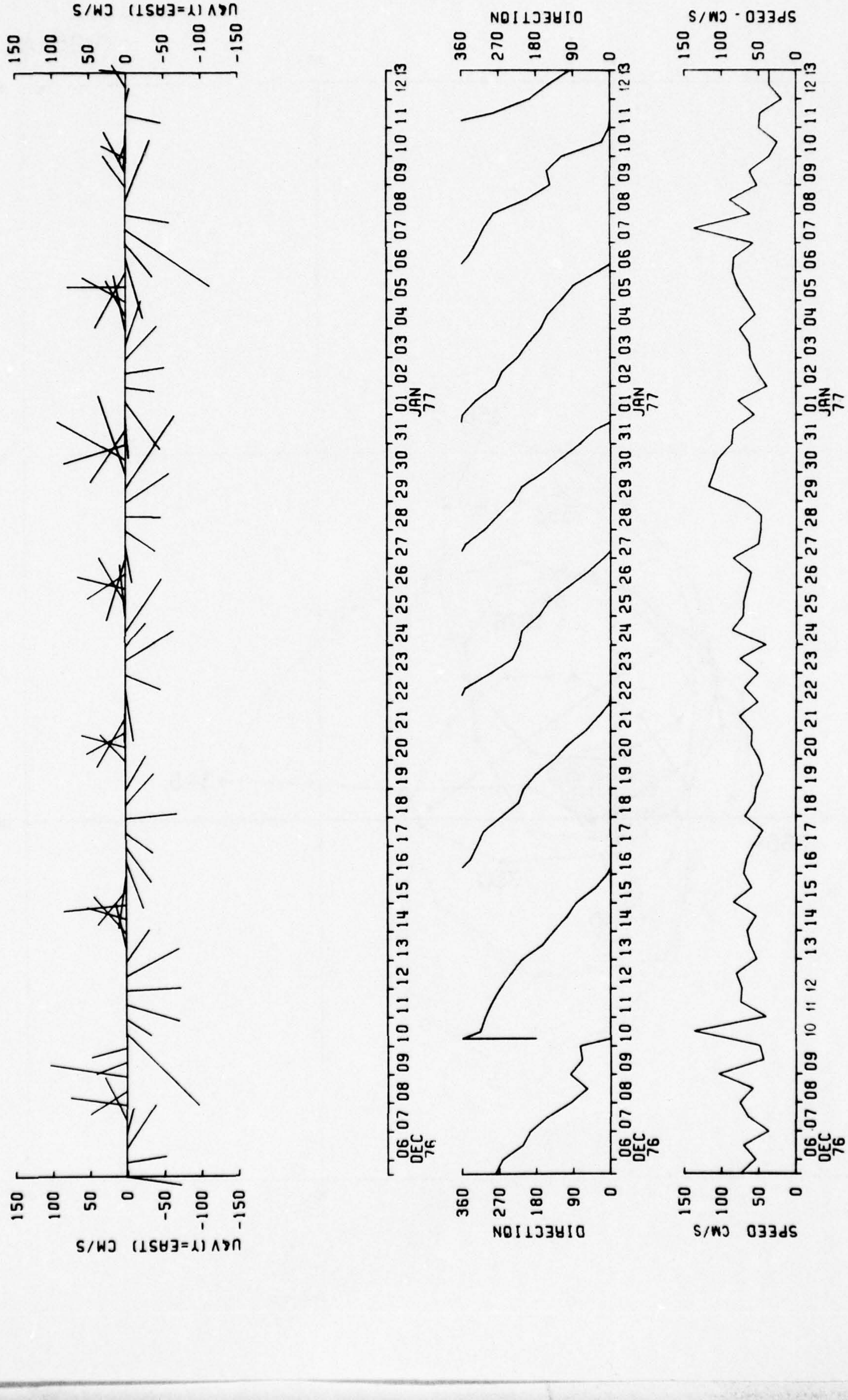
Life of Buoy (days) 40

Depth 15°C

Date Drogue came off

0125 A





O125 A

Buoy Identification Number 0125B (reused ID)

Project Gulf Stream

Funding NSF (OCE77-08045)

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 66

Date/Time (GMT) 9 July 1977, 2100 z, (JD 190)

Position 39°48'N, 57°15'W

Depth of 15° 615

Comments South side of Gulf Stream

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue WS

Tether 600 ft, 1-1/2" dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

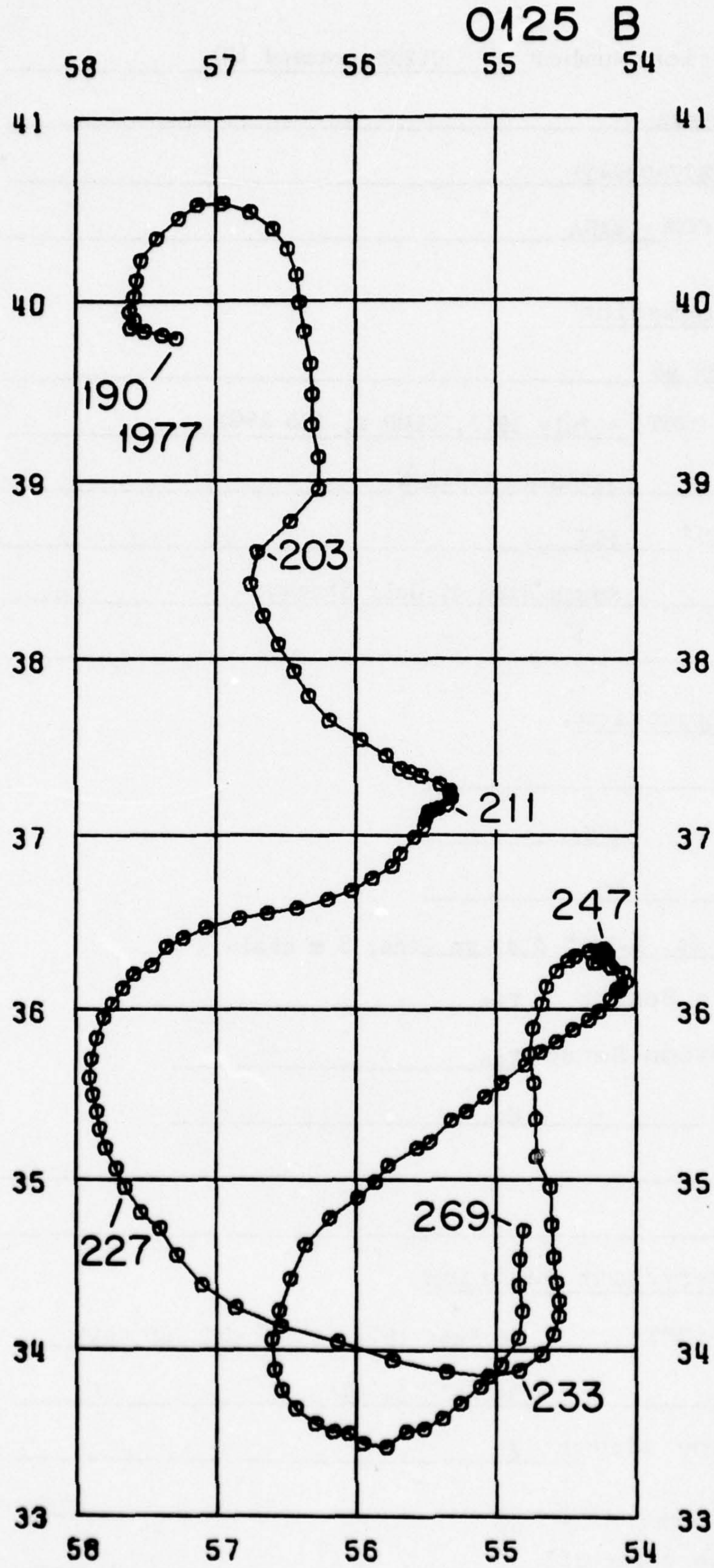
Date/Time (GMT) 26 Sept 1977, 1340 GMT (JD 269)

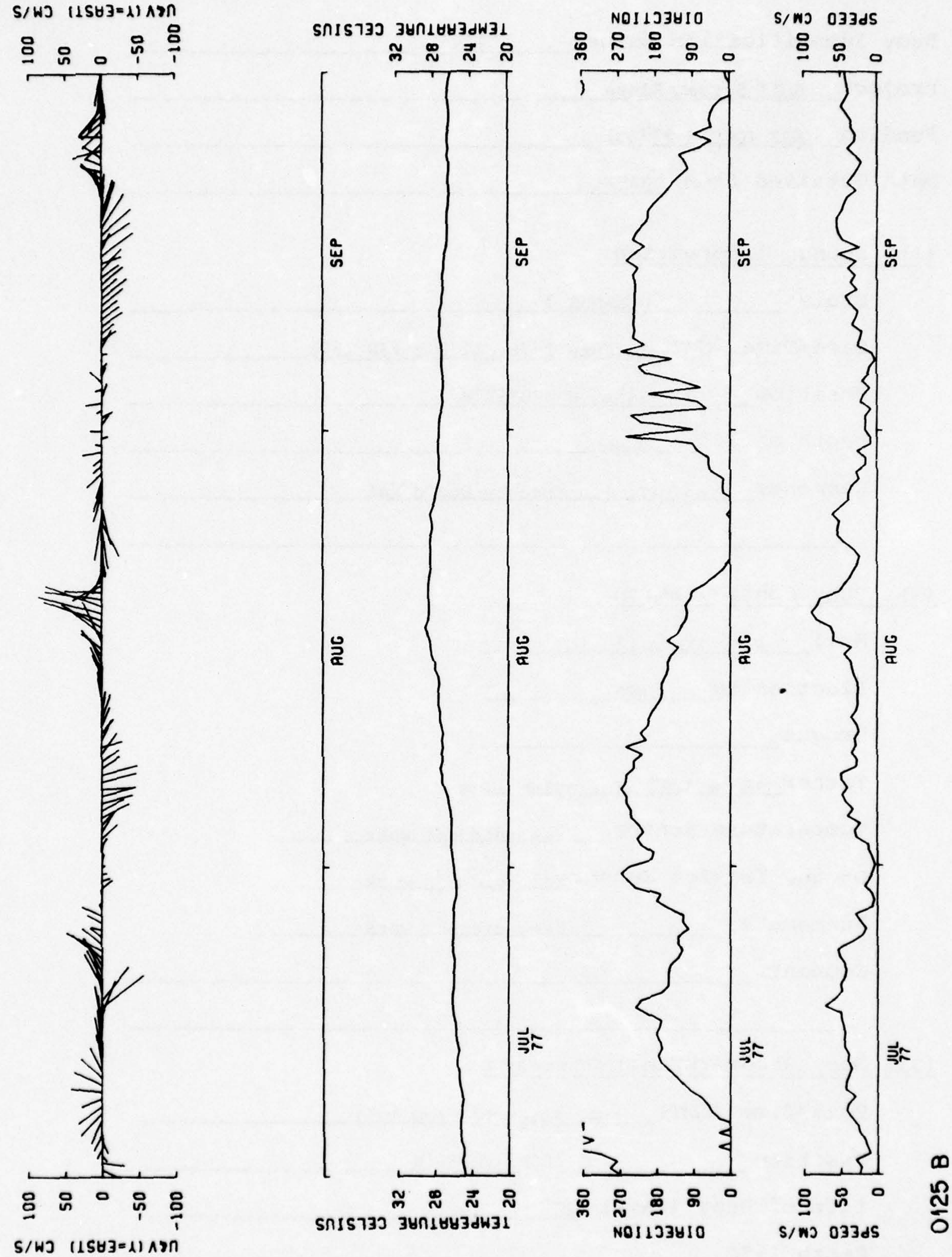
Position 34°44' 54°47'

Life of Buoy (days) 80

Depth 15°C

Date Drogue came off


0125 B
58
57
56
55
54
41
40
39
38
37
36
35
34
33
190
1977
203
211
247
269
227
233


U&V(Y=EAST) CM/S
100
50
0
-50
-100
TEMPERATURE CELSIUS
32
28
24
20
DIRECTION
360
270
180
90
0
SPEED CM/S
100
50
0
JUL
77
AUG
SEP
0125 B

Buoy Identification Number 0154A

Project Gulf Stream Rings

Funding NSF (OCE75-08765)

Data Obtained from NASA

(1) Launch Information

Cruise OCEANUS 7

Date/Time (GMT) 12 June 1976, 1430 z (JD 164)

Position 34°45'N 70°17'W

Depth of 15° 304m

Comments Ring LAI, launched by David Lai

(2) Buoy Configuration

Hull F.G. (Nova U)

Electronics AEL

Drogue WS

Tether 200 m 5/8" dia. nylon line

Temperature Sensor Yes, did not work

Drogue Tension Sensor Yes, did not work

Anemometer Yes, did not work

Comments

(3) Buoy Recovery/Last Position

Date/Time (GMT) 9 July 1976 (JD 191)

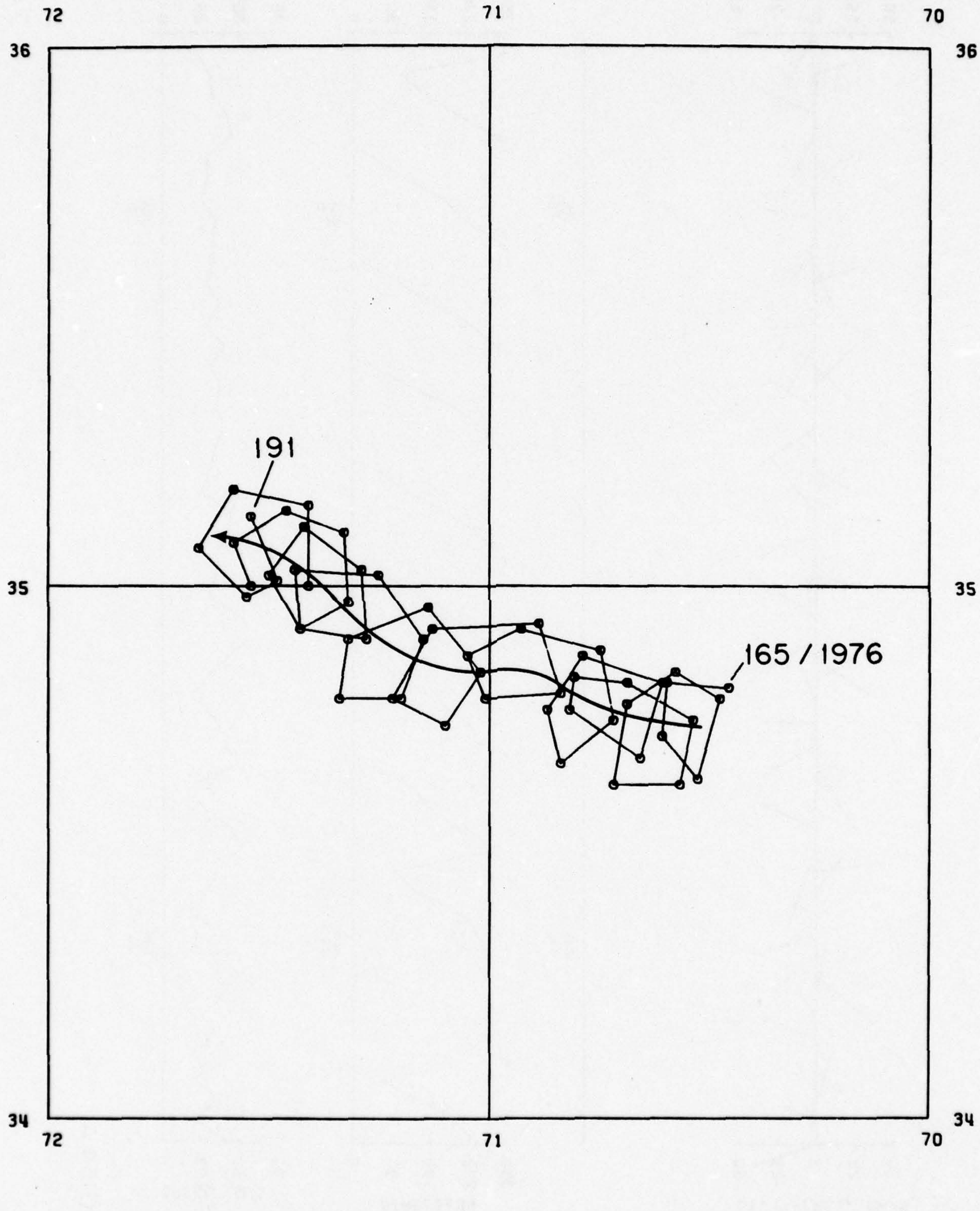
Position 35°10'N 71°34'W

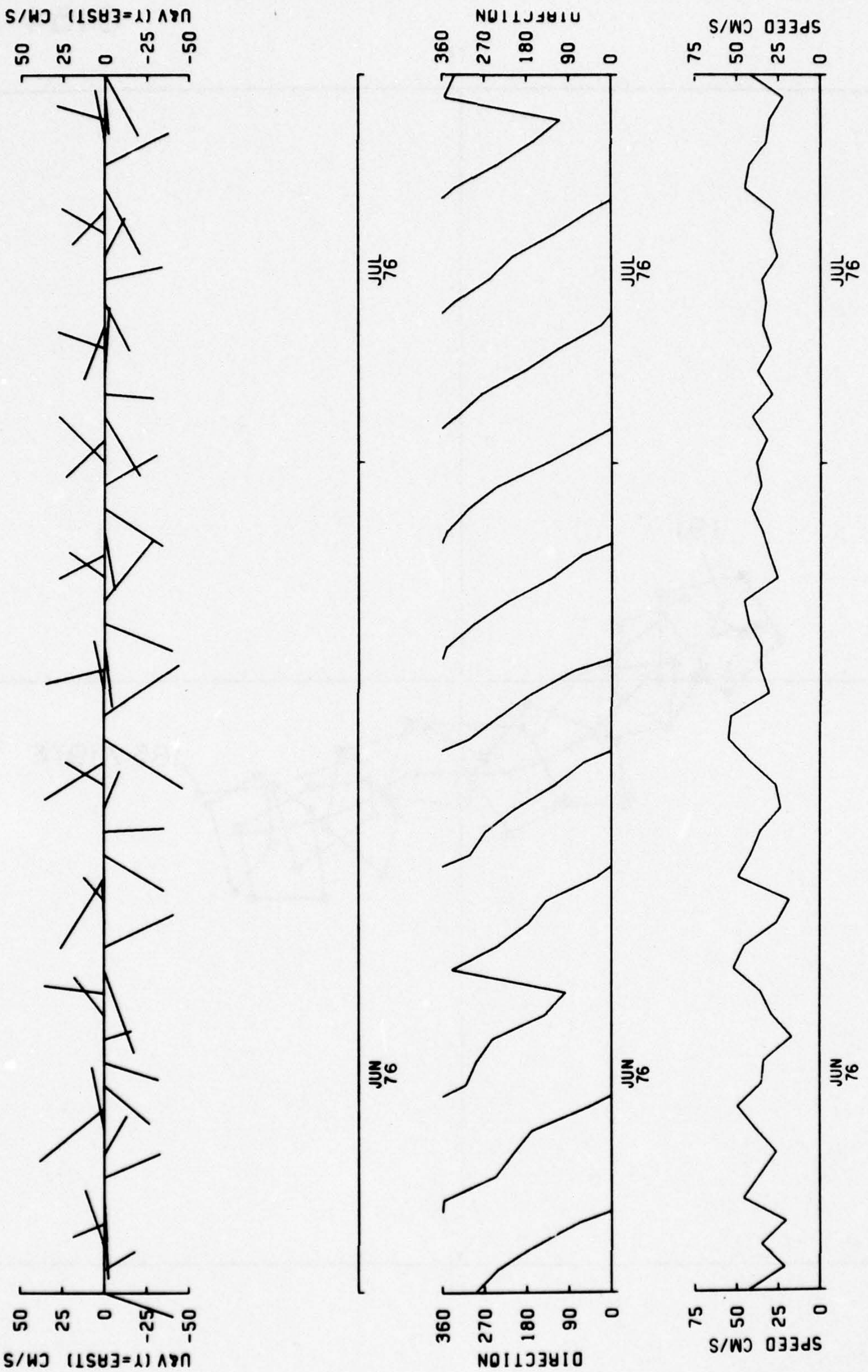
Life of Buoy (days) 28

Depth 15°C

Date Drogue came off

0154 A




U&V (Y=EAST) CM/S
50 25 0 -25 -50
DIRECTION
360 270 180 90 0
SPEED CM/S
75 50 25 0
JUN 76
JUL 76

0154 A

Buoy Identification Number 0154B (reused ID)

Project Gulf Stream

Funding NSF (OCE77-08045)

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 66

Date/Time (GMT) 10 July 1977, 0530 z (JD 191)

Position 38°54'N, 58°42'W

Depth of 15° 670

Comments South side of Gulf Stream

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 200 m, 1 1/4 in. dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

Date/Time (GMT) Aug. 20, 1977, 1431 GMT (JD 232)

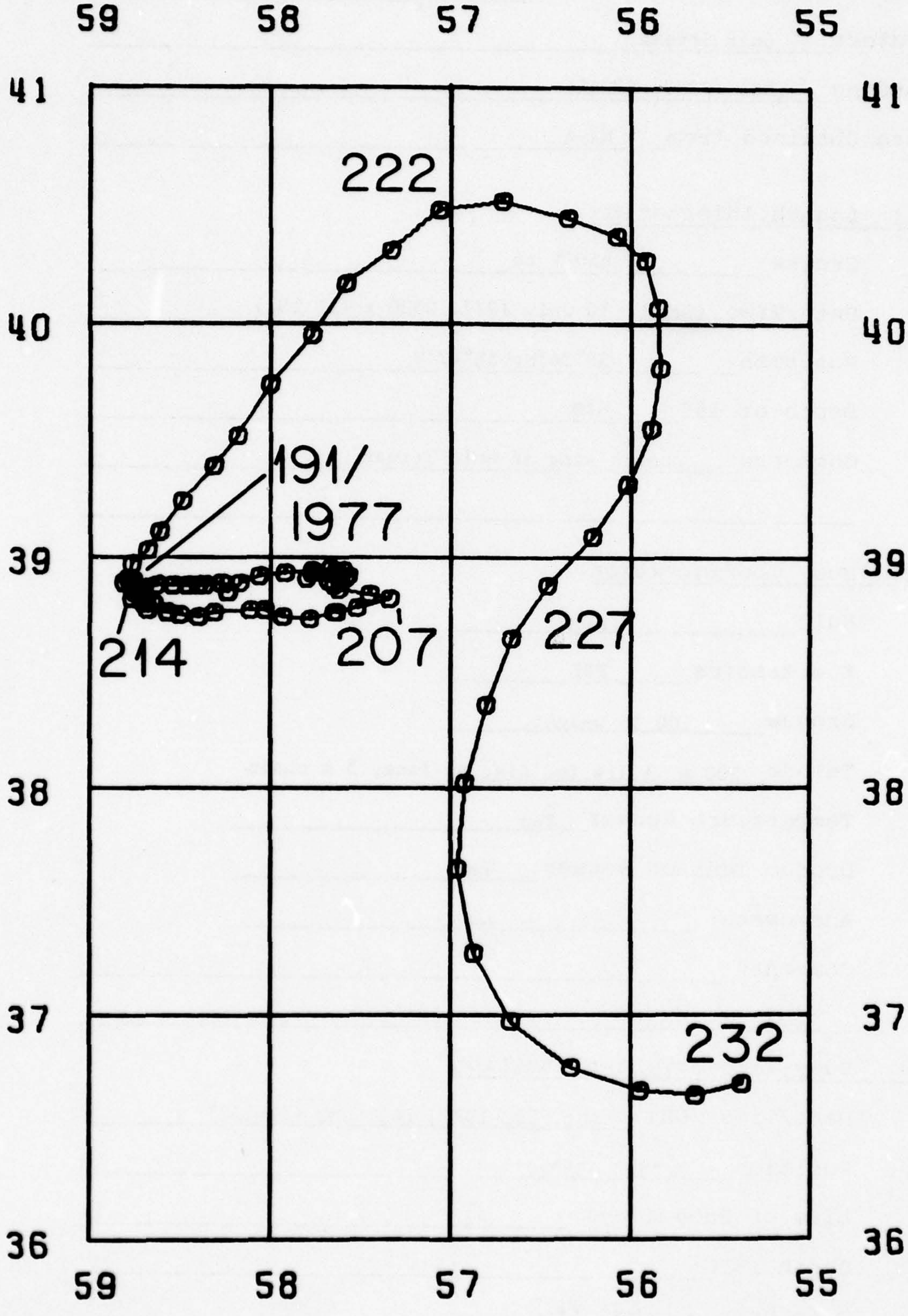
Position 36°42' 55°20'

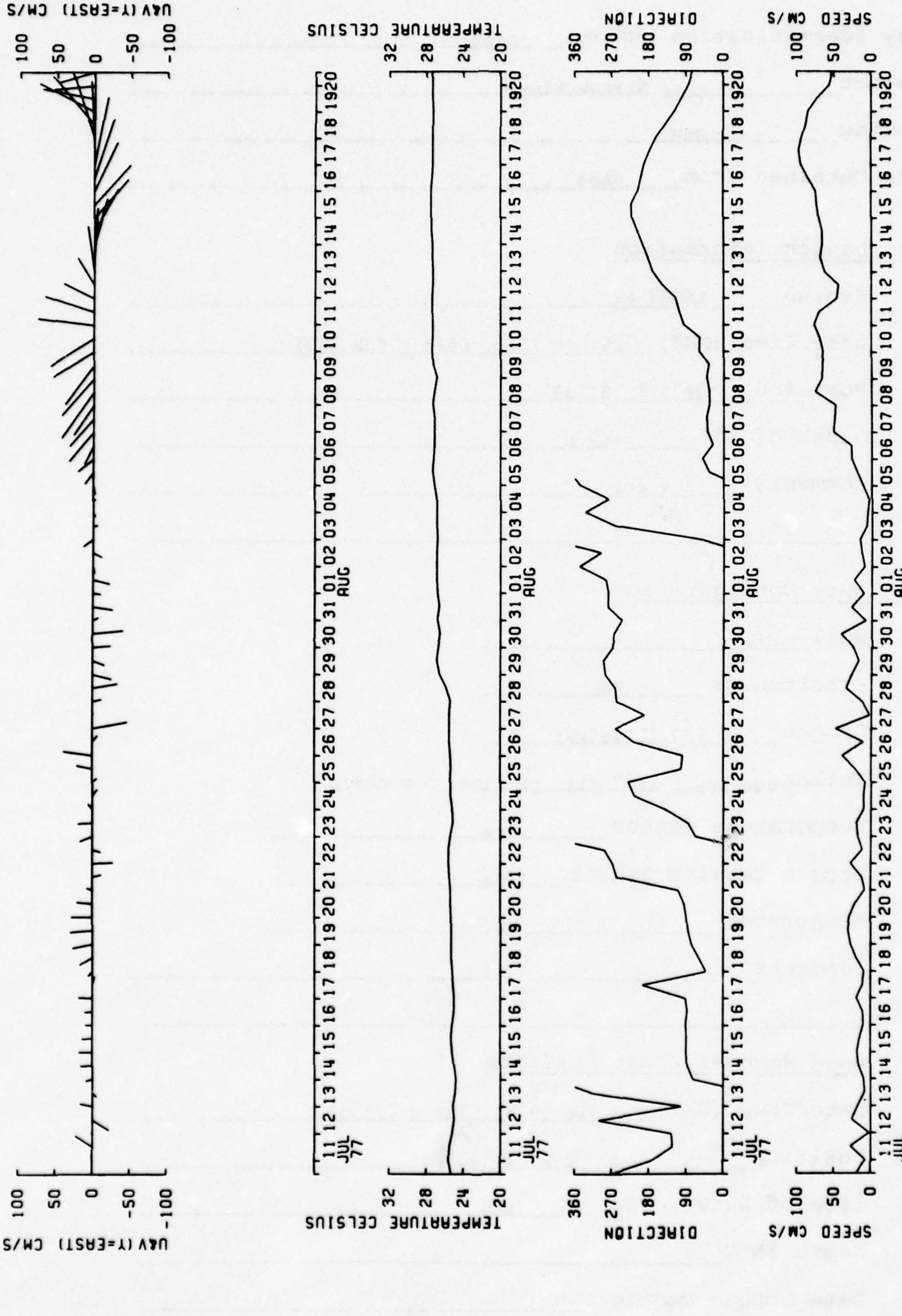
Life of Buoy (days) 42

Depth 15°C

Date Drogue came off

0154 B




SPEED CM/S
DIRECTION
TEMPERATURE CELSIUS
U&V(Y=EAST) CM/S
JUL
77
AUG

0154 B

Buoy Identification Number 0162A

Project Gulf Stream Rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 62

Date/Time (GMT) 14 Dec 1976, 0628 z (JD 349)

Position 36°37' 62°33'

Depth of 15° 465 m

Comments Ring Art

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 600 ft, 1 1/2" dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

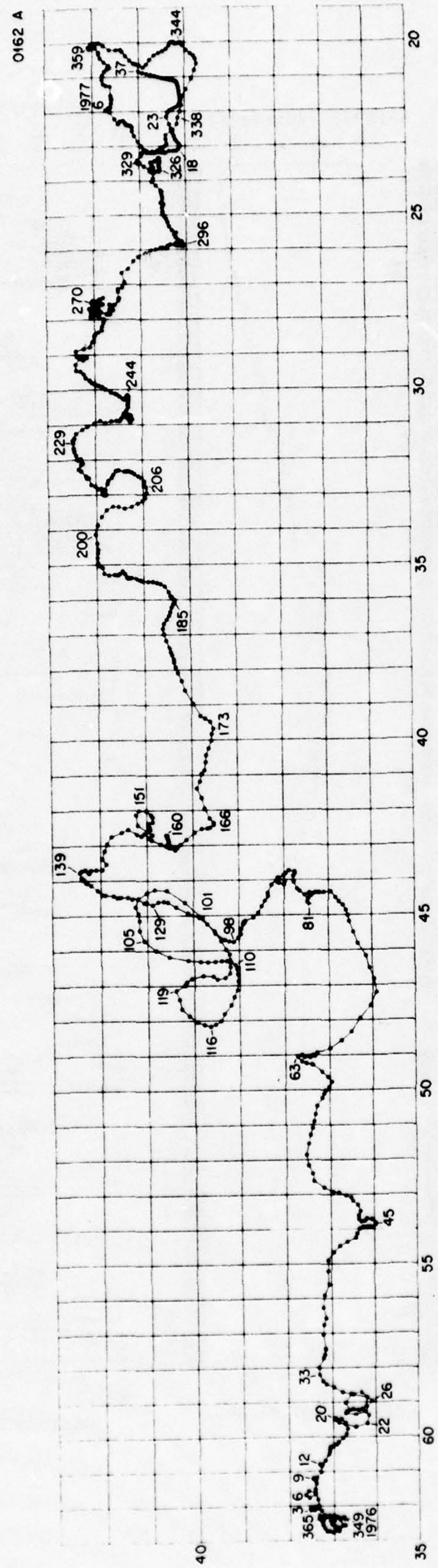
Date/Time (GMT) 6 Feb 1978, 1323 z (JD 037)

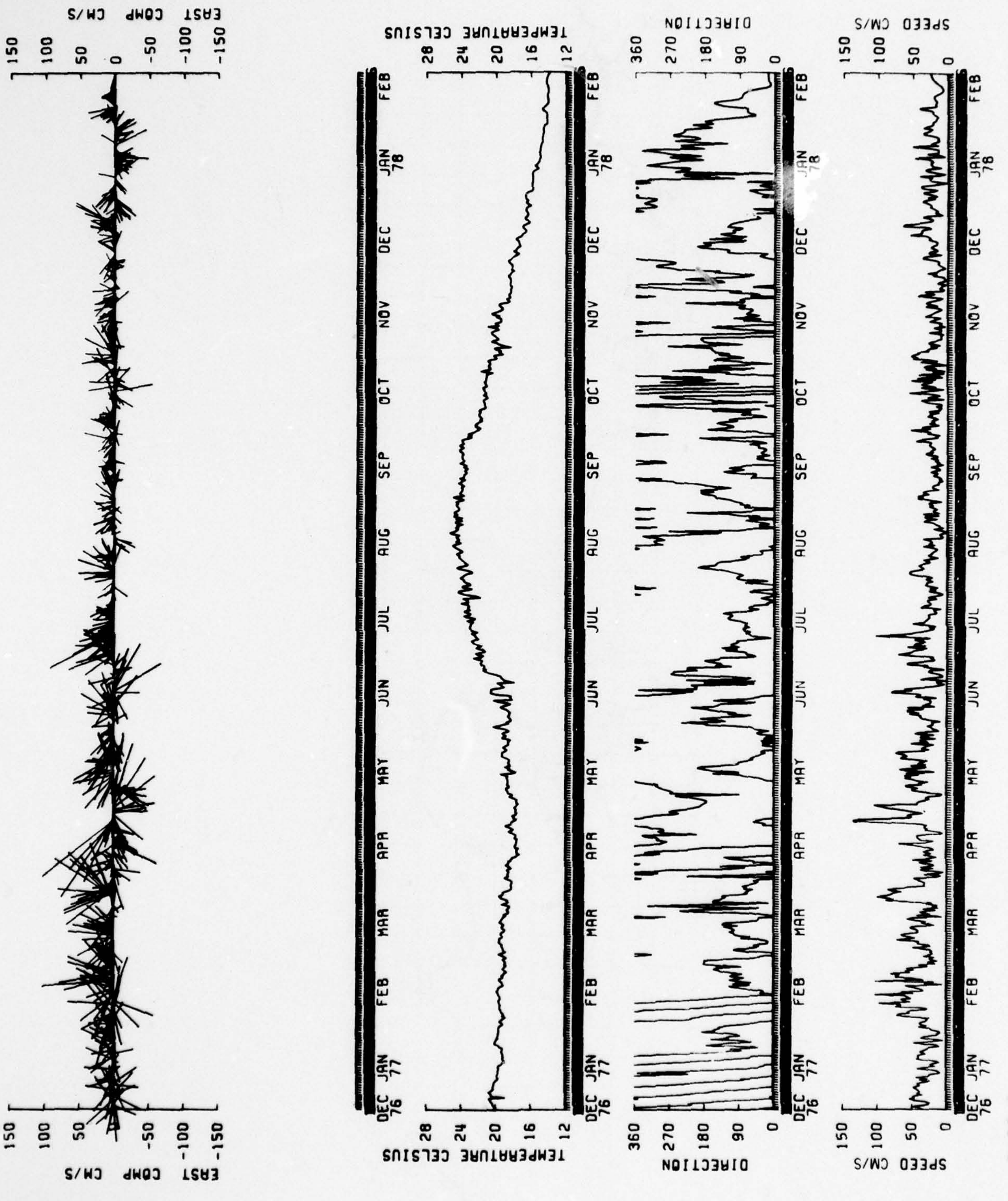
Position 41°01'N 20°50'W

Life of Buoy (days) 420

Depth 15°C

Date Drogue came off


0162 A
1977
1976
20
25
30
35
40
45
50
55
60
35
40


EAST COMP CM/S
150 100 50 0 -50 -100 -150
TEMPERATURE CELSIUS
28 24 20 16 12
DIRECTION
360 270 180 90 0
SPEED CM/S
150 100 50 0
DEC 76 JAN 77 FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN 78 FEB

0162 A

Buoy Identification Number 0215A

Project Gulf Stream Rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 62

Date/Time (GMT) 4 Dec 1976, 0319 z, (JD 339)

Position 36°14' 65°34'

Depth of 15° 290 m

Comments Ring A1

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 600 ft, 1 1/2 " dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

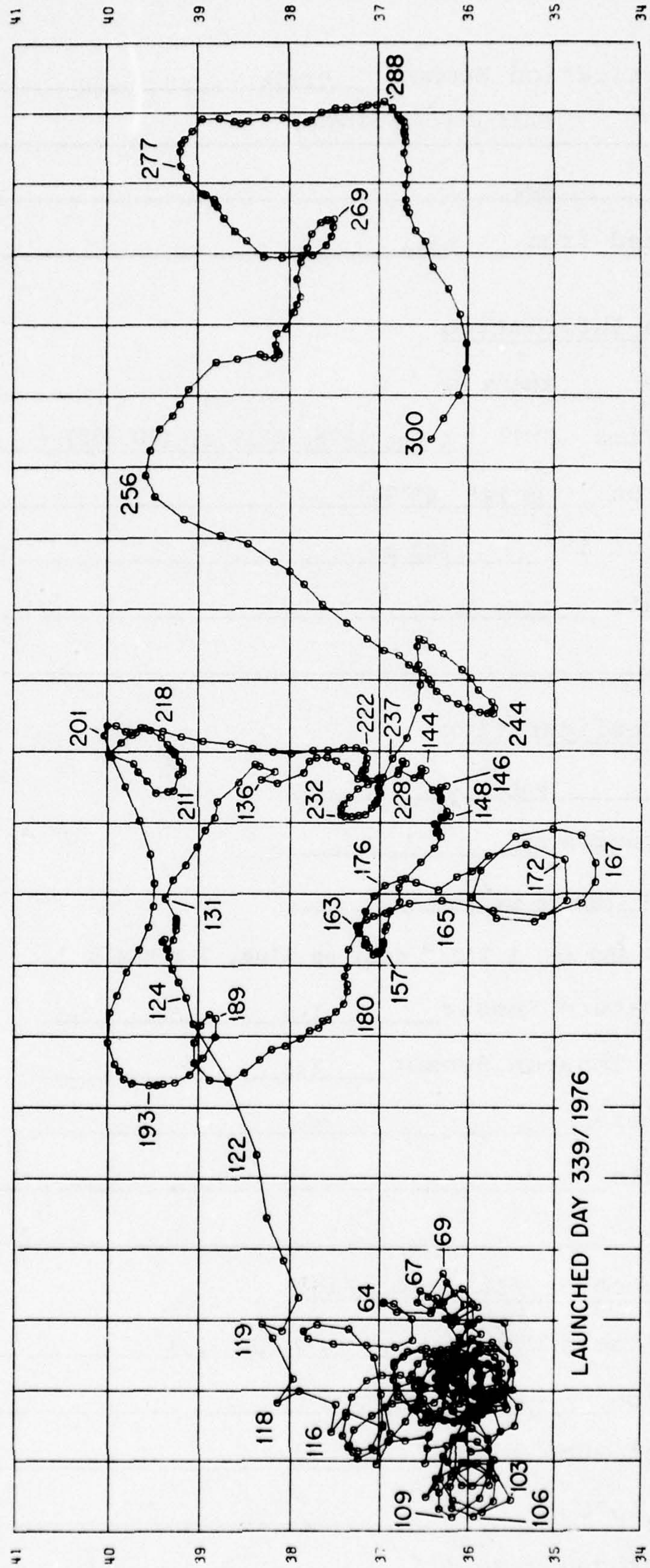
Date/Time (GMT) 27 Oct 1977 (JD 300)

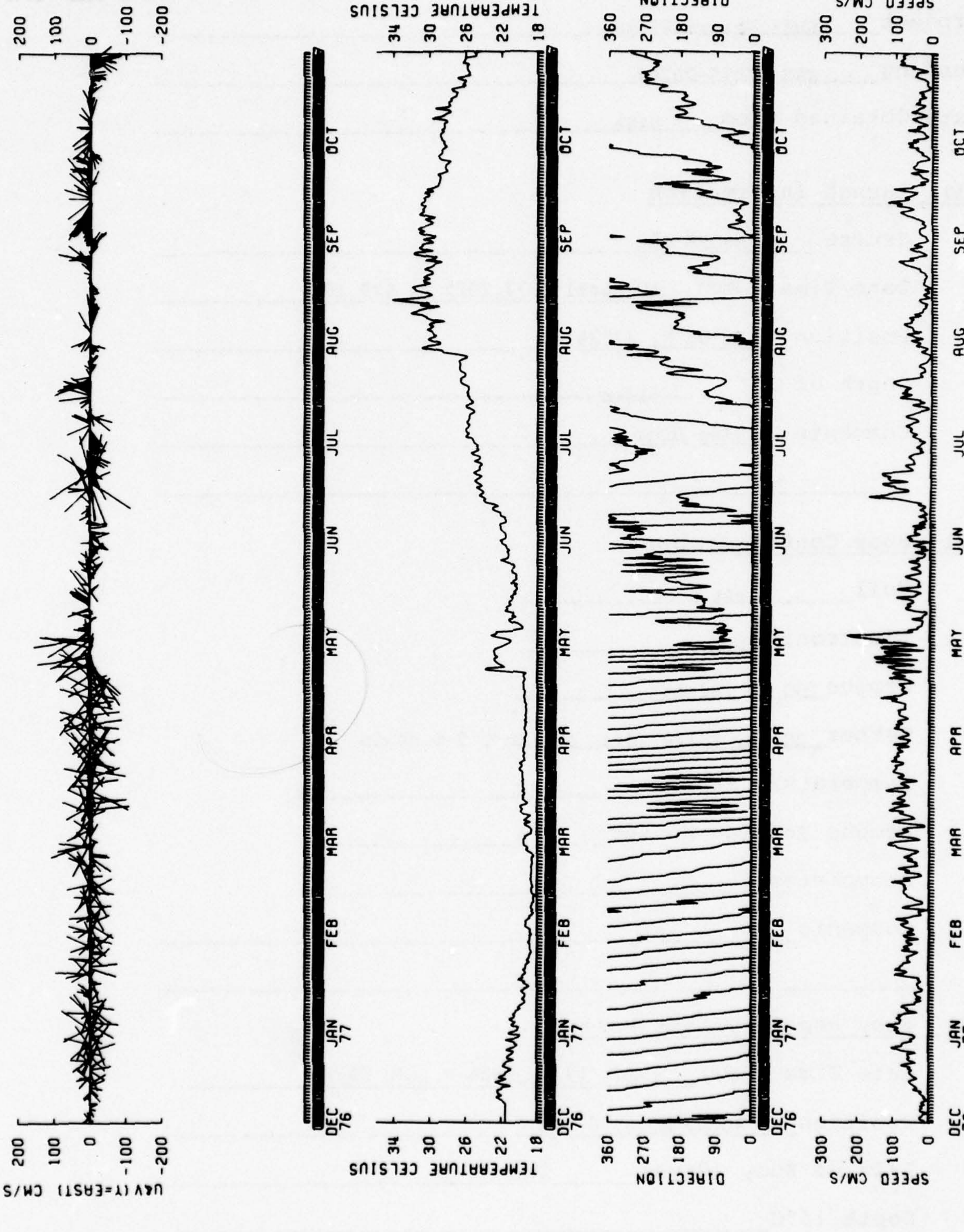
Position 36°26'N 52°38'W

Life of Buoy (days) 328

Depth 15°C

Date Drogue came off


0215 A
LAUNCHED DAY 339/1976


U&V(Y=EAST) CM/S
200
100
0
-100
-200
TEMPERATURE CELSIUS
34
30
26
22
18
DIRECTION
360
270
180
90
0
SPEED CM/S
300
200
100
0
DEC 76
JAN 77
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT

0215 A

Buoy Identification Number 0252A

Project Gulf Stream Rings

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 65

Date/Time (GMT) 10 April 1977, 2025 z, (JD 100)

Position 29°01'N, 77°26'W

Depth of 15° 415 m

Comments Ring Dave

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 200 m, 1 1/4" dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

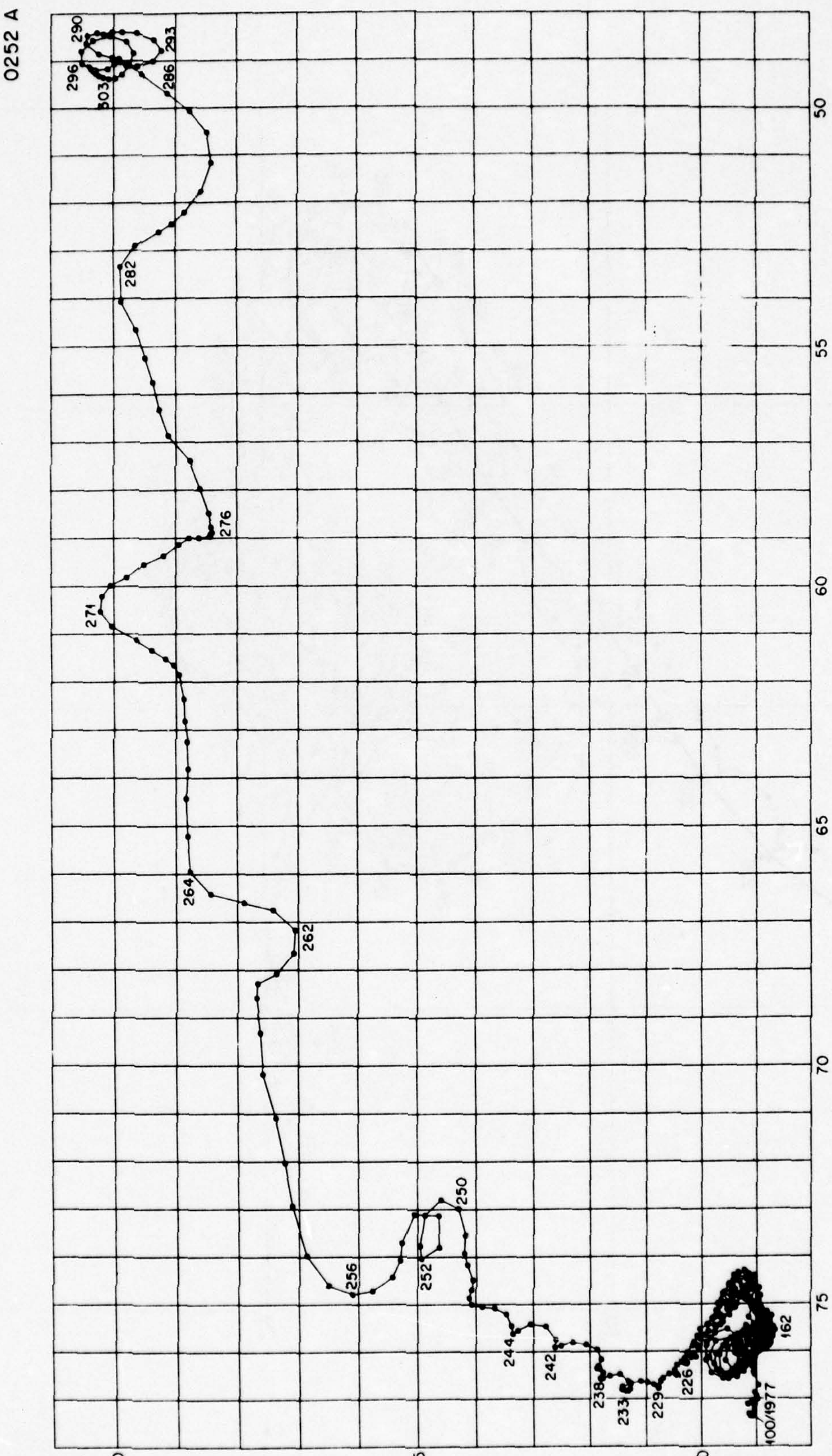
Date/Time (GMT) 1 Nov 1977, 1326 z, (JD 305)

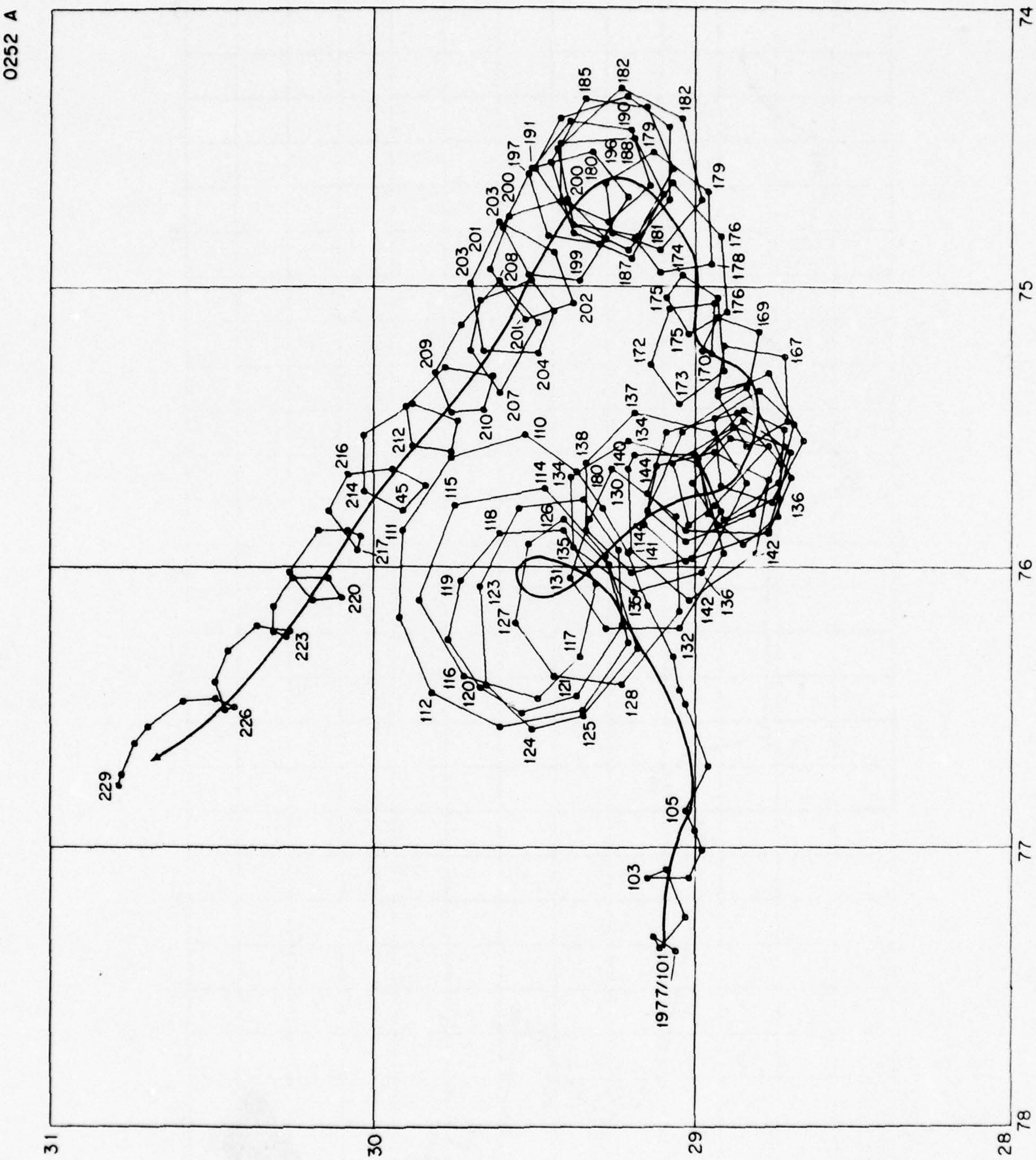
Position 40°23'N, 49°07'W

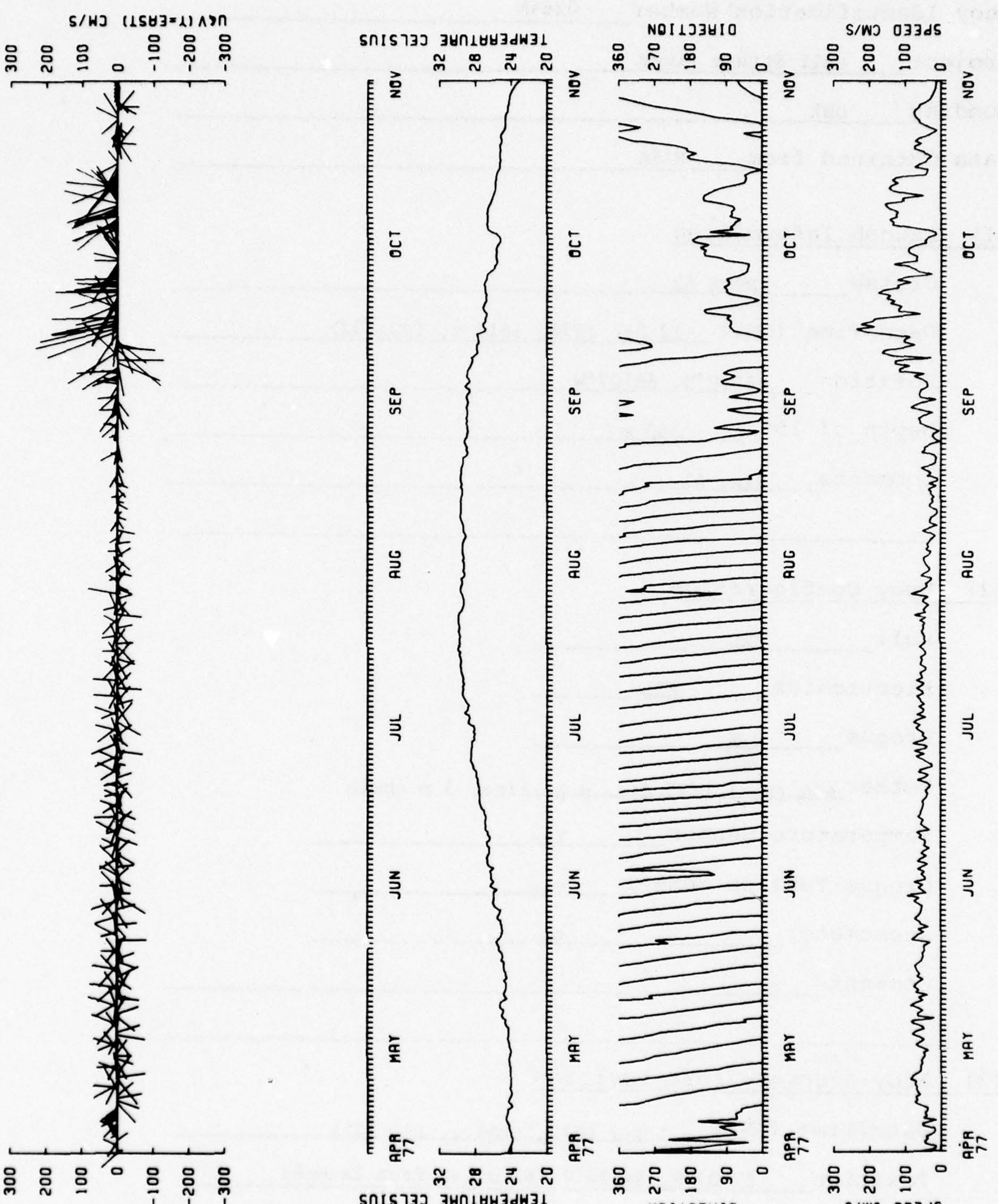
Life of Buoy (days) 206

Depth 15°C

Date Drogue came off


0252 A
290
293
296
303
286
282
276
271
264
262
256
252
250
244
242
238
233
229
226
162
100/1977
50
55
60
65
70
75
40
35
30


0252 A
31
30
29
28
74
75
76
77
78
1977/101
103
105
229
226
223
220
217
216
214
212
210
209
208
207
204
203
202
201
200
199
197
196
191
190
188
187
185
182
181
180
179
178
176
175
174
173
172
170
169
167
144
142
141
140
138
137
136
135
134
132
131
130
128
127
126
125
124
123
121
120
119
118
117
116
115
114
112
111
110
45


U&V(Y=EAST) CM/S
300
200
100
0
-100
-200
-300
TEMPERATURE CELSIUS
32
28
24
20
DIRECTION
360
270
180
90
0
SPEED CM/S
300
200
100
0
APR 77
MAY
JUN
JUL
AUG
SEP
OCT
NOV

0252 A

Buoy Identification Number: 0264A

Project: Gulf Stream rings

Funding: ONR

Data Obtained from: NASA

(1) Launch Information

Cruise: KNORR 62

Date/Time (GMT): 17 Dec 1976, 1615 z, (JD 352)

Position: 36°10'N, 66°07'W

Depth of 15°: 360 m

Comments: Ring A1

(2) Buoy Configuration

Hull: PRL

Electronics: PRL

Drogue: W.S.

Tether: 600 ft, 1 1/2" dia. p.p. line, 5 m chain

Temperature Sensor: Yes

Drogue Tension Sensor: Yes

Anemometer: No

Comments:

(3) Buoy Recovery/Last Position

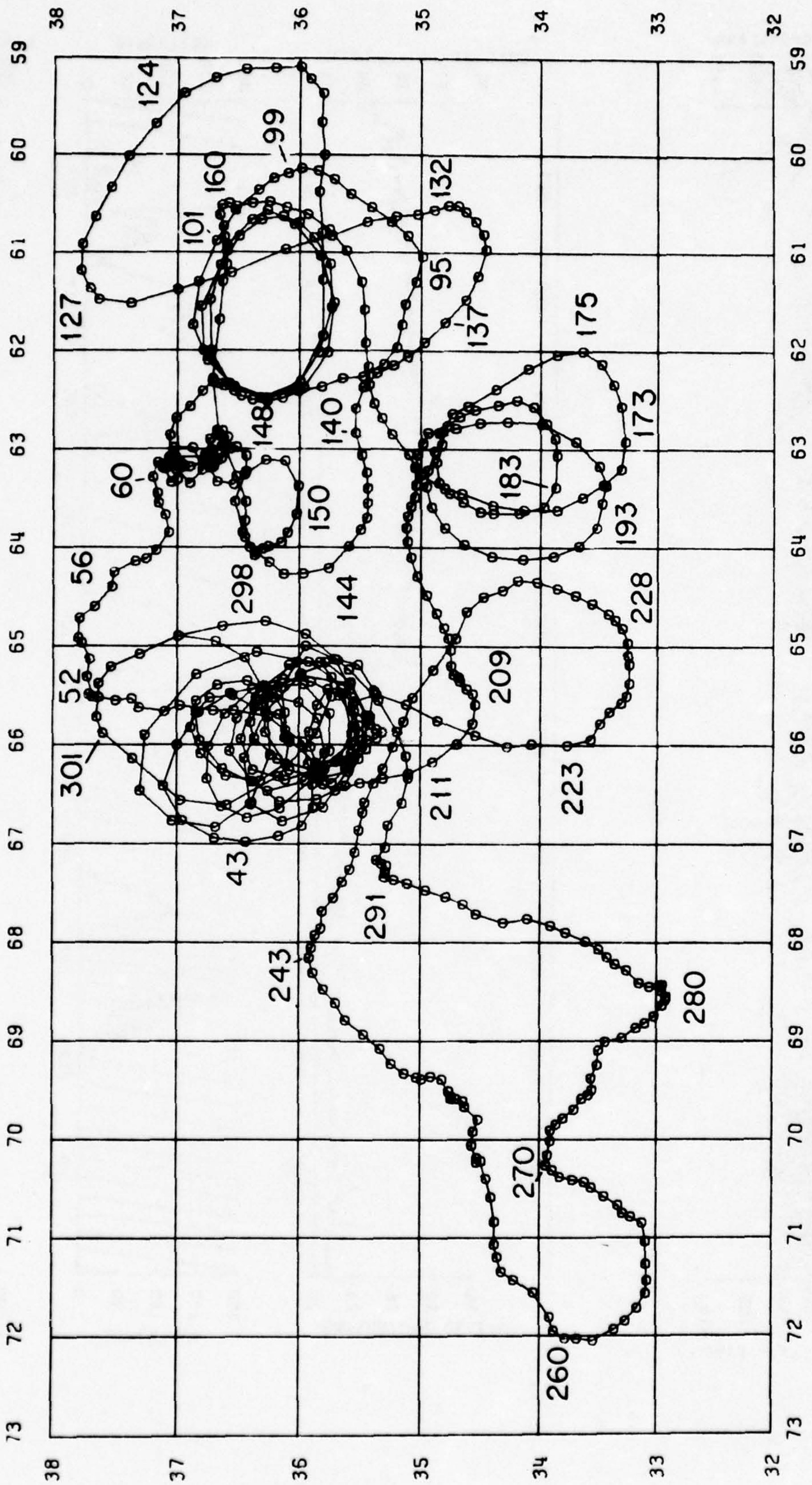
Date/Time (GMT): 7 Nov 1977, 1705 z, (JD 311)

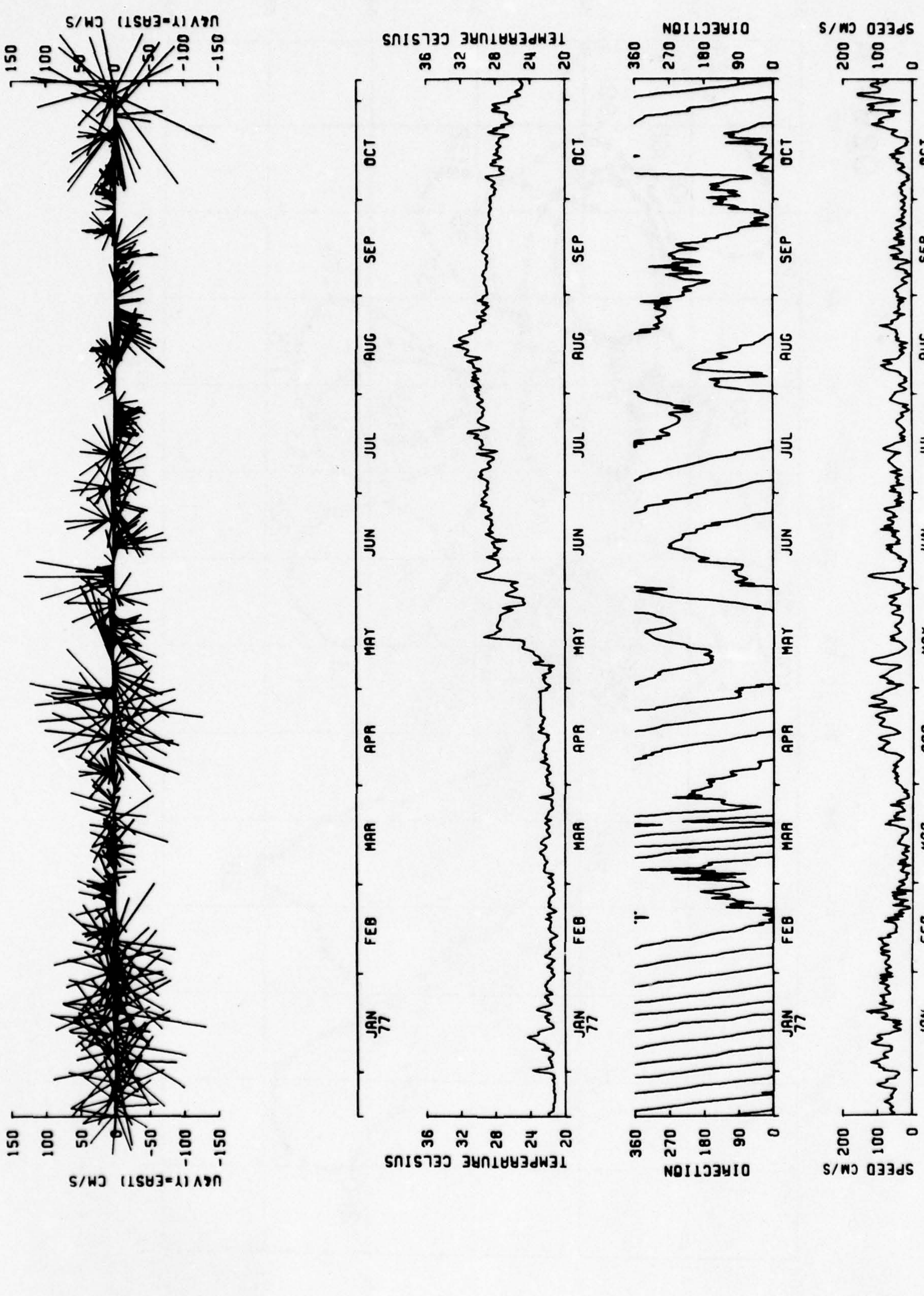
Position: 37°07'N, 64°54'W (85 miles from launch)

Life of Buoy (days): 326 Recovered on KNORR 71

Depth 15°C:

Date Drogue came off: No drogue or line when recovered, chain only, shackle corroded and let go.


0264 A
38
37
36
35
34
33
32
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
124
99
160
101
132
127
95
137
175
173
148
140
183
60
150
193
56
298
144
228
52
209
301
211
223
43
291
243
280
270
260


U4V(Y=EAST) CM/S
150
100
50
0
-50
-100
-150
TEMPERATURE CELSIUS
36
32
28
24
20
DIRECTION
360
270
180
90
0
SPEED CM/S
200
100
0
JAN 77
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT

0264 A

Buoy Identification Number 0264B (relaunched)

Project Gulf Stream

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise EVERGREEN

Date/Time (GMT) 5 April 1978, 0521 z, (JD 095)

Position 42°43'N, 45°11'W

Depth of 15°

Comments East of Grand Banks

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 600 ft, 1 1/2" dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes, modified-stops added

Anemometer No

Comments Taped thimbles

(3) Buoy Recovery/Last Position

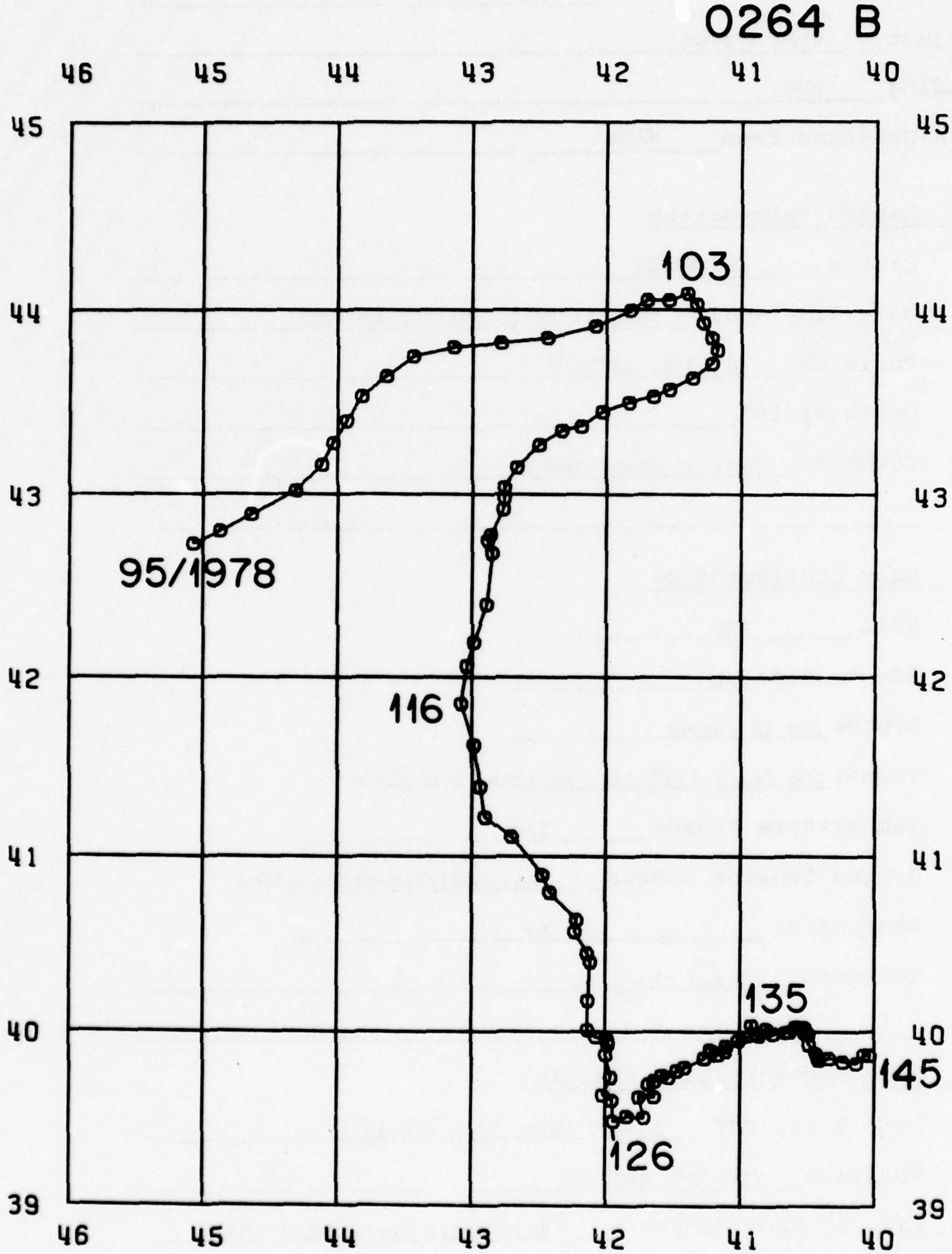
Date/Time (GMT) 25 May 1978, 1245 (JD 145)

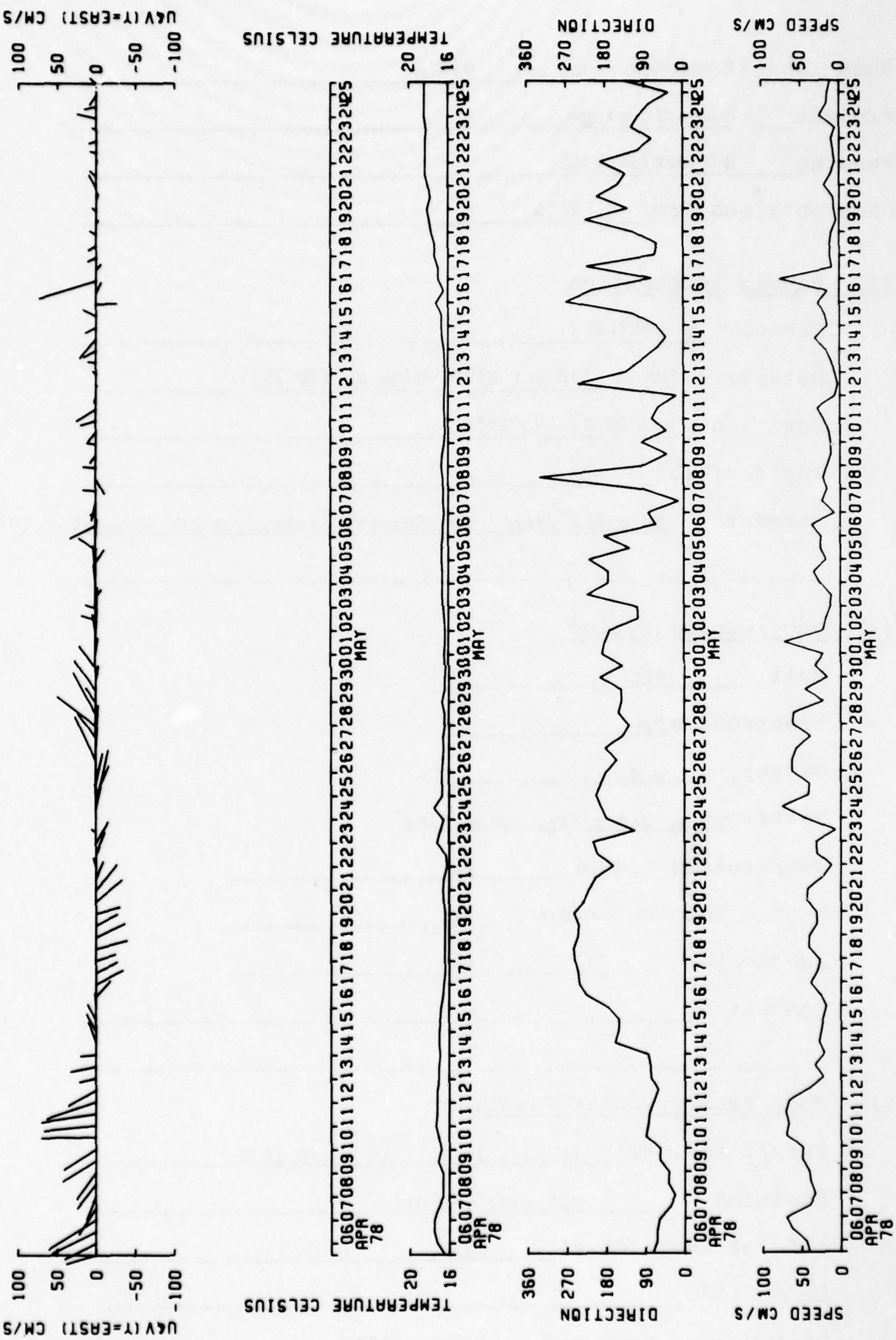
Position 39°52', 40°02'W

Life of Buoy (days) Buoy still operational (51+)

Depth 15°C

Date Drogue came off


0264 B
46
45
44
43
42
41
40
45
44
43
42
41
40
39
103
95/1978
116
135
145
126


U&V(Y=EAST) CM/S
TEMPERATURE CELSIUS
DIRECTION
SPEED CM/S
APR 78
MAY

0264 B

Buoy Identification Number 0401A

Project Kuroshio rings

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise BARTLETT

Date/Time (GMT) 28 Oct 1976, 0700 z, (JD 297)

Position 33°00'N, 143°19'E

Depth of 15°

Comments Kuroshio ring See Cheney, Richardson and Nagasaka (1978)

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue W.S.

Tether 200 m, 3/8 m dia. nylon line

Temperature Sensor No

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

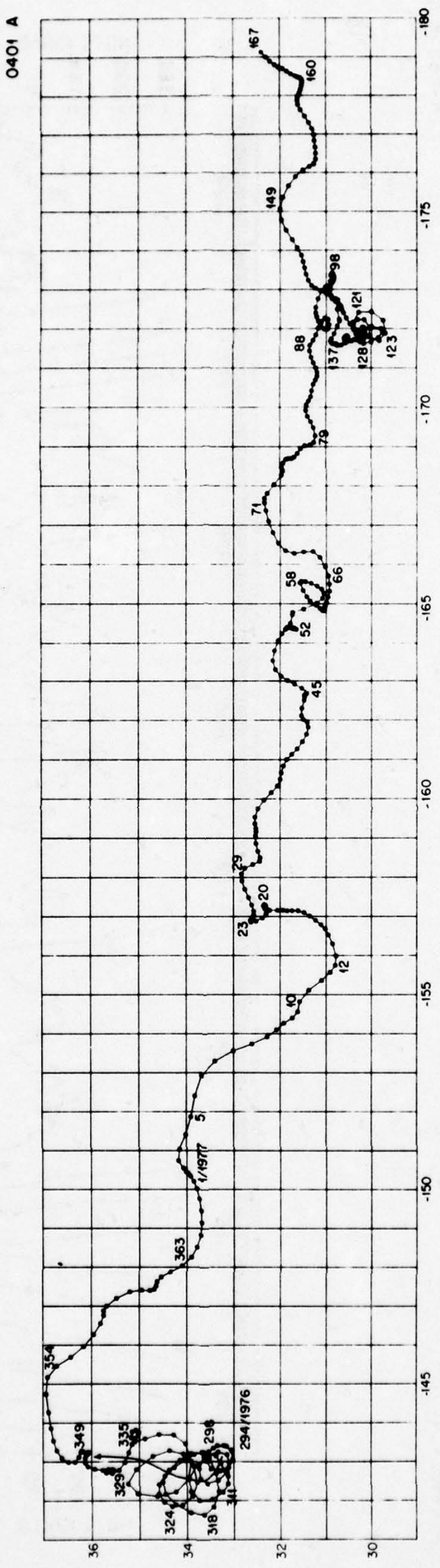
Date/Time (GMT) 16 June 1977, 1210 z (JD 167)

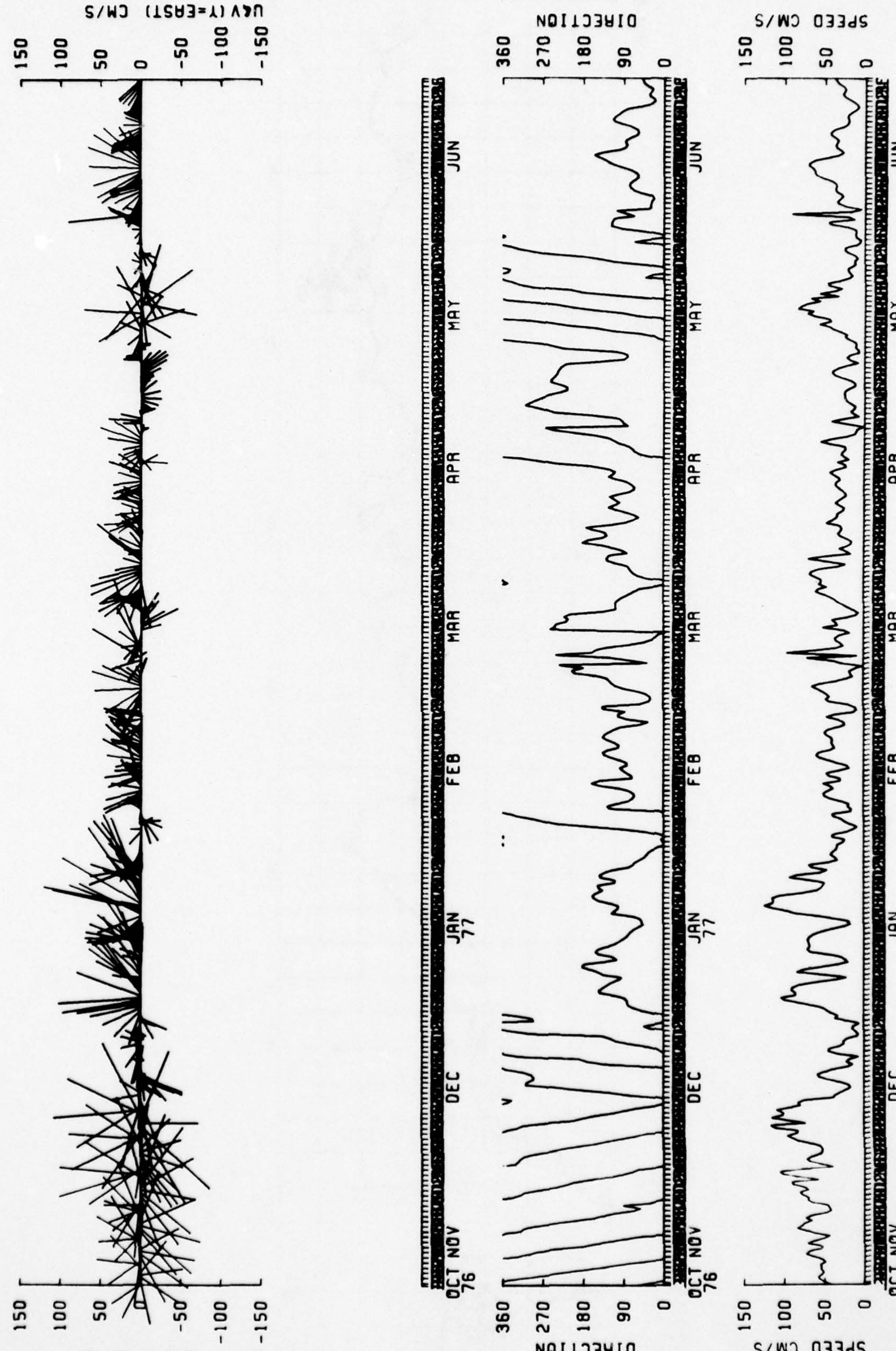
Position 32°24'N, 179°08'

Life of Buoy (days) 237

Depth 15°C

Date Drogue came off 6 Nov 1976


0401 A
-180
-175
-170
-165
-160
-155
-150
-145
36
34
32
30
167
160
149
98
121
88
137
128
123
79
71
58
66
52
45
29
20
23
12
10
5
1/1977
363
354
349
335
329
324
318
311
298
294/1976


U&V (Y=EAST) CM/S
150
100
50
0
-50
-100
-150
DIRECTION
360
270
180
90
0
SPEED CM/S
150
100
50
0
OCT 76
NOV
DEC
JAN 77
FEB
MAR
APR
MAY
JUN
0401 A

Buoy Identification Number 0437A

Project Gulf Stream rings

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 60

Date/Time (GMT) 26 Oct 1976, 1400 z, (JD 300)

Position 37°20', 58°08'

Depth of 15° 265

Comments Ring Valentine

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue W.S.

Tether 400 m, 1/4" dia., dacron line

Temperature Sensor No

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

Date/Time (GMT) 26 June 1977, 1150 (JD 177)

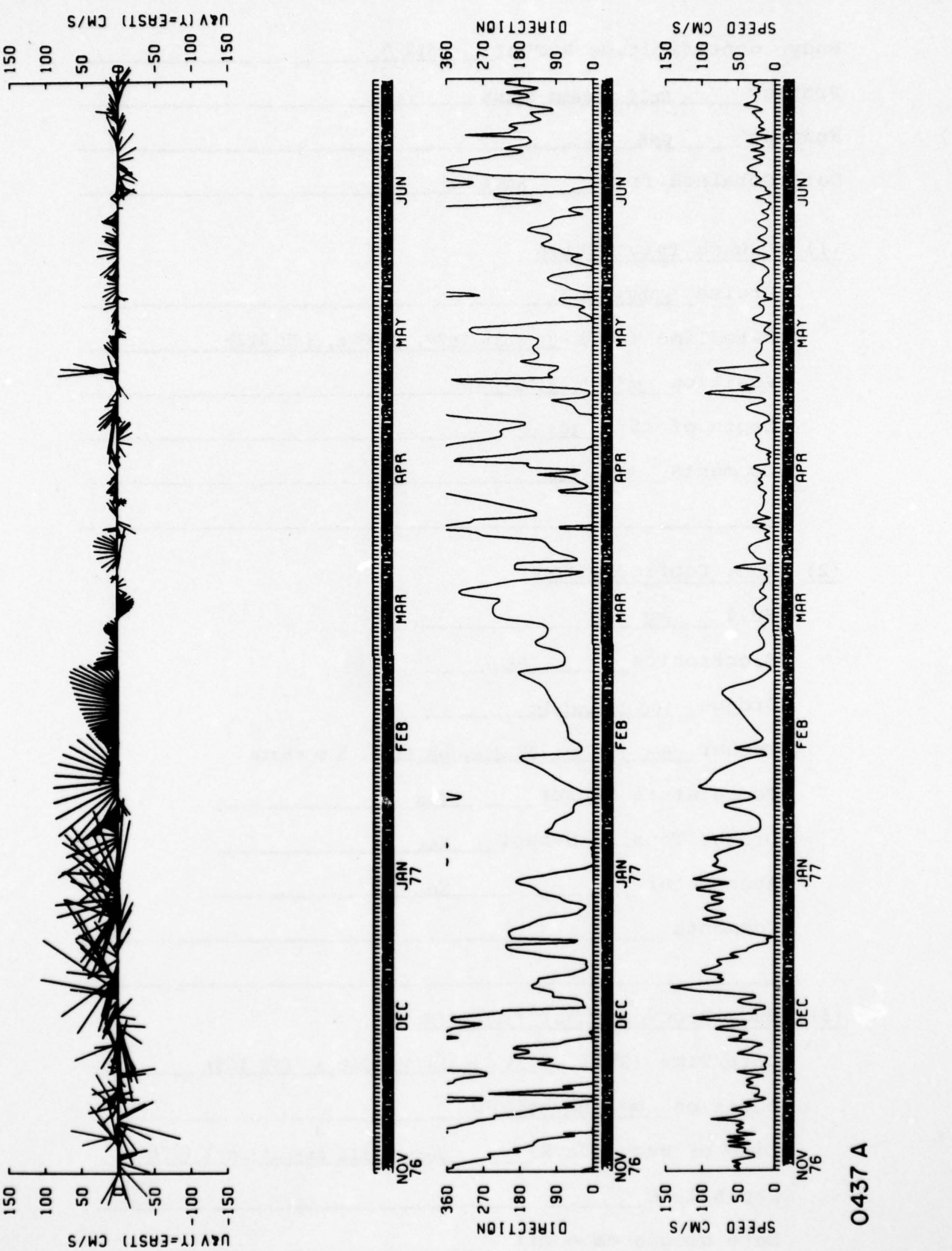
Position 41°02', 26°41'

Life of Buoy (days) 244 (retrieved by fishing boat, taken to France)

Depth 15°C

Date Drogue came off 7 Nov 1976, no line when recovered, only empty thimble


0437 A
25
30
35
40
45
50
55
60
44
42
40
38
159
155
151
177
138
135
167
120
115
108
57
93
71
47
40
28
20
17
9
1/1977
362
358
350
344
340
333
304
314
308
310
300
1976


U&V (Y=EAST) CM/S
150
100
50
0
-50
-100
-150
DIRECTION
360
270
180
90
0
SPEED CM/S
150
100
50
0
NOV 76
DEC
JAN 77
FEB
MAR
APR
MAY
JUN

0437 A

Buoy Identification Number 0512 A

Project Gulf Stream rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise ENDEAVOR 11

Date/Time (GMT) 31 July 1977, 0100 z, (JD 212)

Position 34°30', 71°27'

Depth of 15° 104 m

Comments Ring Bob

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 600 ft, 1 1/2" dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

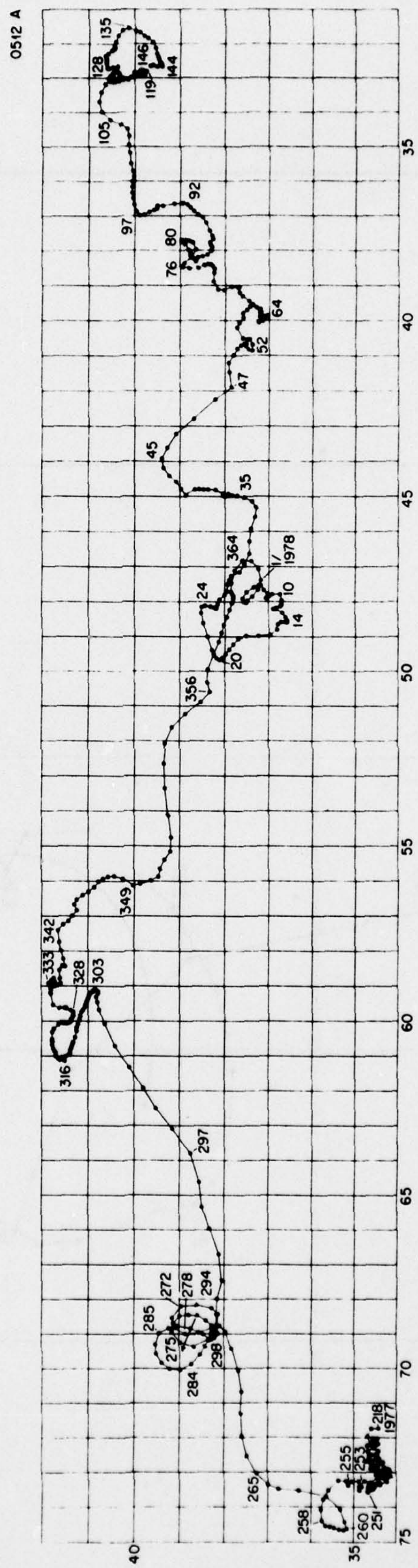
Date/Time (GMT) 25 May 1978, 1240 z, (JD 145)

Position 39°40'N, 32°39'W

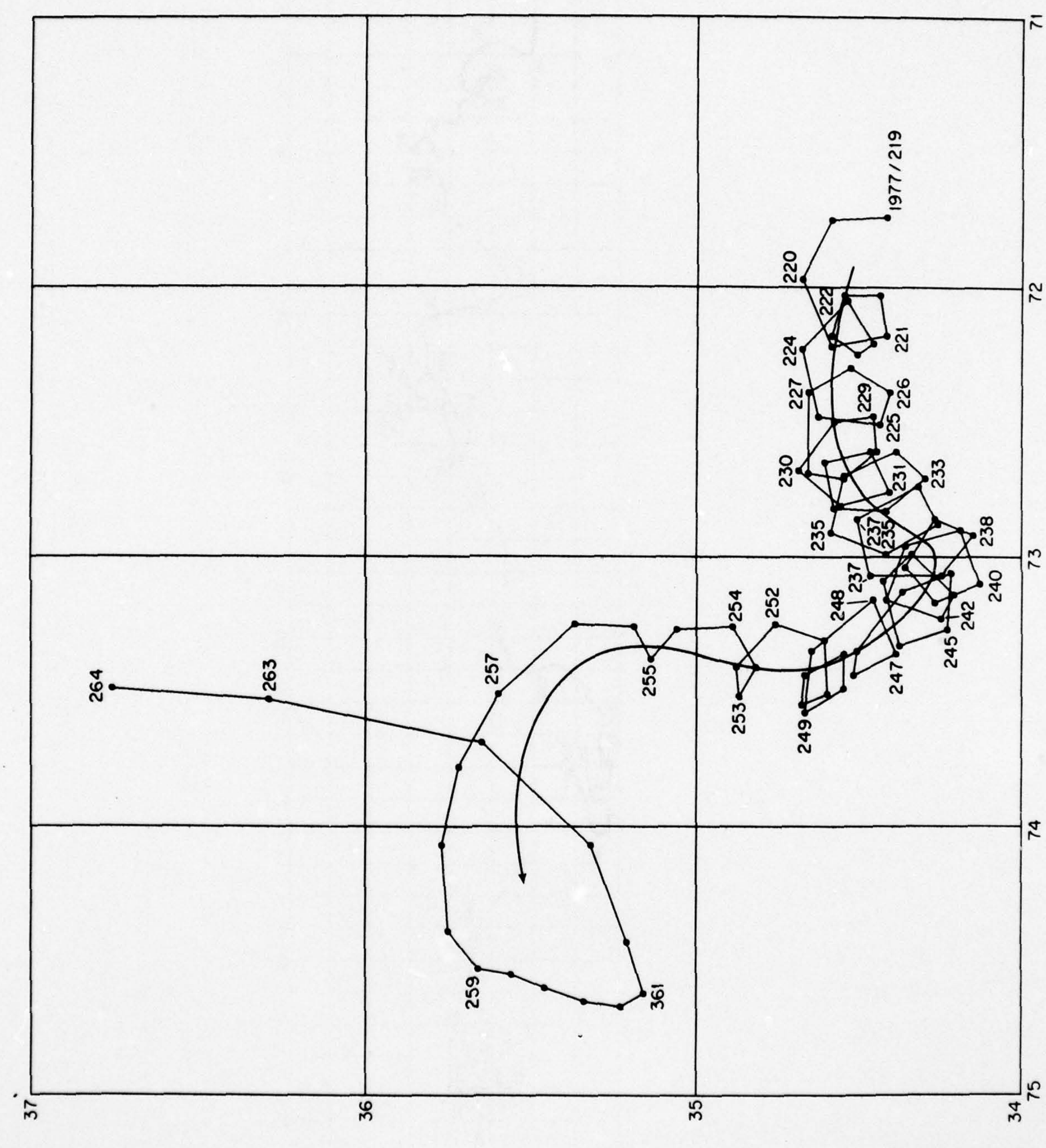
Life of Buoy (days) buoy still operational (298+)

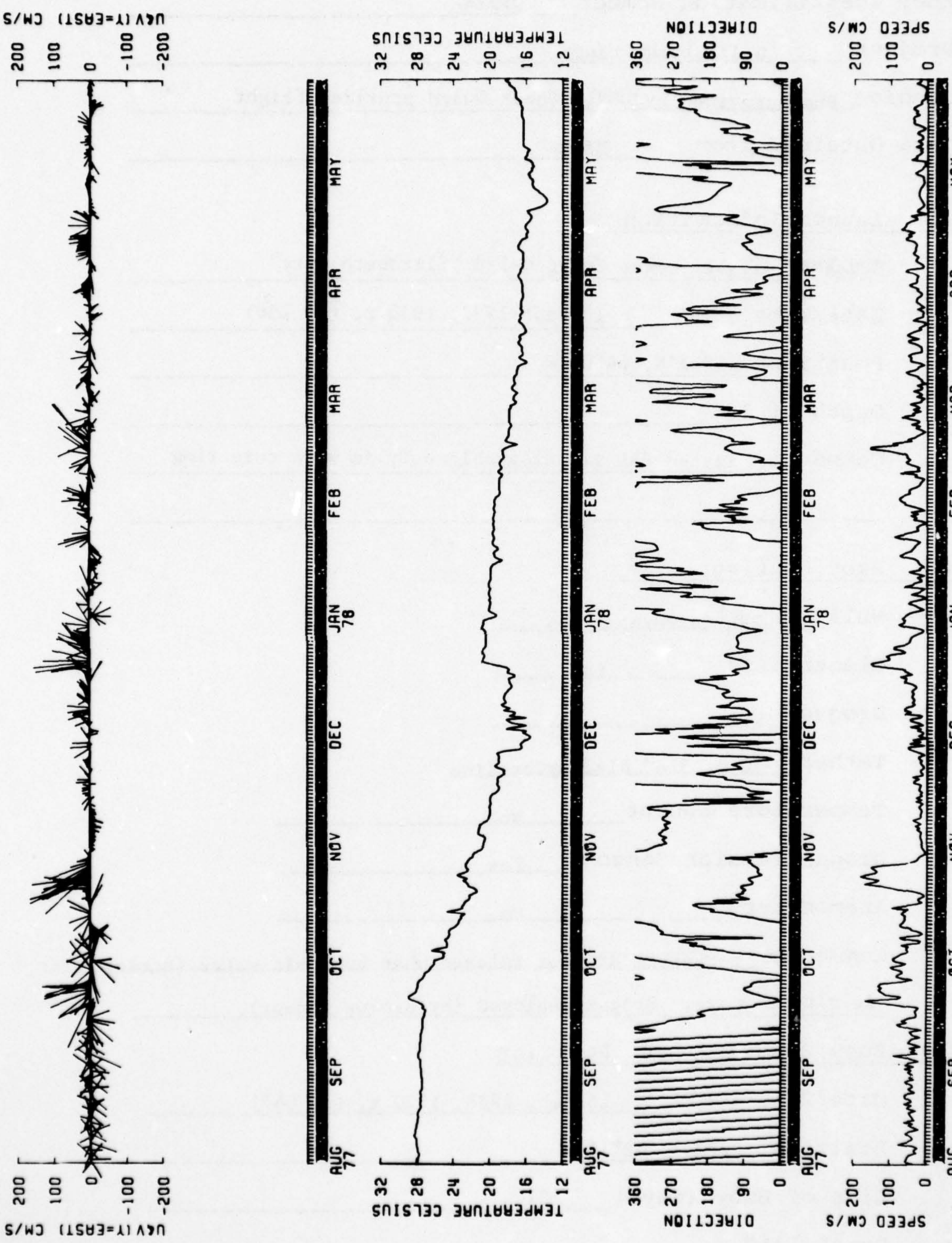
Depth 15°C

Date Drogue came off


0512 A
35
40
45
50
55
60
65
70
75
40
35
135
128
146
119
144
105
92
97
80
76
64
52
47
45
35
364
1978
24
10
14
20
356
349
342
333
328
303
316
297
272
278
294
285
275
298
284
218
1977
255
253
265
258
260
251

0512 A


1977/219
220
221
222
224
225
226
227
229
230
231
233
235
235
237
237
238
240
242
245
247
248
249
252
253
254
255
257
259
361
263
264
37
36
35
34
71
72
73
74
75


U&V(Y=EAST) CM/S
200
100
0
-100
-200
TEMPERATURE CELSIUS
32
28
24
20
16
12
DIRECTION
360
270
180
90
0
SPEED CM/S
200
100
0
AUG 77
SEP
OCT
NOV
DEC
JAN 78
FEB
MAR
APR
MAY

0512 A

Buoy Identification Number 0557A

Project Gulf Stream rings

Funding Buoy provided by NDBO, Coast Guard provided flight

Data Obtained from NASA

(1) Launch Information

Cruise/ Flight Coast Guard C-130 "Elizabeth City"

Date/Time (GMT) 13 Sept 1977, 1930 z, (JD 256)

Position 41°31'N, 64°00'W

Depth of 15°

Comments Tested PRL air droppable buoy in warm core ring

(2) Buoy Configuration

Hull PRL (airdroppable)

Electronics PRL

Drogue W.S.

Tether 50 m, 3/8" dia. nylon line

Temperature Sensor No

Drogue Tension Sensor Yes

Anemometer No

Comments parachute did not release when buoy hit water (during first 10 min. anyway). Drogue deployed (by drogue sensor).

(3) Buoy Recovery/Last Position

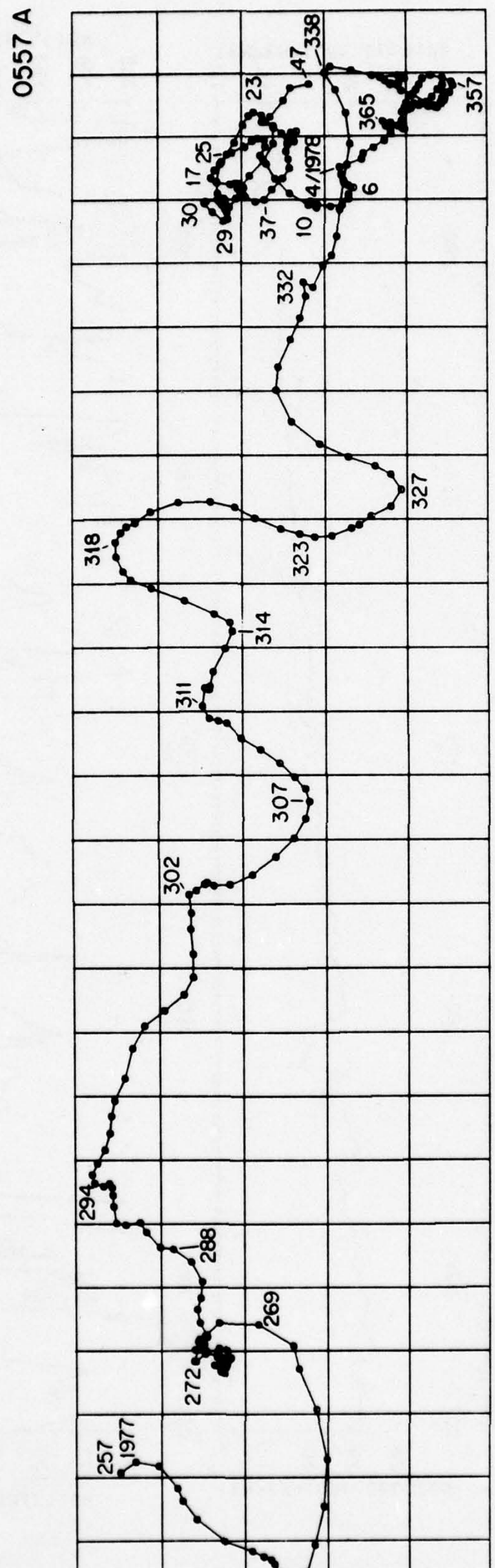
Date/Time (GMT) 16 Feb. 1978, 1520 z, (JD 047)

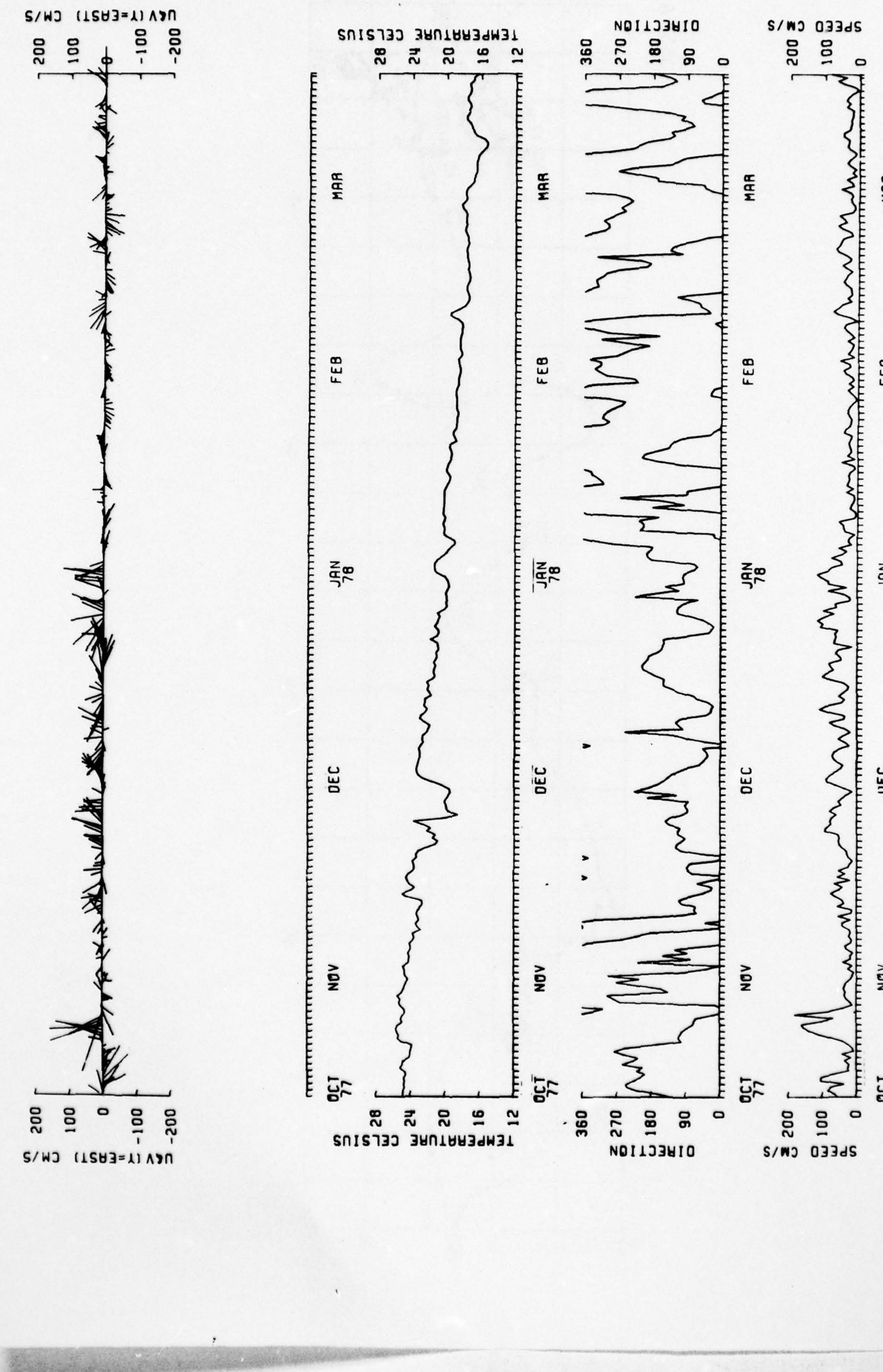
Position 39°06', 42°10'

Life of Buoy (days) 157

Depth 15°C

Date Drogue came off 24 Sept. 1977


0557 A
42
40
38
45
50
55
60
65
257
1977
265
269
272
288
294
302
307
311
314
318
323
327
332
338
357
365
4/1978
6
10
17
23
25
29
30
37
47


U&V(Y=EAST) CM/S
200
100
0
-100
-200
TEMPERATURE CELSIUS
28
24
20
16
12
DIRECTION
360
270
180
90
0
SPEED CM/S
200
100
0
OCT 77
NOV
DEC
JAN 78
FEB
MAR

0557 A

Buoy Identification Number 0614A

Project Gulf Stream rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise ENDEAVOR 11

Date/Time (GMT) 14 Aug 1977, 1030 z, (JD 226)

Position 34°39'N, 78°02'W

Depth of 15° 259 m

Comments Ring Bob

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 600 ft, 1 1/2", pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

Date/Time (GMT) 13 Sept. 1977 (JD256)

Position 36°46', 73°47'

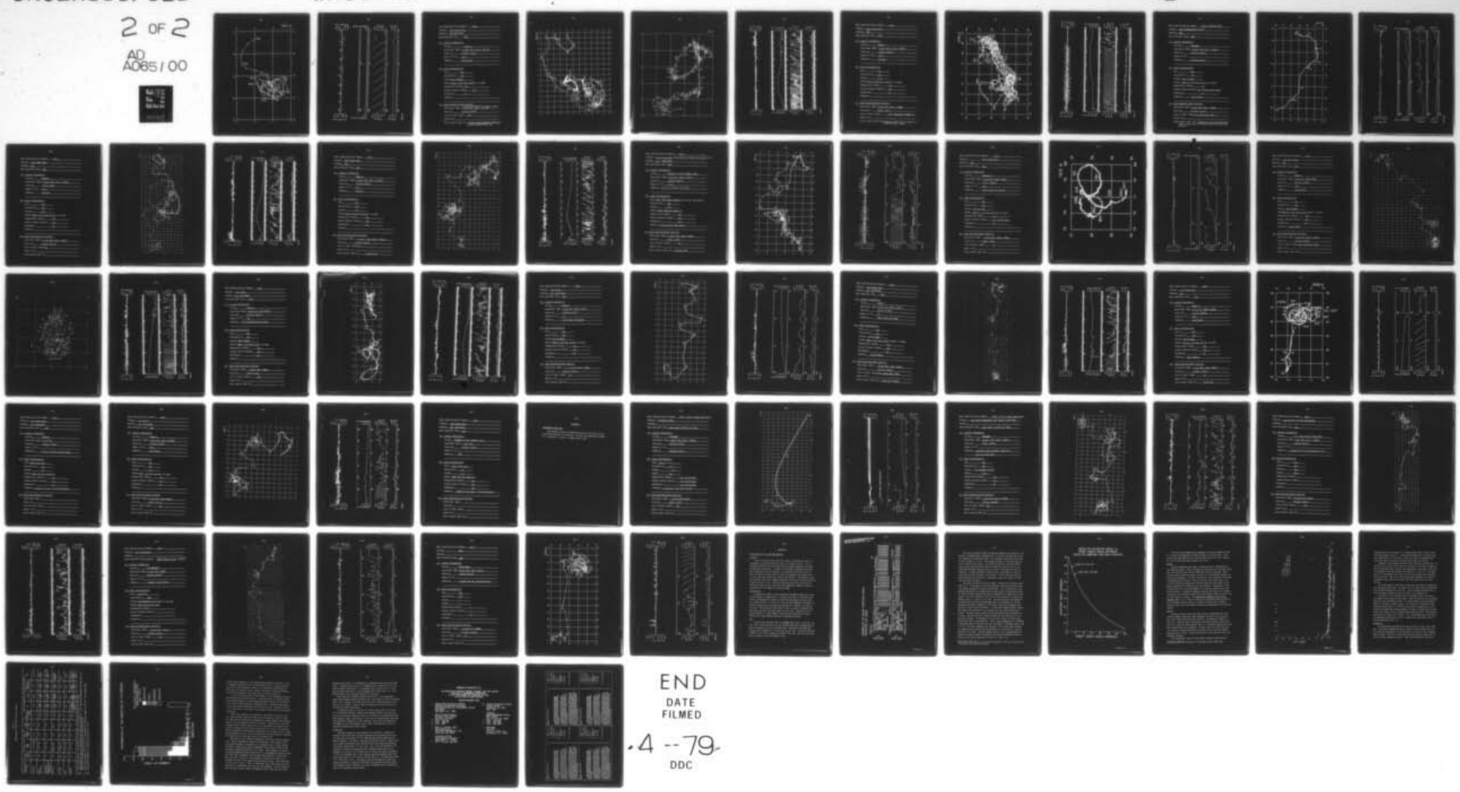
Life of Buoy (days) 31

Depth 15°C

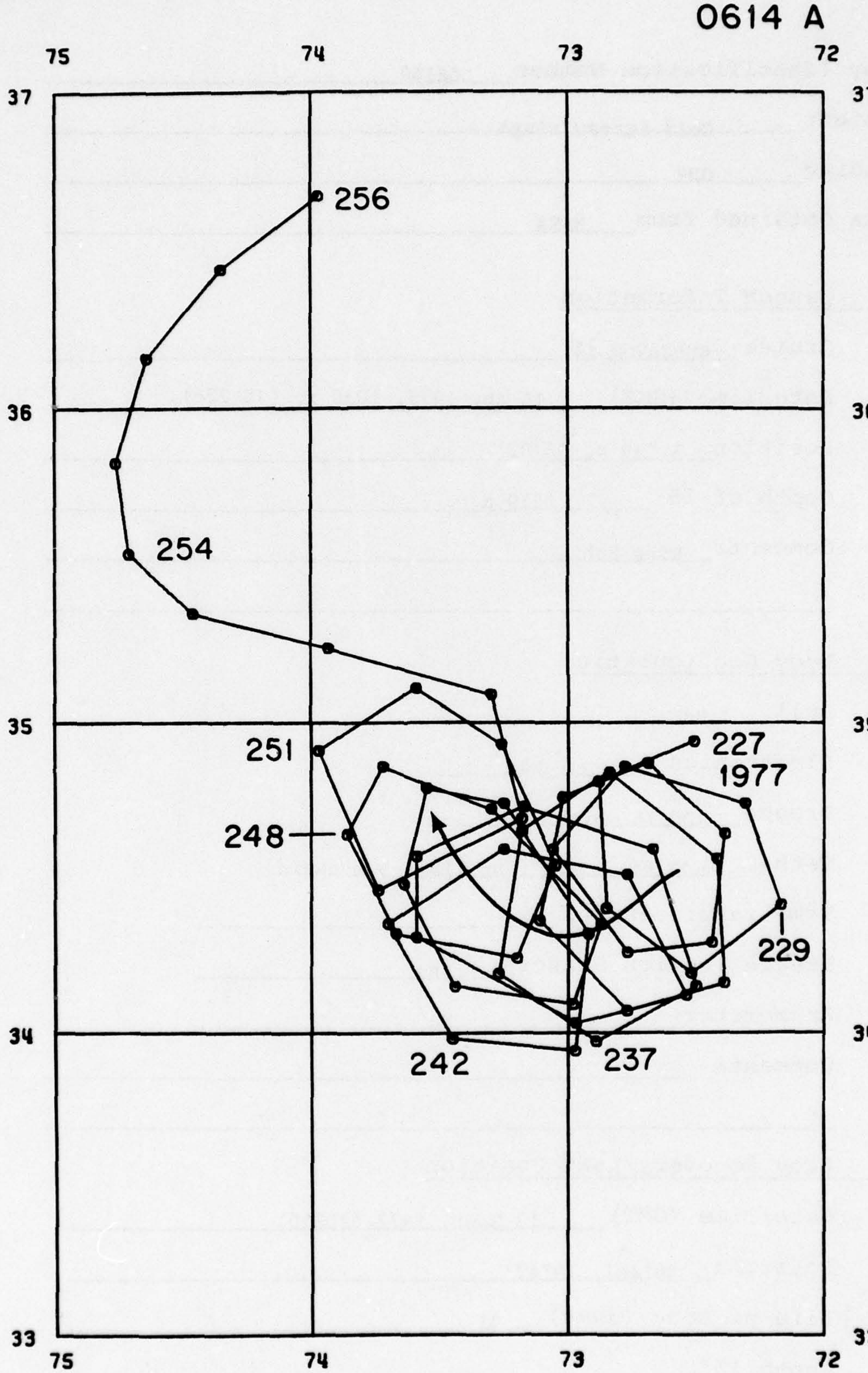
Date Drogue came off

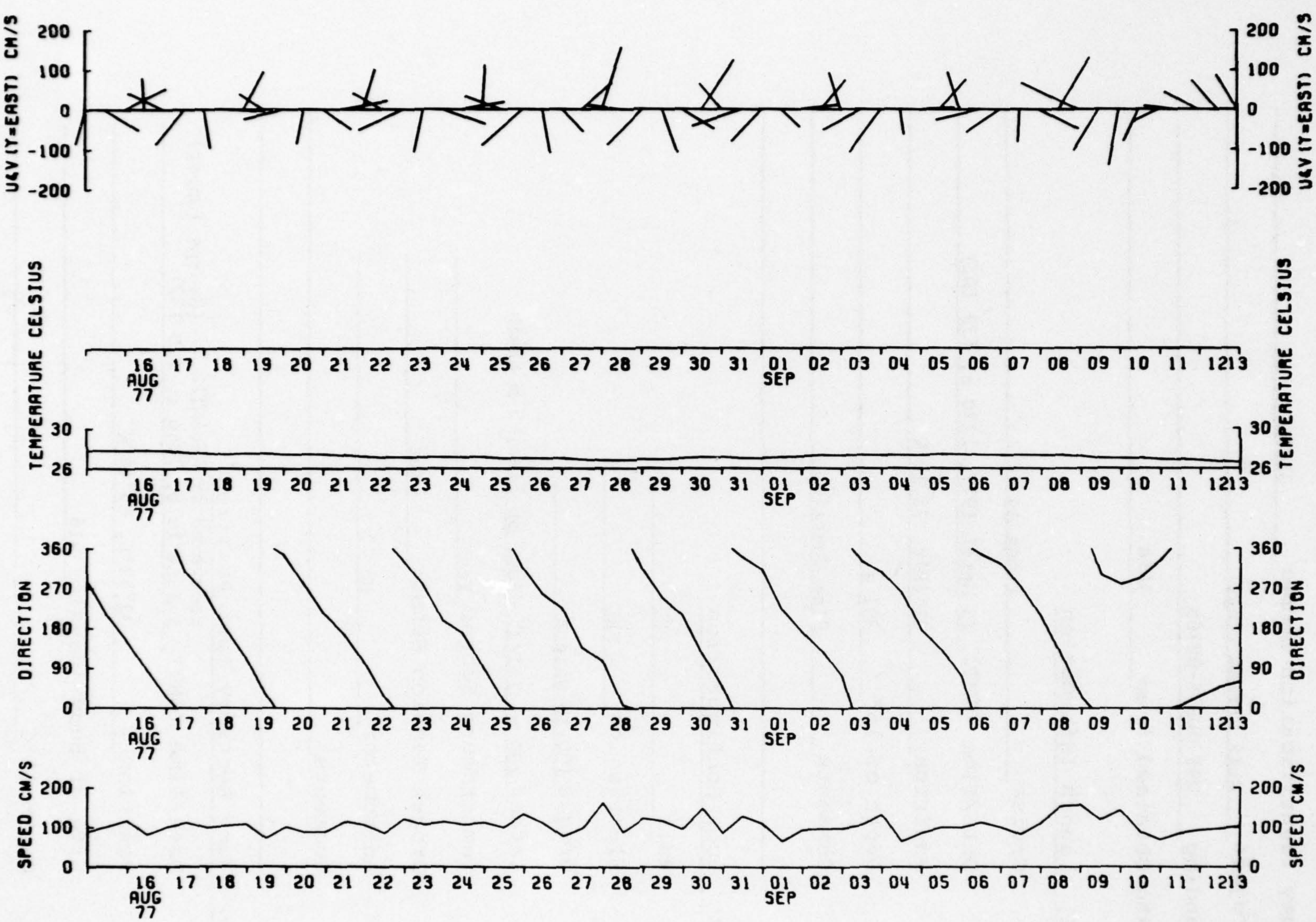
AD-A065 100 WOODS HOLE OCEANOGRAPHIC INSTITUTION MASS F/G 13/10
FREE-DRIFTING BUOY TRAJECTORIES IN THE GULF STREAM SYSTEM (1975--ETC(U)
JAN 79 P L RICHARDSON, J J WHEAT, D BENNETT N00014-74-C-0262
UNCLASSIFIED WHOI-79-4 NL

2 OF 2
AD
A065100



END
DATE
FILMED
4--79
DDC


0614 A
75
74
73
72
37
36
35
34
33
256
254
251
248
242
237
227
1977
229


U&V (Y=EAST) CM/S
200
100
0
-100
-200
TEMPERATURE CELSIUS
30
26
DIRECTION
360
270
180
90
0
SPEED CM/S
200
100
0
16 AUG 77
17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
01 SEP
02 03 04 05 06 07 08 09 10 11 12 13

0614 A

Buoy Identification Number 0707A

Project Gulf Stream rings

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 65

Date/Time (GMT) 12 April 1977, 1230 z, (JD 102)

Position 32°48'N, 73°10'W

Depth of 15° 391 m

Comments Ring Charlie

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 200 m, 1 1/2" dia., pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

Date/Time (GMT) recovered by ATLANTIS II (George Tupper) 1 June 1978, 1840 z, (JD 152)

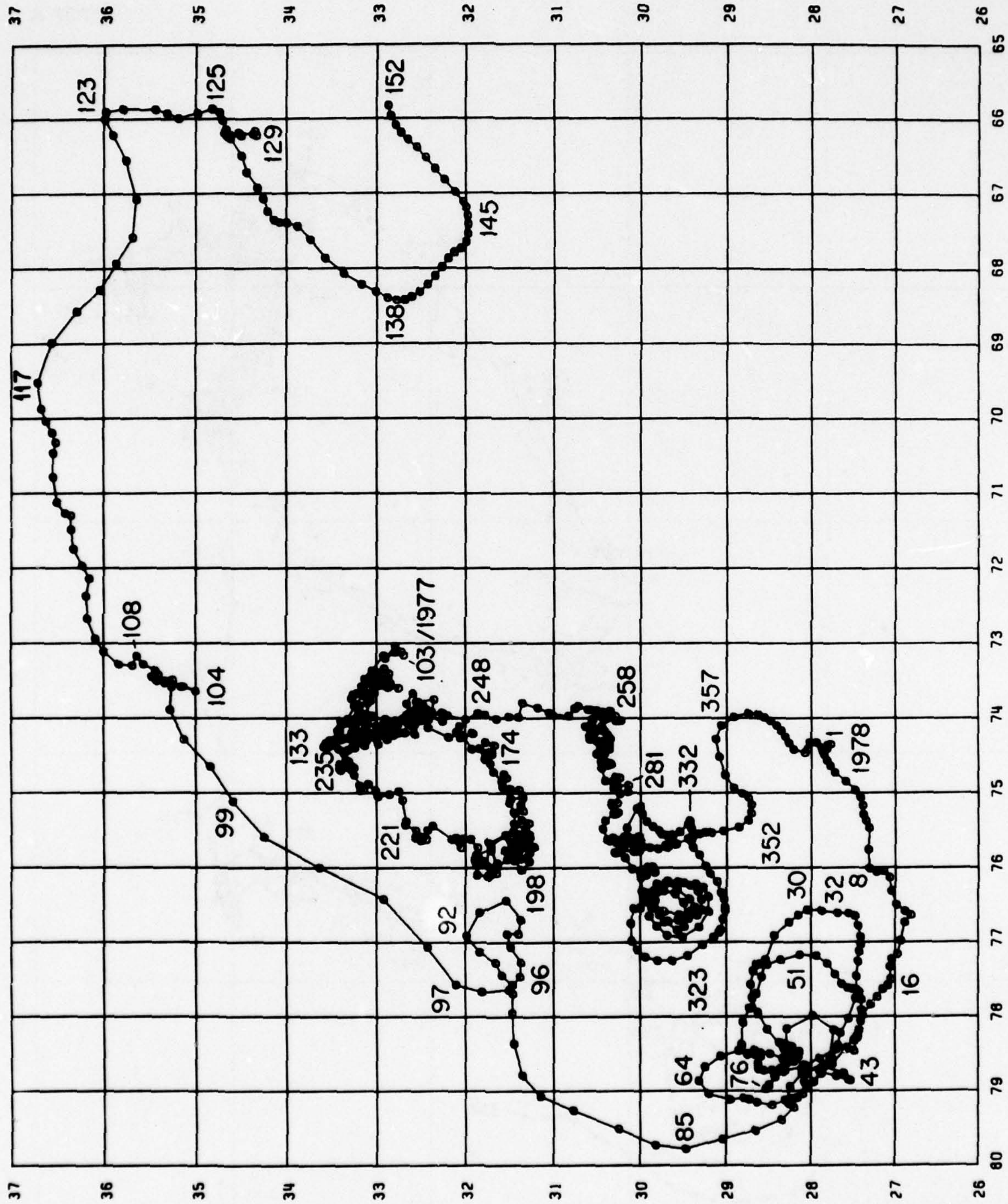
Position 32°53'N, 65°44'W

Life of Buoy (days) 416

Depth 15°C

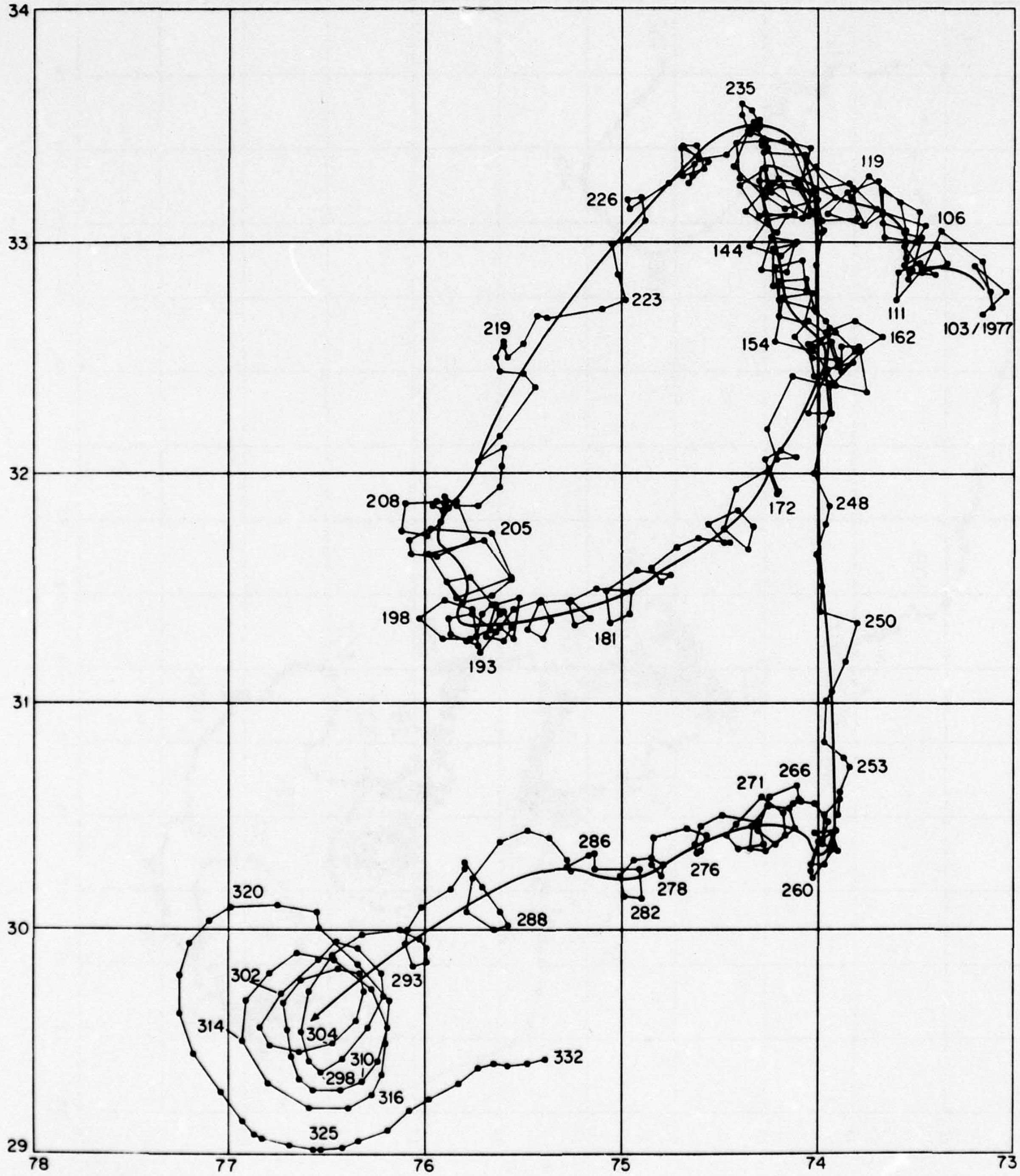
Date Drogue came off no drogue when recovered, chain only, shackle corroded and let go

0707 A

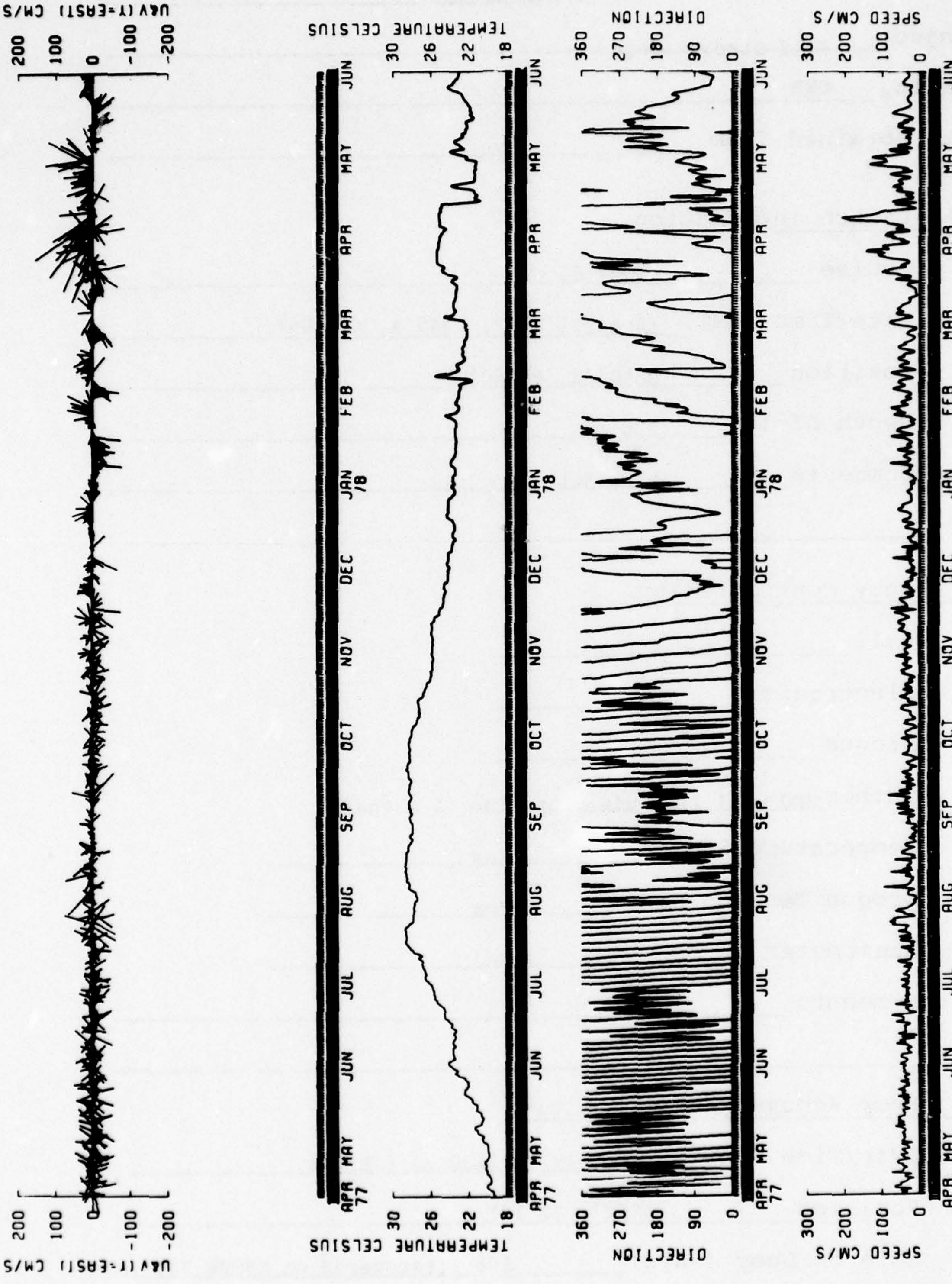


37
36
35
34
33
32
31
30
29
28
27
26
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
123
125
129
152
145
138
117
108
104
103/1977
248
258
357
133
235
174
281
332
1
1978
99
221
352
198
30
32
8
92
96
97
323
51
16
64
76
43
85

0707 A



34
33
32
31
30
29
78
77
76
75
74
73
235
119
226
106
144
223
111
103/1977
219
154
162
172
248
208
205
198
250
181
193
253
266
271
286
276
278
260
282
320
288
302
293
314
304
310
298
316
332
325


U&V(Y=EAST) CM/S
200
100
0
-100
-200
TEMPERATURE CELSIUS
30
26
22
18
DIRECTION
360
270
180
90
0
SPEED CM/S
300
200
100
0
APR 77
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN 78
FEB
MAR
APR
MAY
JUN

0707 A

Buoy Identification Number 0731A

Project Gulf Stream rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 65

Date/Time (GMT) 14 April 1977, 1545 z, (JD104)

Position 36°04'N, 69°40'W

Depth of 15° 230 m

Comments Ring Bob

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue W.S.

Tether 200 m, 1 1/4" dia., pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

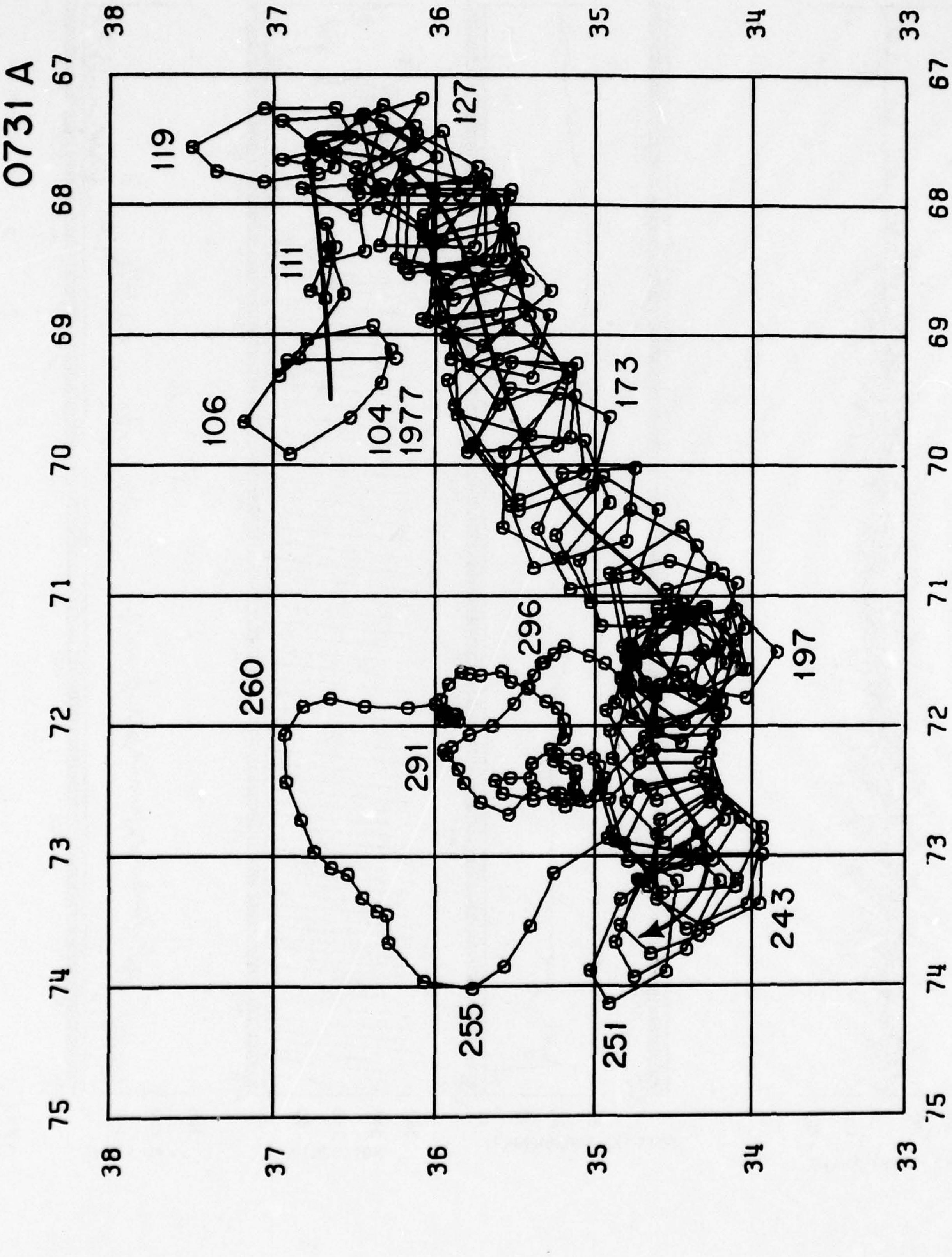
Date/Time (GMT) 26 Oct 1977, 2230 z, (JD299)

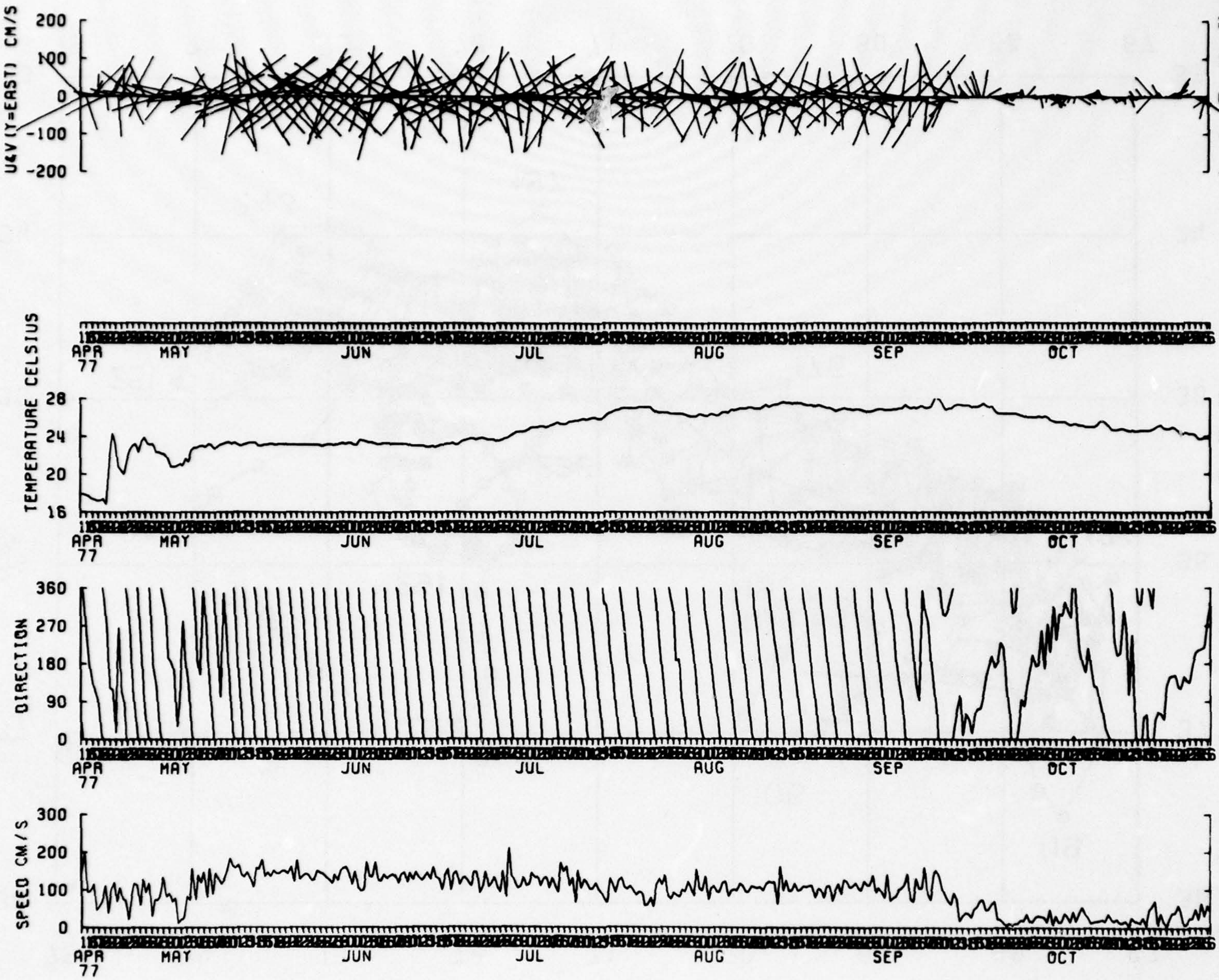
Position 34°52', 72°17'

Life of Buoy (days) 196 (recovered on KNORR 71)

Depth 15°C

Date Drogue came off no drogue nor line when recovered, only chain and empty thimble.


0731 A
119
127
111
106
104
1977
173
296
260
197
291
243
255
251
67
68
69
70
71
72
73
74
75
38
37
36
35
34
33


U&V(Y=EAST) CM/S
200
100
0
-100
-200
TEMPERATURE CELSIUS
28
24
20
16
DIRECTION
360
270
180
90
0
SPEED CM/S
300
200
100
0
APR
77
MAY
JUN
JUL
AUG
SEP
OCT

0731 A

Buoy Identification Number 0731B (relaunched buoy)

Project Gulf Stream/Labrador Current

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise EVERGREEN

Date/Time (GMT) 13 April 1978, 1317 z. (JD103)

Position 48°34'N, 49°02'W

Depth of 15°

Comments Labrador Current

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 600 ft, 1 1/2" dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes; modified (stops added)

Anemometer No

Comments taped thimble

(3) Buoy Recovery/Last Position

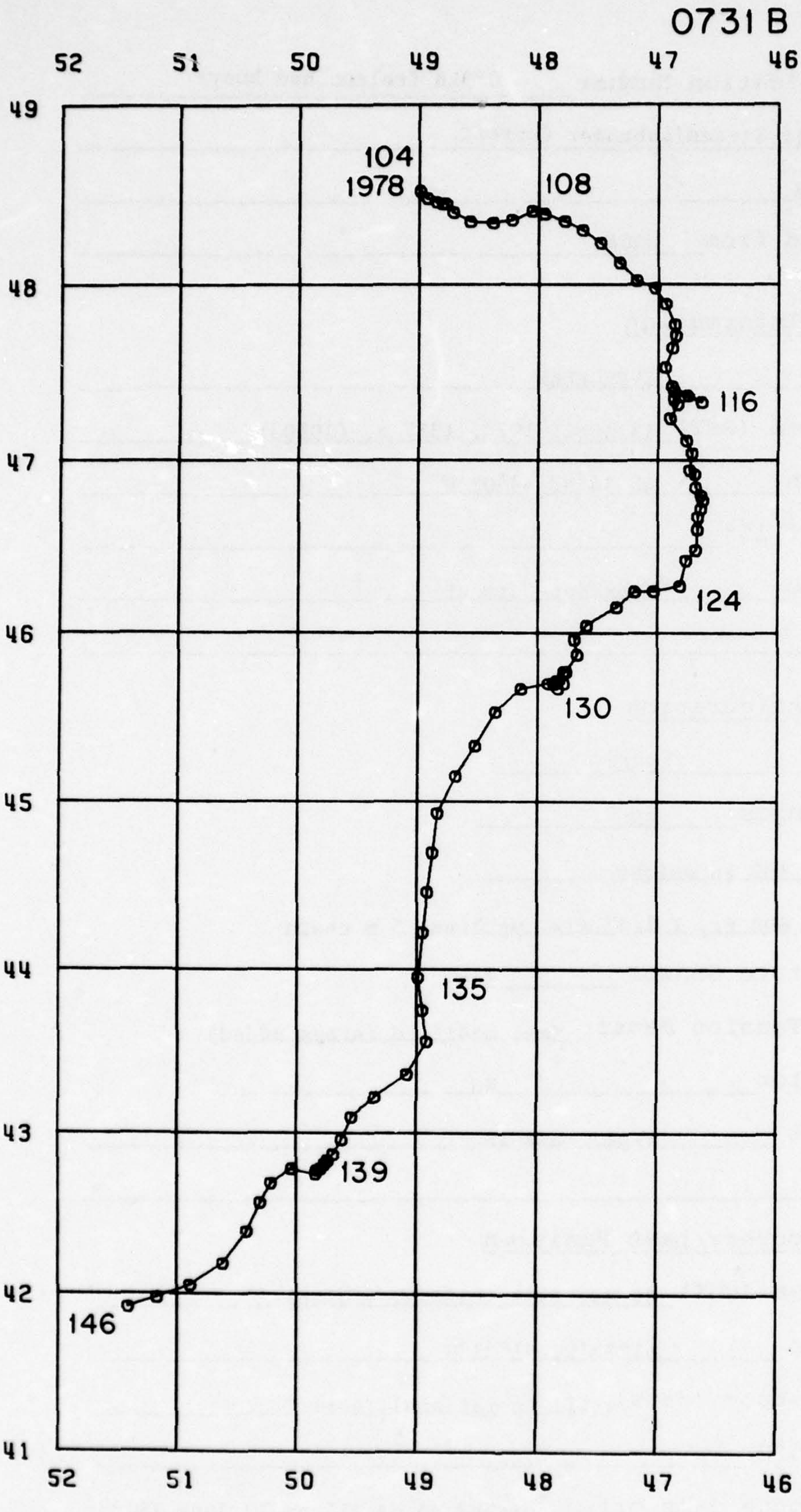
Date/Time (GMT) 26 May 1978, 0520 z. (JD146)

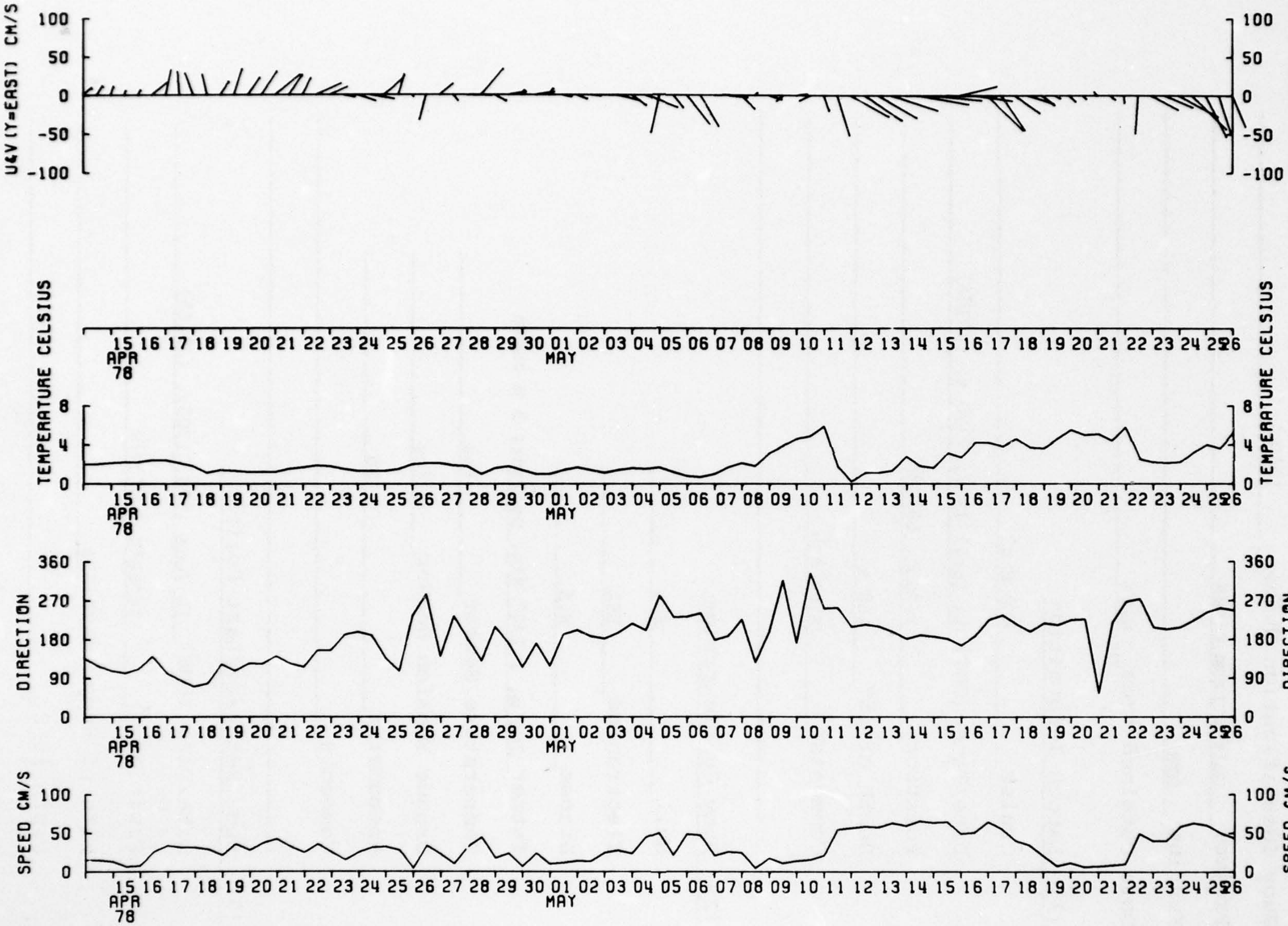
Position 41°53'N, 51°31'W

Life of Buoy (days) still operational (44+) *

Depth 15°C

Date Drogue came off *picked up by AII on 23 June 1978
Drogue, drogue sensor and tether in good condition when recovered.


0731 B
52
51
50
49
48
47
46
49
48
47
46
45
44
43
42
41
104
1978
108
116
124
130
135
139
146


U4V (Y=EAST) CM/S
TEMPERATURE CELSIUS
DIRECTION
SPEED CM/S
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
APR
78
MAY

0731 B

Buoy Identification Number 1040 A

Project Gulf Stream rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 65

Date/Time (GMT) 14 April 1977, 2150 z, (JD104)

Position 37°03', 68°58'

Depth of 15° 460 m

Comments Ring Bob

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue W.S.

Tether 200 m, 1 1/4" dia. pp line; 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

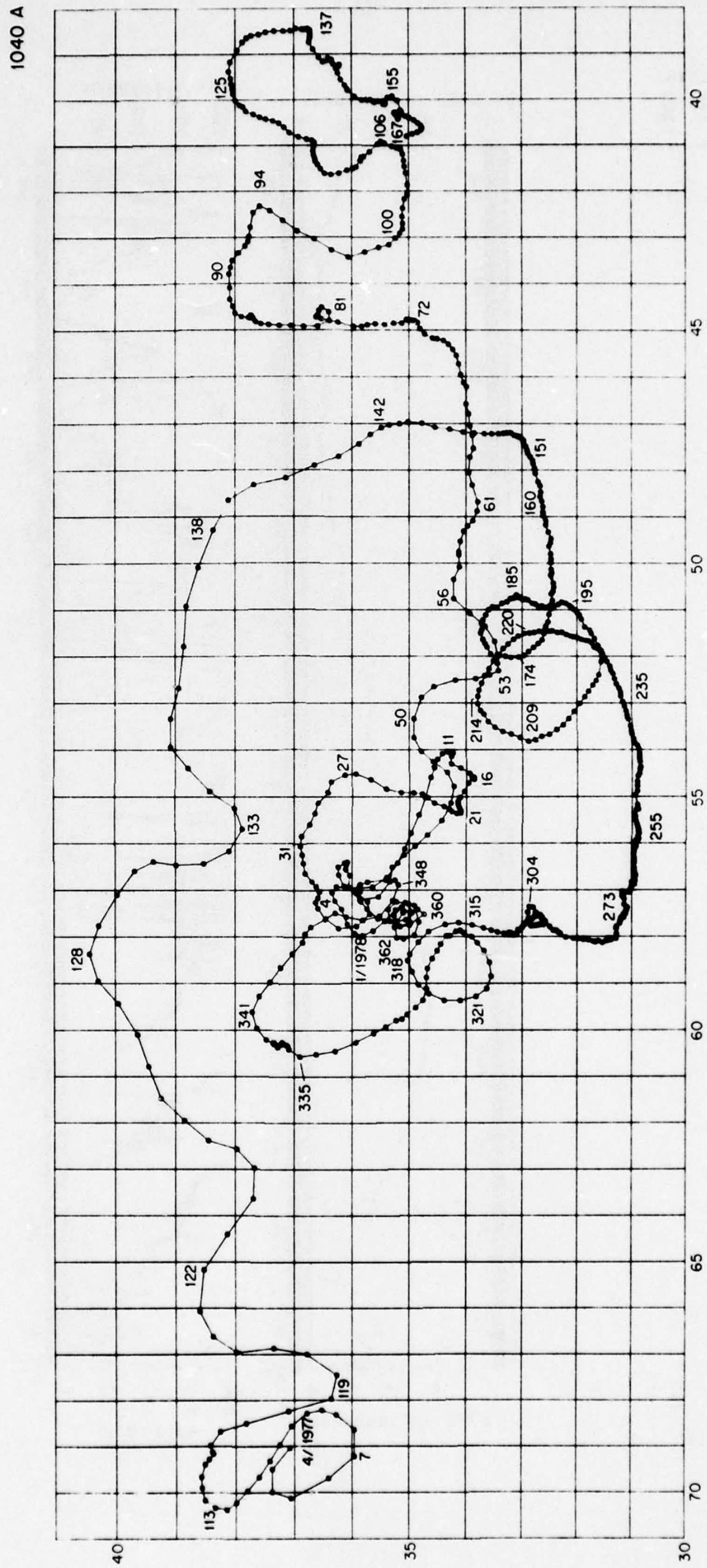
Date/Time (GMT) 14 June 1978, 1305z, (JD165)

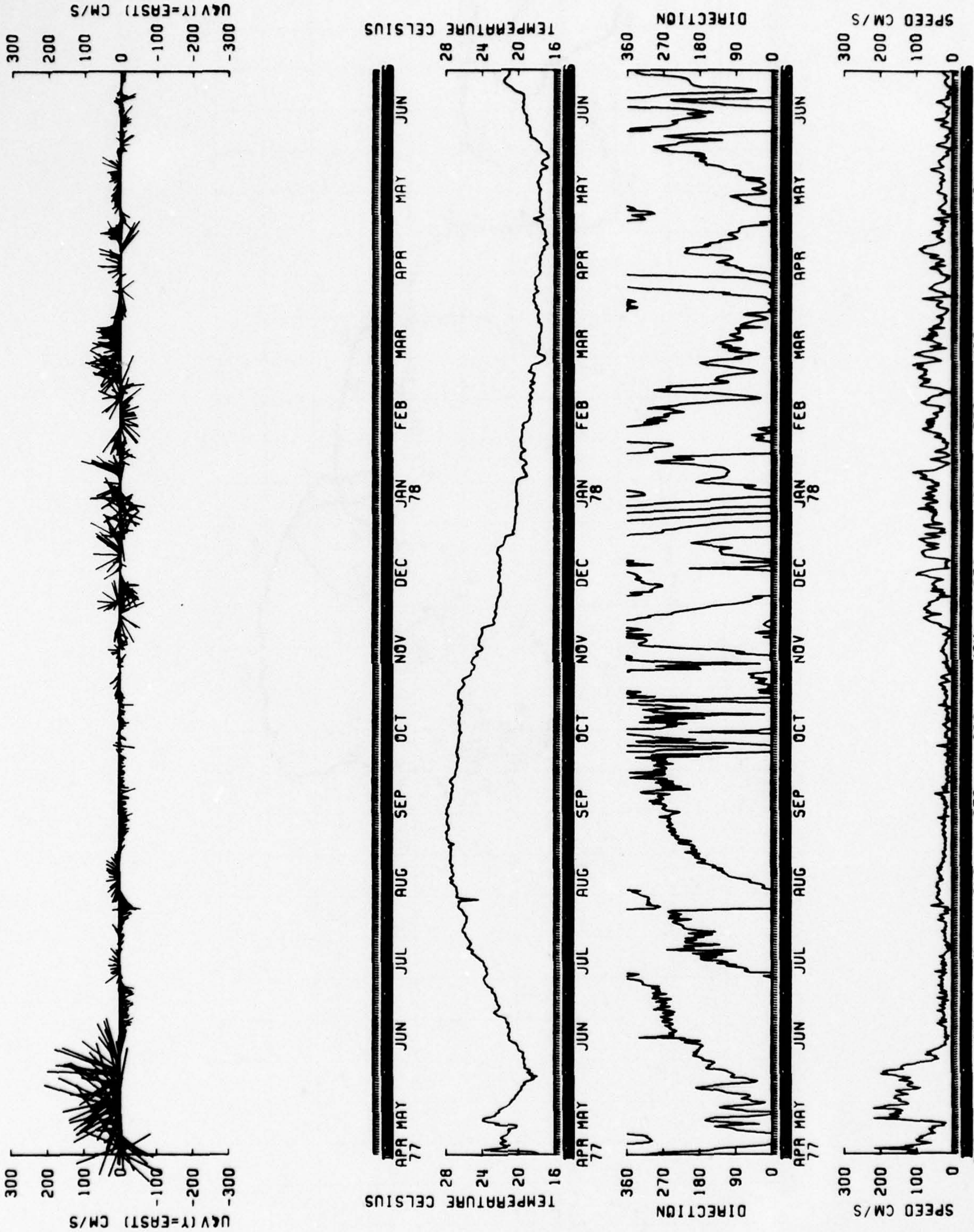
Position 34°46'N, 40°37'W

Life of Buoy (days) 426

Depth 15°C

Date Drogue came off


1040 A
40
45
50
55
60
65
70
40
35
30
137
125
155
106
167
94
100
90
81
72
142
151
138
61
160
56
185
195
220
53
174
235
50
214
209
11
27
16
21
133
255
31
348
304
4
360
315
273
1/1978
362
318
128
341
321
335
122
119
4/1977
7
113


U&V (Y=EAST) CM/S
300 200 100 0 -100 -200 -300
TEMPERATURE CELSIUS
28 24 20 16
DIRECTION
360 270 180 90 0
SPEED CM/S
300 200 100 0
APR 77 MAY JUN JUL AUG SEP OCT NOV DEC JAN 78 FEB MAR APR MAY JUN

1040 A

Buoy Identification Number 1076 A

Project Gulf Stream rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 65

Date/Time (GMT) 15 April 1977, 1515 z, (JD105)

Position 36°34'N, 69°32'W

Depth of 15° 40 m

Comments Ring Bob

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue W.S.

Tether 200 m 1 1/4" dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

Date/Time (GMT) 23 April, 1978, 0150 z, (JD113)

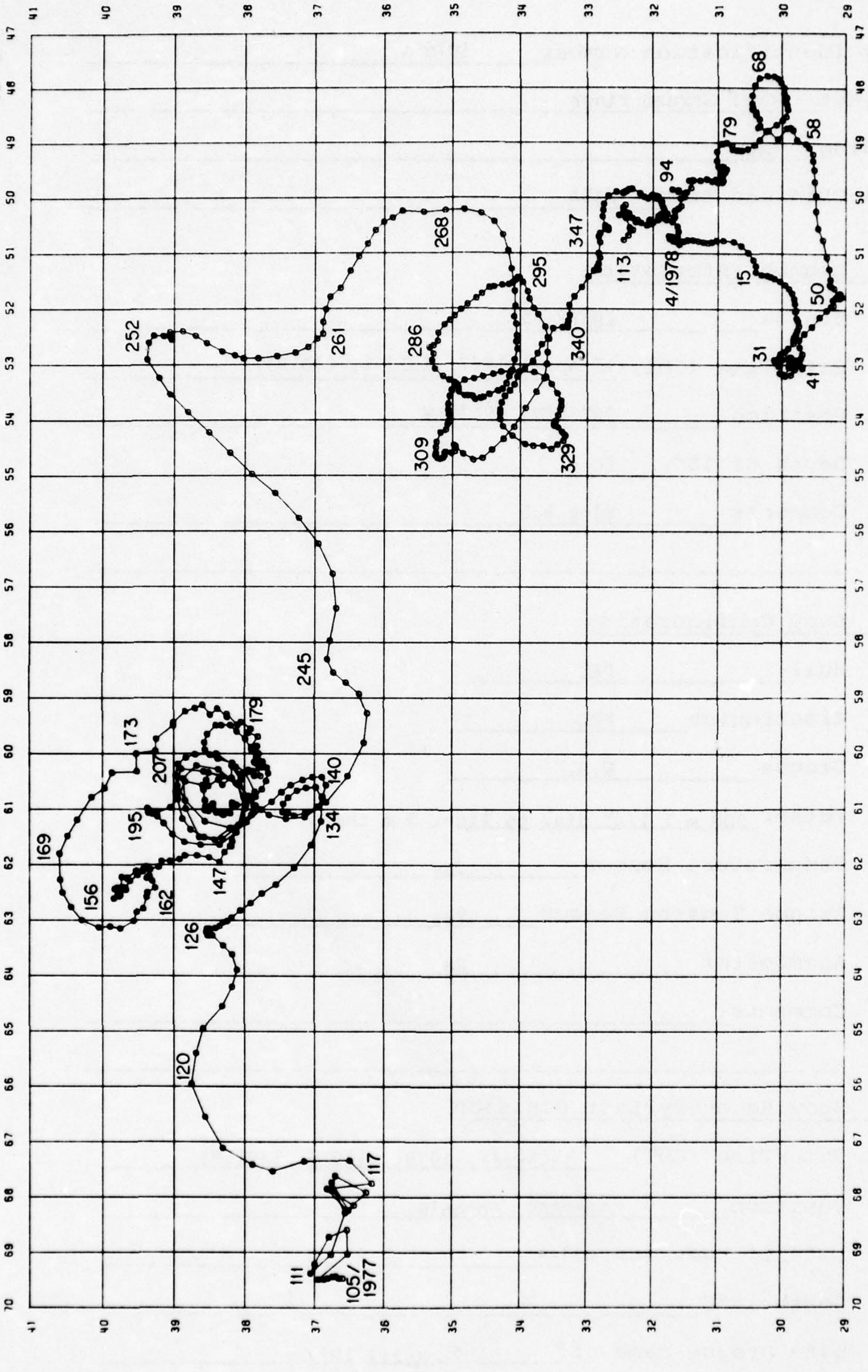
Position 32°28'N, 50°46'W

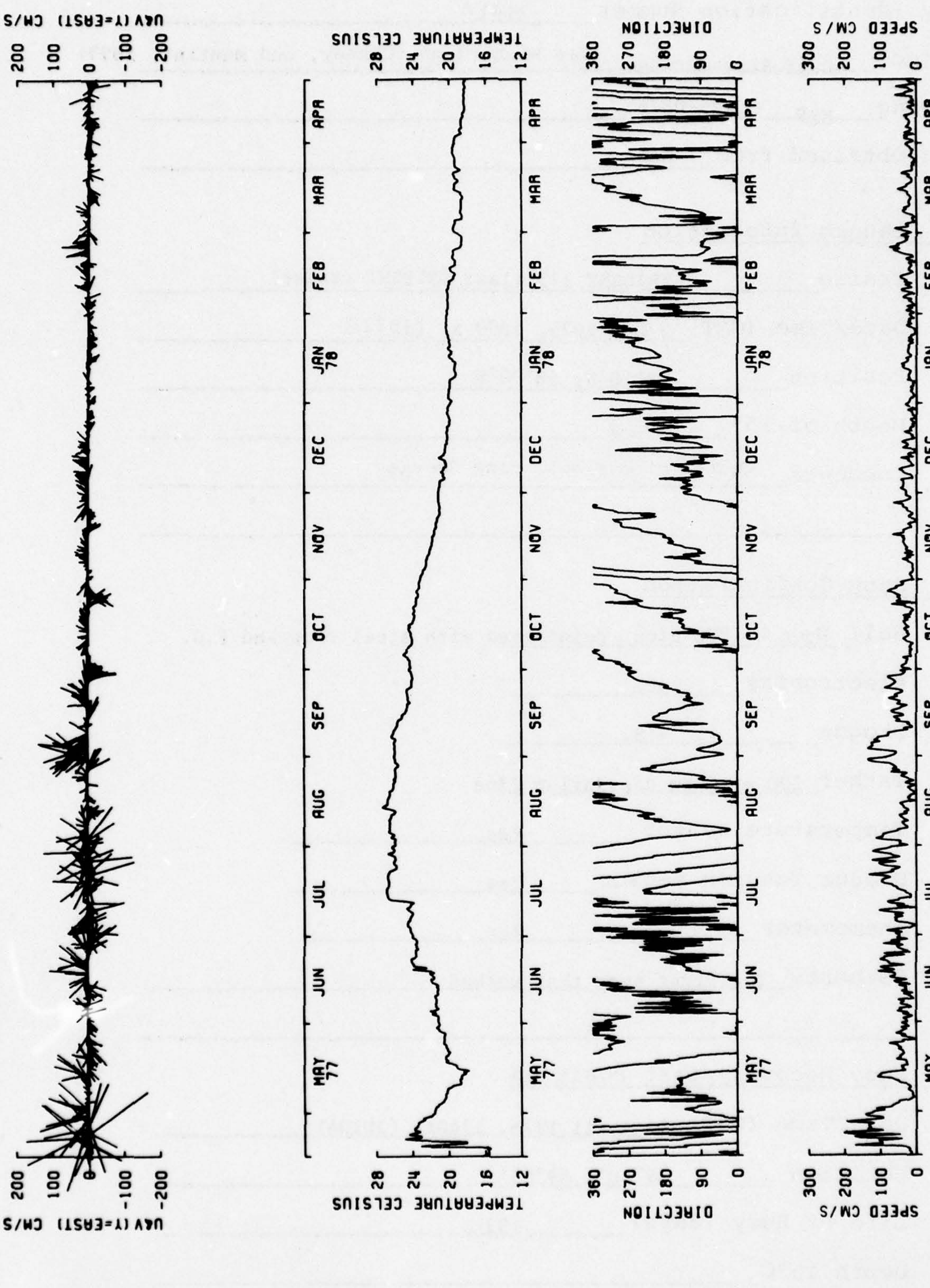
Life of Buoy (days) 374

Depth 15°C

Date Drogue came off 28 April 1977

1076 A


105/
1977
111
117
120
126
134
140
147
156
162
169
173
179
195
207
245
252
261
268
286
295
309
329
340
347
113
94
4/1978
15
31
41
50
58
68
79



UAV(Y=EAST) CM/S
TEMPERATURE CELSIUS
DIRECTION
SPEED CM/S
MAY 77
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN 78
FEB
MAR
APR

1076 A

Buoy Identification Number 1151 A

Project Gulf Stream rings (see Richardson, Cheney, and Mantini, 1977)

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise TRIDENT 175 (last TRIDENT cruise)

Date/Time (GMT) 3 Dec 1975, 1600 z, (JD337)

Position 36°10'N, 58°00'W

Depth of 15° 132 m

Comments Center of cyclonic ring George

(2) Buoy Configuration

Hull Nova U (PVC pipe) reinforced with steel rods and F.G.

Electronics AEL

Drogue W.S.

Tether 200 m, 5/8m dia. nylon line

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer Yes

Comments The first buoy that worked

(3) Buoy Recovery/Last Position

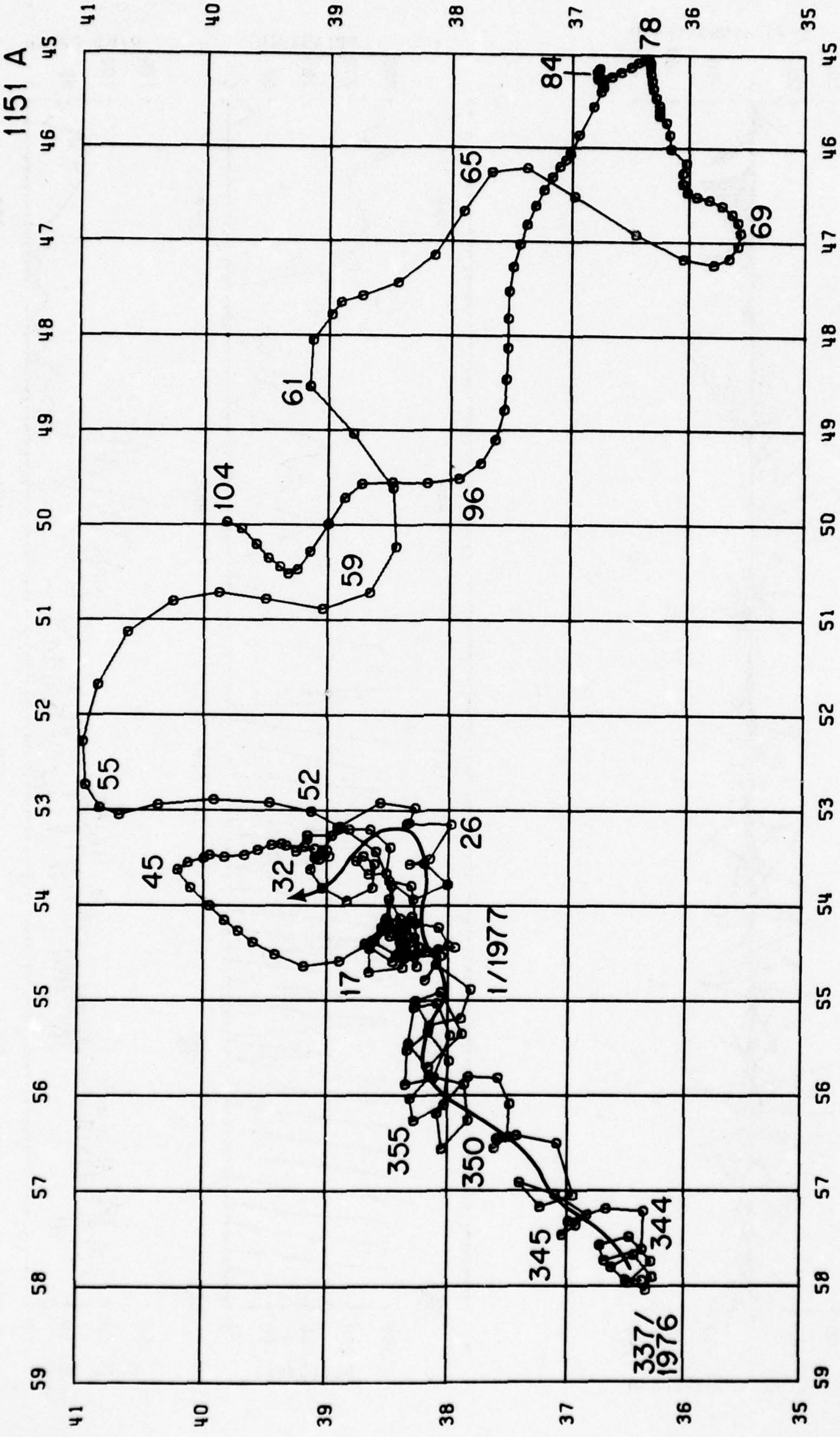
Date/Time (GMT) 14 April 1976, 1340z, (JD104)

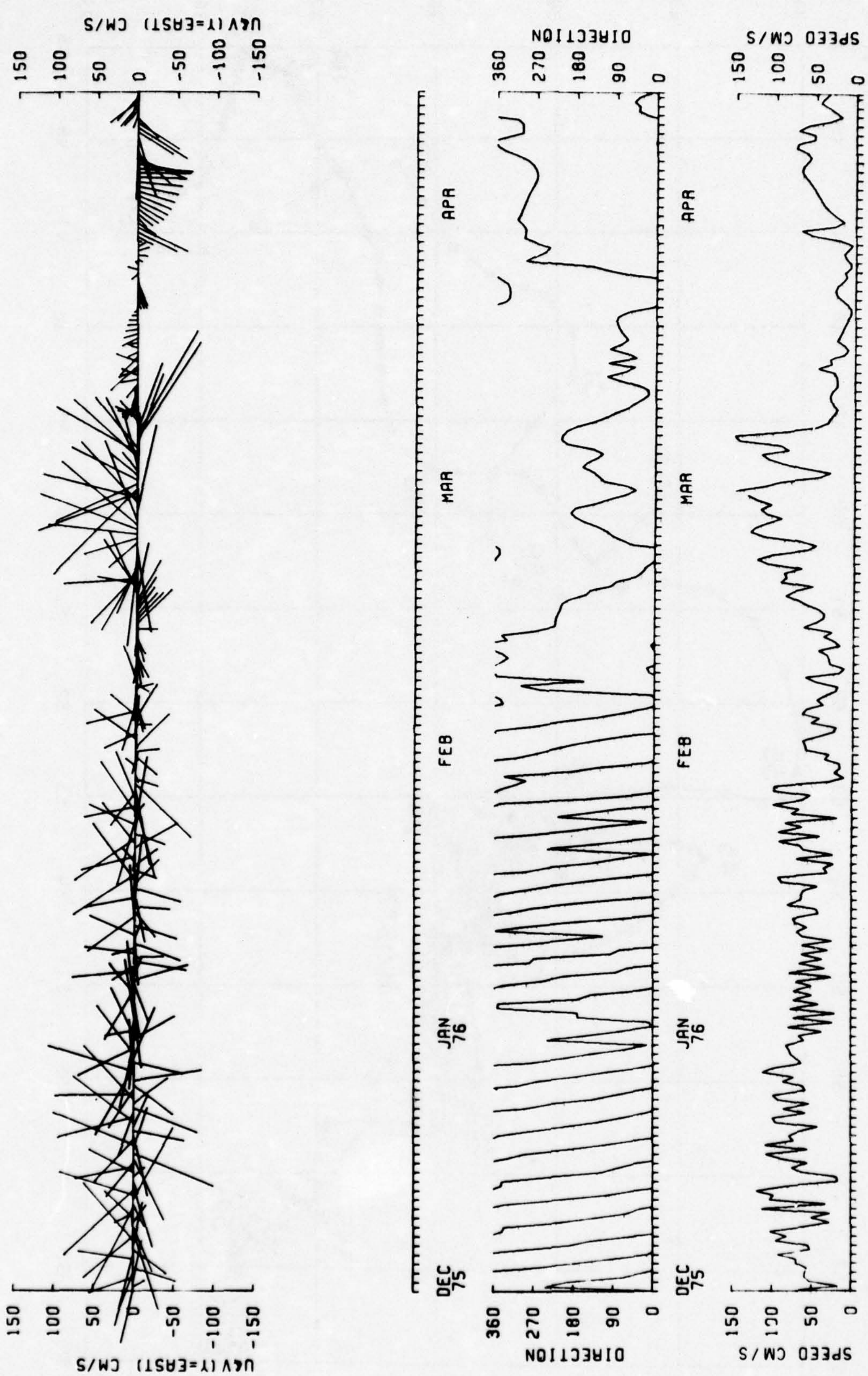
Position 39°50', 49°58'

Life of Buoy (days) 133

Depth 15°C

Date Drogue came off 29 Janury 1976


1151 A
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
41
40
39
38
37
36
35
78
84
65
69
61
104
96
59
55
52
45
32
26
17
1/1977
355
350
345
344
337/
1976


U&V(Y=EAST) CM/S
150
100
50
0
-50
-100
-150
DIRECTION
360
270
180
90
0
SPEED CM/S
150
100
50
0
DEC 75
JAN 76
FEB
MAR
APR

1151 A

Buoy Identification Number 1212A

Project Gulf Stream rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise ENDEAVOR II

Date/Time (GMT) 12 Aug 1977, 2210z, (JD224)

Position 34°17', 70°26'W

Depth of 15° 680 m

Comments Behind (east) of Ring Bob

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 600 ft, 1 1/2" dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes, did not work

Anemometer No

Comments

(3) Buoy Recovery/Last Position

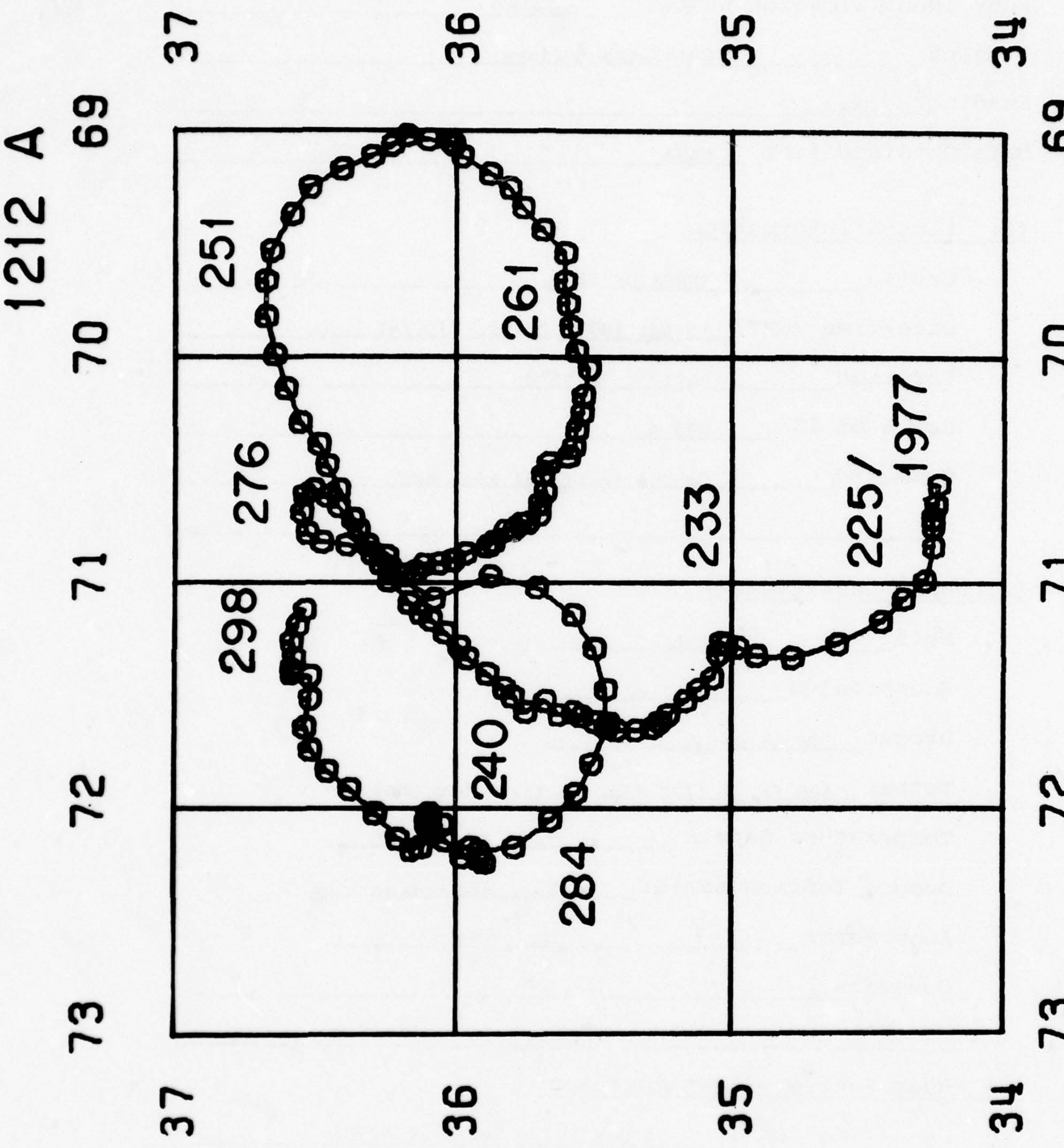
Date/Time (GMT) 25 Oct 1977, 1440z, (JD298)

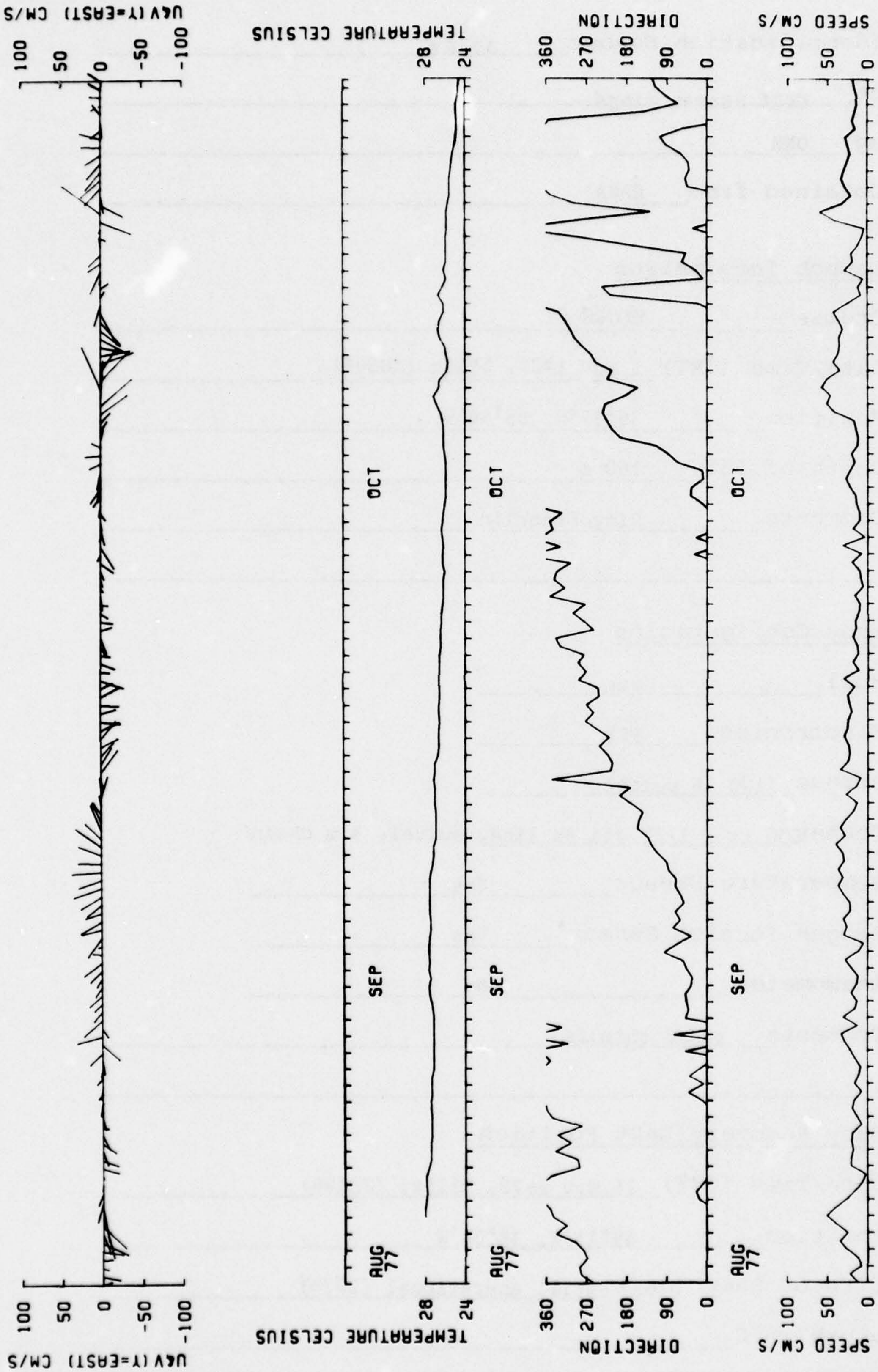
Position 36°32', 71°06'

Life of Buoy (days) 75

Depth 15°C

Date Drogue came off


1212 A
69
70
71
72
73
37
36
35
34
251
261
276
233
225/
1977
298
240
284


SPEED CM/S
DIRECTION
TEMPERATURE CELSIUS
U&V(Y=EAST) CM/S
AUG 77
SEP
OCT

1212 A

Buoy Identification Number 1224A

Project Gulf Stream rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 71

Date/Time (GMT) 1 Nov 1977, 1915z (JD305)

Position 36°37'N, 65°46'W

Depth of 15° 160 m

Comments Ring Franklin

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 600 ft 1 1/2" dia pp line, swivel, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments taped thimble

(3) Buoy Recovery/Last Position

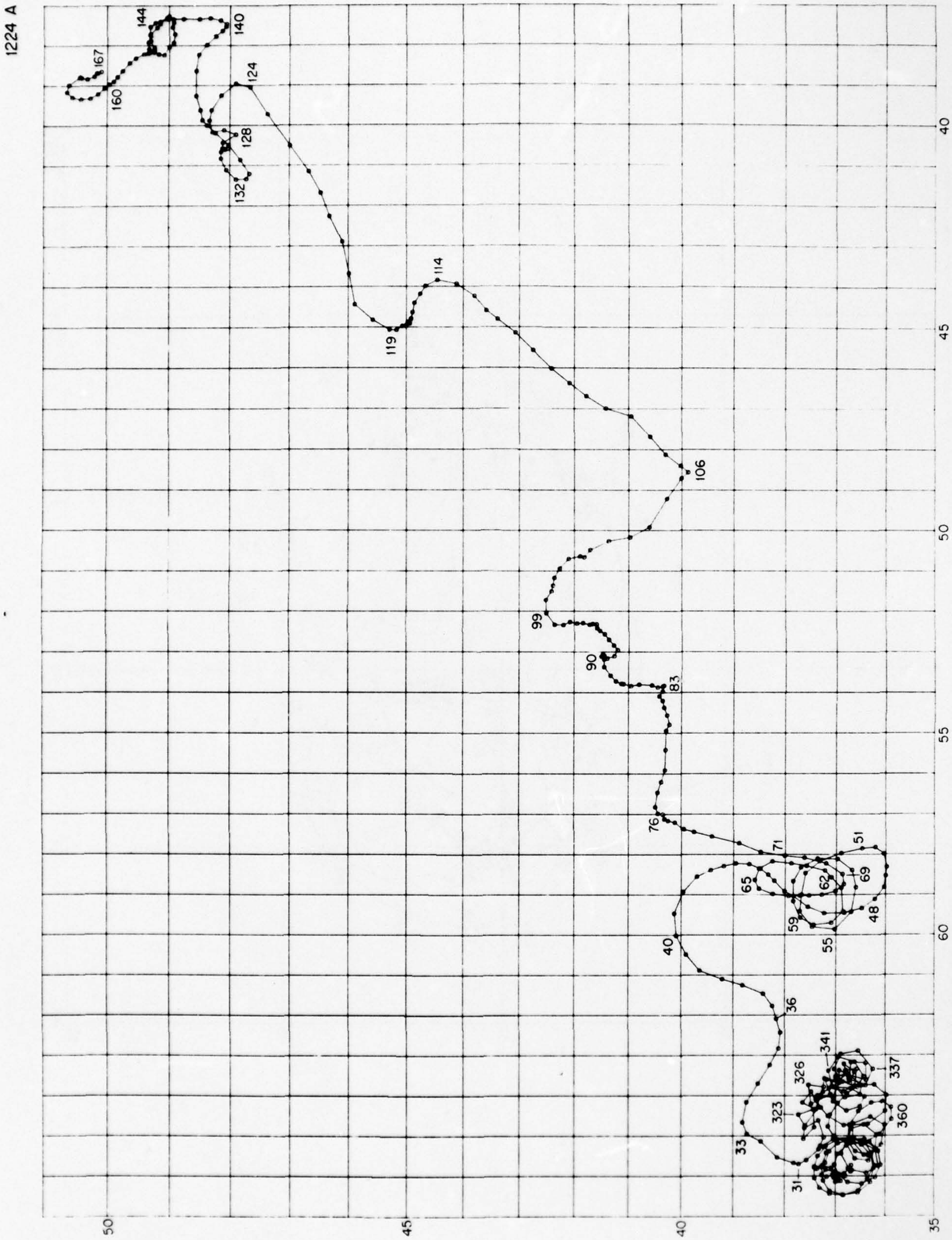
Date/Time (GMT) 26 May 1978, 0515z, (JD146)

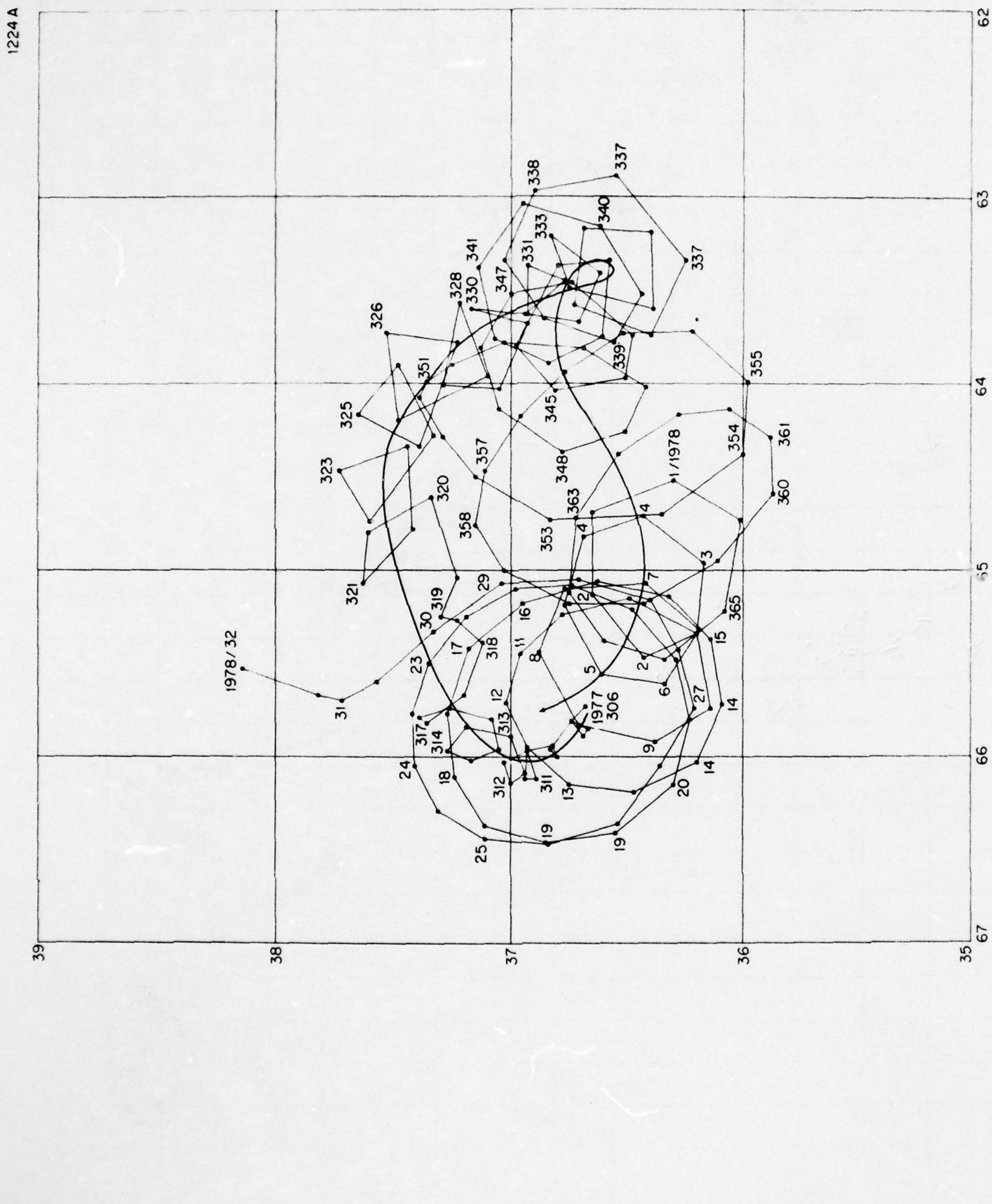
Position 49°15'N, 38°08'W

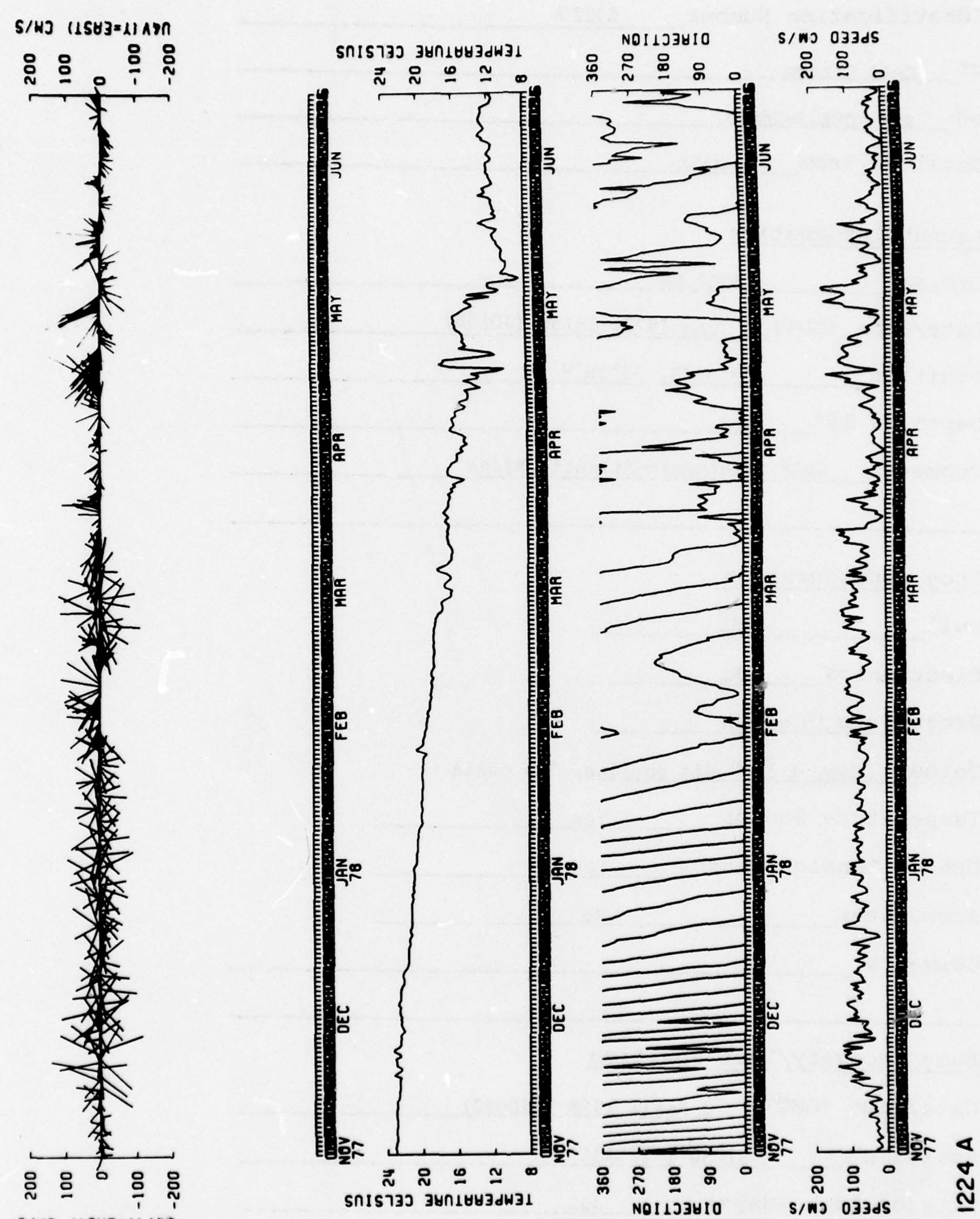
Life of Buoy (days) still operational (207+)

Depth 15°C

Date Drogue came off


1224 A
40
45
50
55
60
50
45
40
35
167
144
140
160
124
128
132
114
119
106
99
90
83
76
71
51
65
62
69
59
48
55
40
36
341
326
337
323
360
33
31


1224 A
39
38
37
36
35
62
63
64
65
66
67


U&V(V=EAST) CM/S
200
100
0
-100
-200
TEMPERATURE CELSIUS
24
20
16
12
8
DIRECTION
360
270
180
90
0
SPEED CM/S
200
100
0
NOV 77
DEC
JAN 78
FEB
MAR
APR
MAY
JUN
1224 A

Buoy Identification Number 1322 A

Project Gulf Stream

Funding NSF OCE77-08045

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 66

Date/Time (GMT) 5 June 1977, 1615z (JD156)

Position 33°31'N, 32°59'W

Depth of 15° 460

Comments Gulf Stream/mid-Atlantic Ridge

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 200m, 1 1/4" dia pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

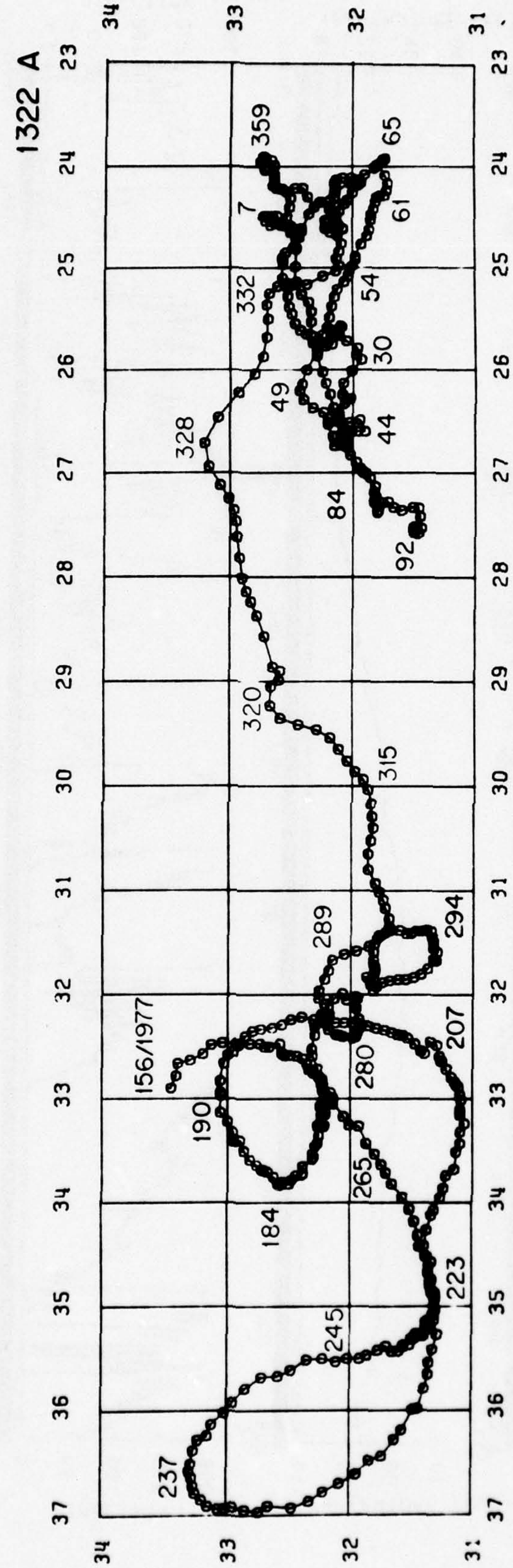
Date/Time (GMT) 2 April 1978 (JD092)

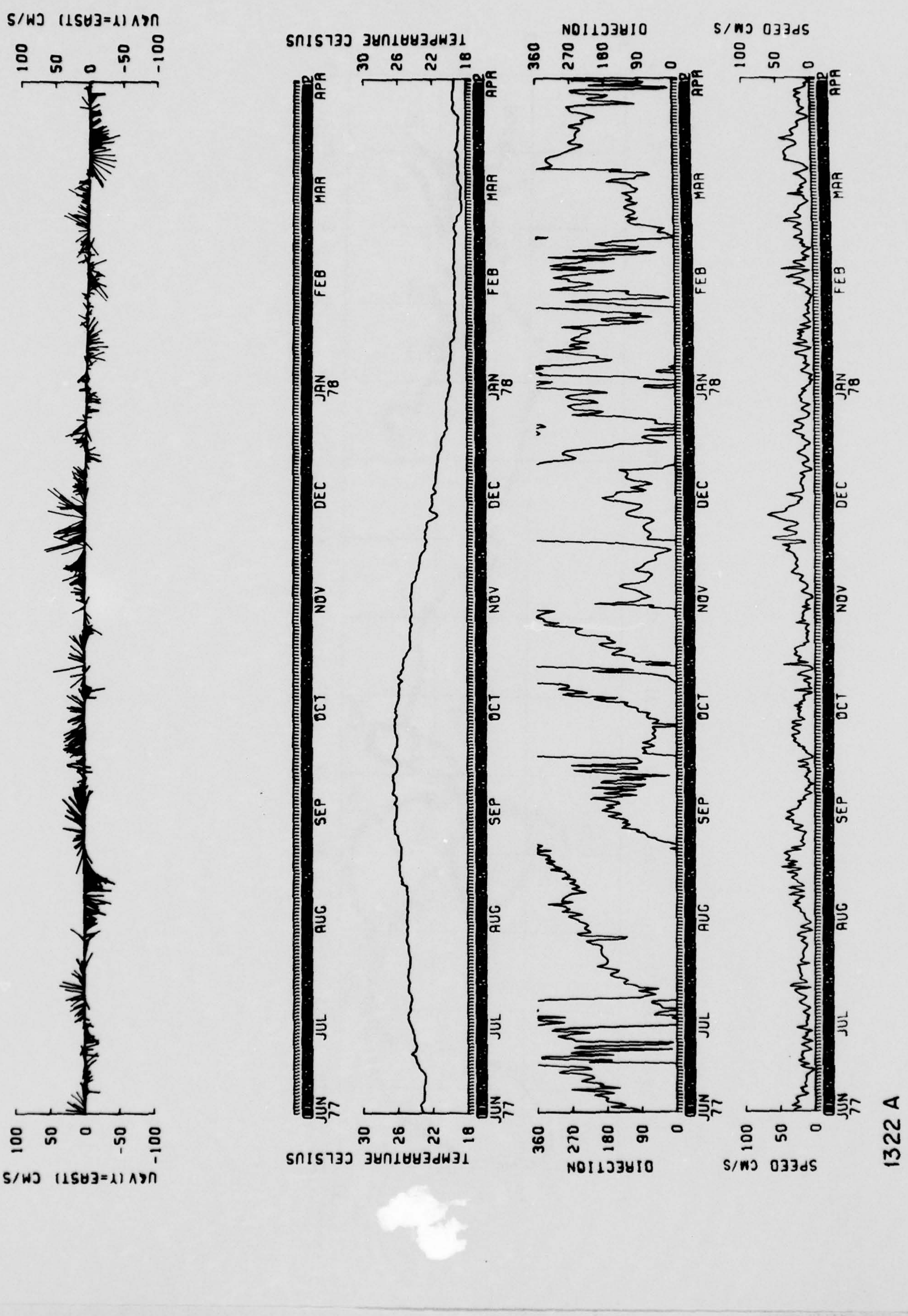
Position 31°30', 27°33'

Life of Buoy (days) 302

Depth 15°C

Date Drogue came off


1322 A
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
34
33
32
31
359
65
7
61
332
54
30
49
44
328
84
92
320
315
289
294
156/1977
207
280
190
265
184
223
245
237


U4V (Y=EAST) CM/S
100
50
0
-50
-100
TEMPERATURE CELSIUS
30
26
22
18
DIRECTION
360
270
180
90
0
SPEED CM/S
100
50
0
JUN 77
JUL
AUG
SEP
OCT
NOV
DEC
JAN 78
FEB
MAR
APR
1322 A

Buoy Identification Number 1346 A

Project Gulf Stream

Funding NSF OCE77-08045

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 66

Date/Time (GMT) 31 May 1977, 2116z, (JD151)

Position 36°50'N, 46°23'W

Depth of 15° 477

Comments Gulf Stream, Grand Banks

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 200 m, 1 1/4" dia. pp line, 5m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

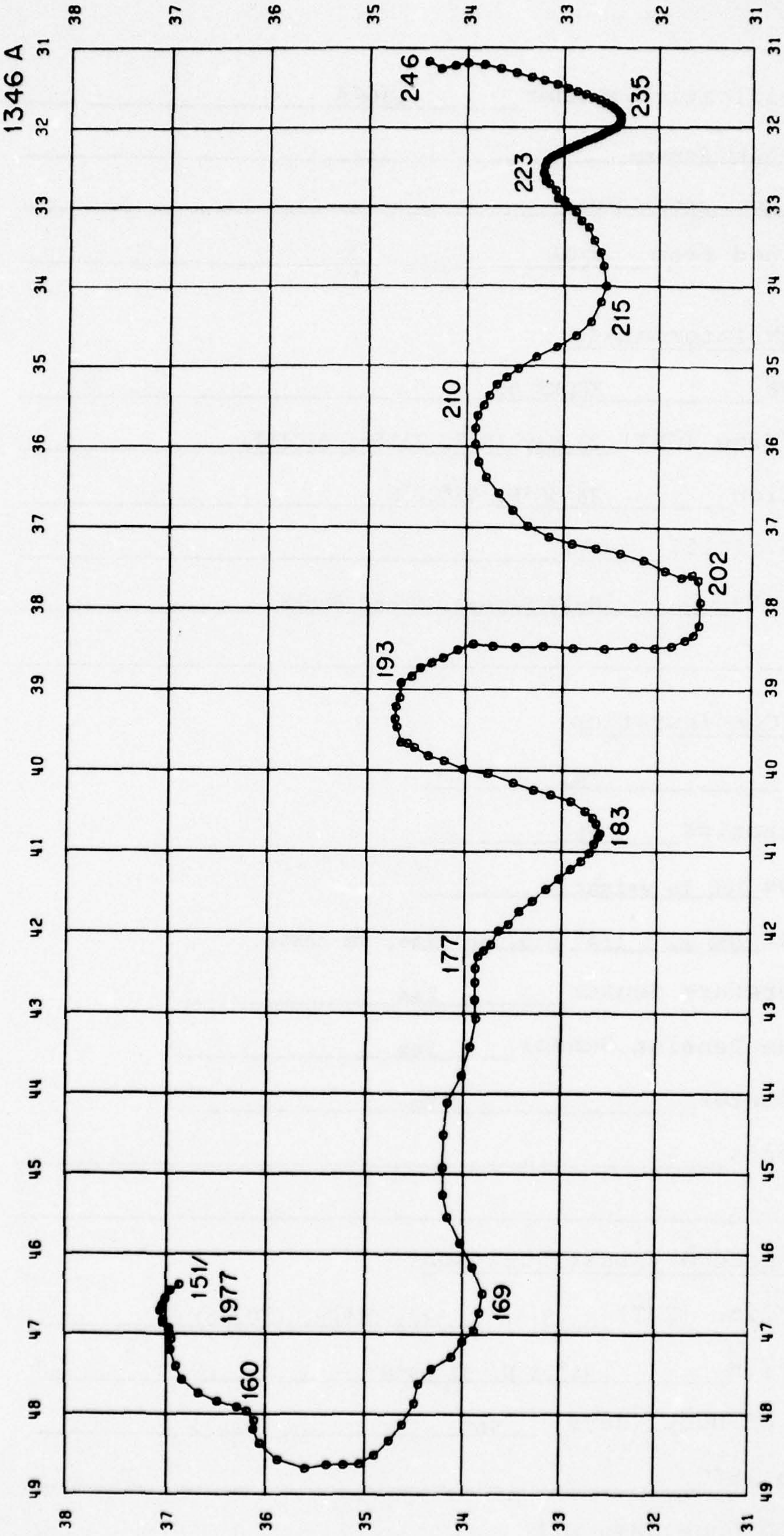
Date/Time (GMT) 3 Sept 1977, 0140z, (JD246)

Position 34°25'N, 31°09'N

Life of Buoy (days) 96

Depth 15°C

Date Drogue came off


1346 A
246
235
223
215
210
202
193
183
177
169
160
151/
1977
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49

SPEED CM/S
100
50
0
DIRECTION
360
270
180
90
0
TEMPERATURE CELSIUS
30
26
22
18
U&V(Y=EAST) CM/S
100
50
0
-50
-100
JUN 77
JUL
AUG
SEP

1346 A

Buoy Identification Number 1370 A

Project Gulf Stream rings

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 71

Date/Time (GMT) 17 Nov 1977, 0415z, (JD321)

Position 39°42'N, 67°30'W

Depth of 15° 401

Comments Ring Q (warm core ring)

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 200m, 1 1/4" dia. pp line, swivel, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments taped thimbles

(3) Buoy Recovery/Last Position

Date/Time (GMT) 25 May 1978, 1105z, (JD145)

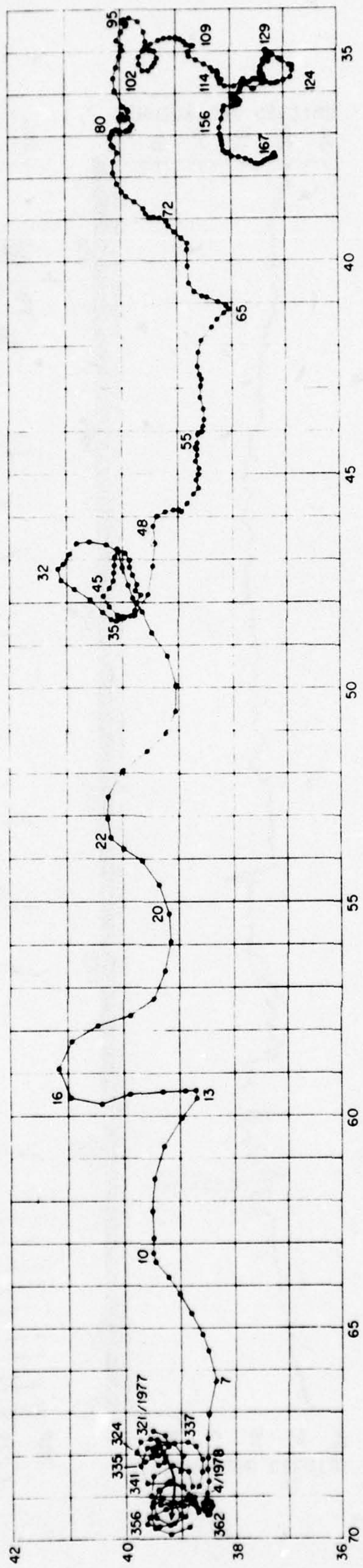
Position 37°47'N, 35°49'W

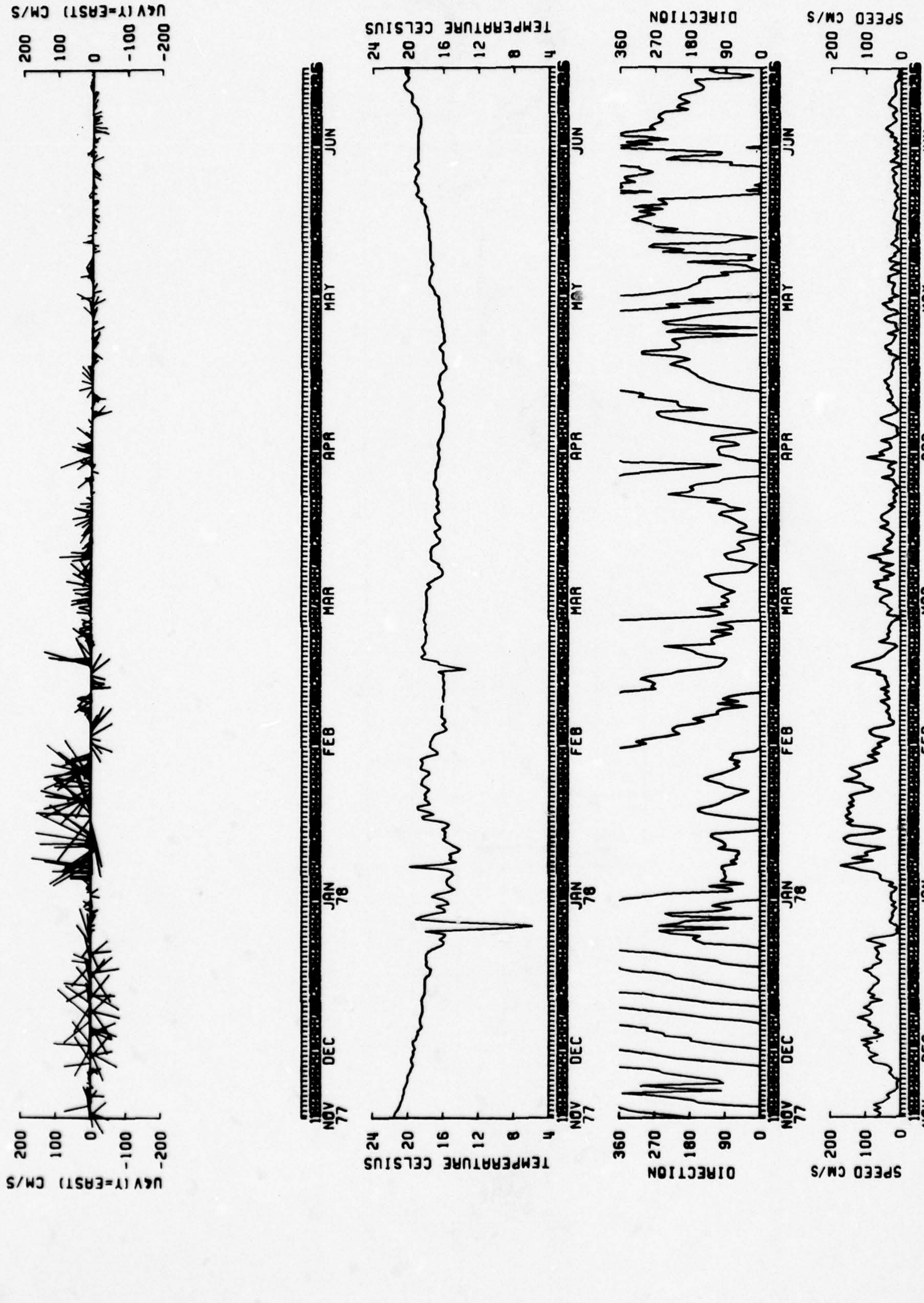
Life of Buoy (days) still operational (190+)

Depth 15°C

Date Drogue came off 28 Nov 1977 (JD332)

1370 A


95
102
109
129
114
124
156
80
167
72
40
65
55
45
48
32
45
35
50
22
55
20
16
13
60
10
65
7
321/1977
324
335
337
341
4/1978
356
362
42
40
38
36
70
35


U&V(Y=EAST) CM/S
200
100
0
-100
-200
TEMPERATURE CELSIUS
24
20
16
12
8
4
DIRECTION
360
270
180
90
0
SPEED CM/S
200
100
0
NOV 77
DEC
JAN 78
FEB
MAR
APR
MAY
JUN

1370 A

Buoy Identification Number 1406 A

Project Gulf Stream rings

Funding ONR

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 71

Date/Time (GMT) 27 Oct 1977, 2032z, (JD300)

Position 34°51'N, 70°08'W

Depth of 15° 240m

Comments Ring Emerson

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue 100 lb weight

Tether 600 ft. 1 1/2" dia. pp line, 5m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments taped thimbles

(3) Buoy Recovery/Last Position

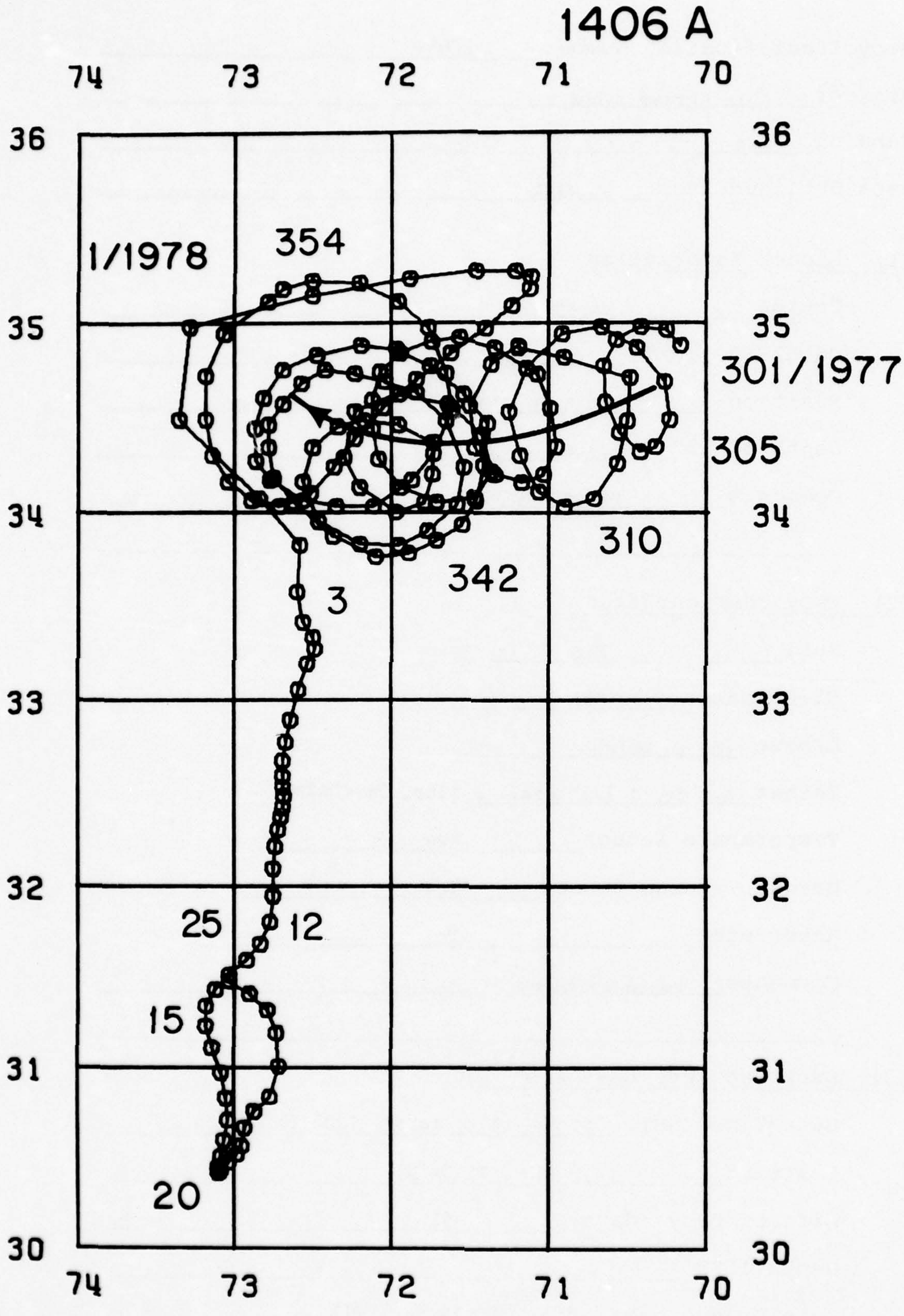
Date/Time (GMT) 25 Jan 1978, 1435z, (JD025)

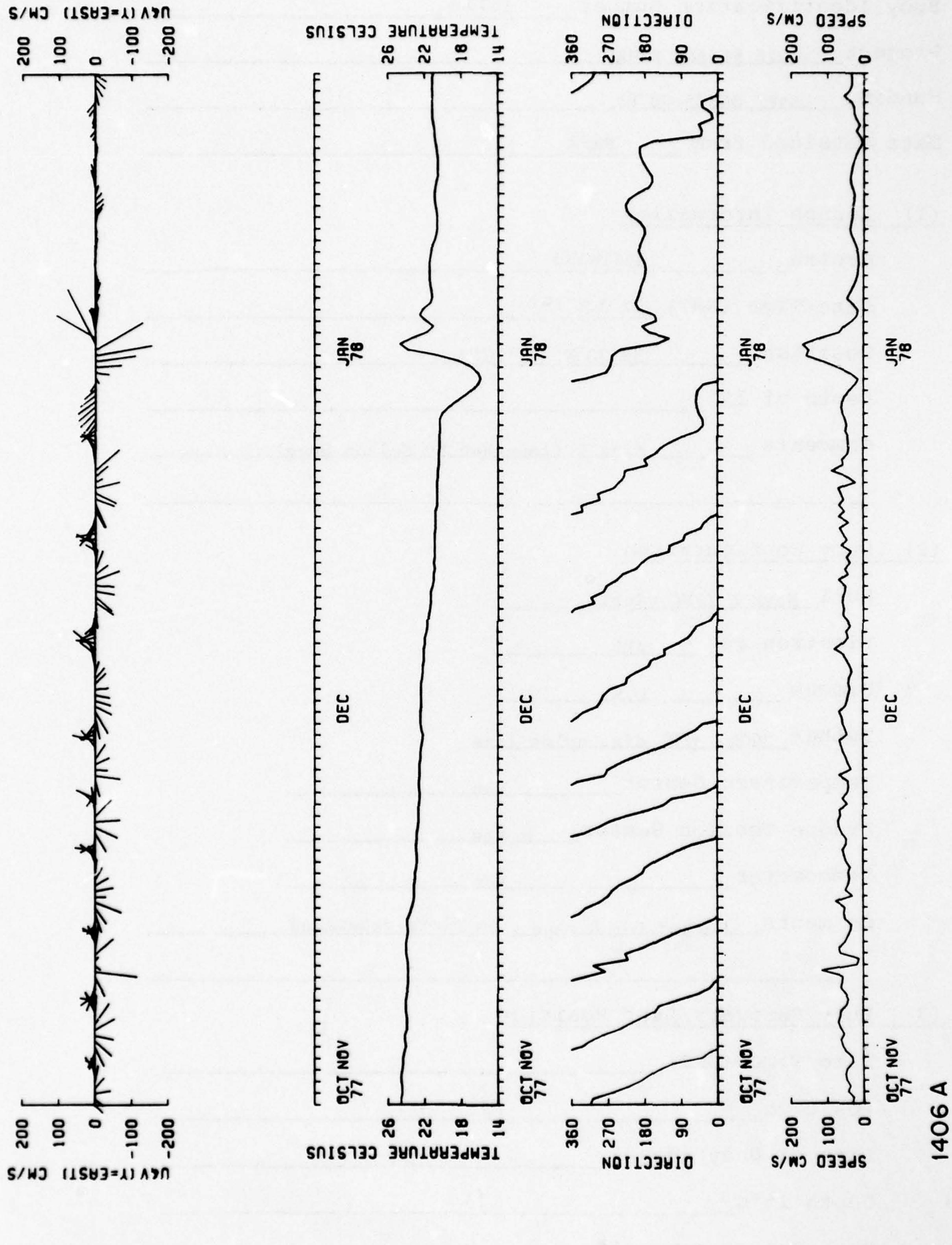
Position 31°30'N, 73°04'W

Life of Buoy (days) 91

Depth 15°C

Date Drogue came off 19 Nov 1977


1406 A
74
73
72
71
70
36
35
34
33
32
31
30
1/1978
354
301/1977
305
310
342
3
25
12
15
20


U&V(Y=EAST) CM/S
200
100
0
-100
-200
TEMPERATURE CELSIUS
26
22
18
14
DIRECTION
360
270
180
90
0
SPEED CM/S
200
100
0
OCT NOV
77
DEC
JAN
78
1406 A

Buoy Identification Number 1475A

Project Gulf Stream rings

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise EASTWARD

Date/Time (GMT) 16 Oct 1975

Position 35°30'N, 71°20'W

Depth of 15°

Comments Ring D (launched by Nelson Hogg)

(2) Buoy Configuration

Hull Nova U (PVC pipe)

Electronics AEL

Drogue W.S.

Tether 200m, 5/8" dia. nylon line

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer Yes

Comments Worked for 4 days, no plots generated

(3) Buoy Recovery/Last Position

Date/Time (GMT)

Position

Life of Buoy (days) 4

Depth 15°C

Date Drogue came off

Buoy Identification Number 1552A

Project Gulf Stream

Funding NSF OCE77-08045

Data Obtained from NASA

(1) Launch Information

Cruise KNORR 66

Date/Time (GMT) 9 July 1977, 1430 z, (JD190)

Position 40°40'N, 56°18'W

Depth of 15° 279 m

Comments Gulf Stream

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue W.S.

Tether 600' 1 1/2" dia. pp line, 5 m chain

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

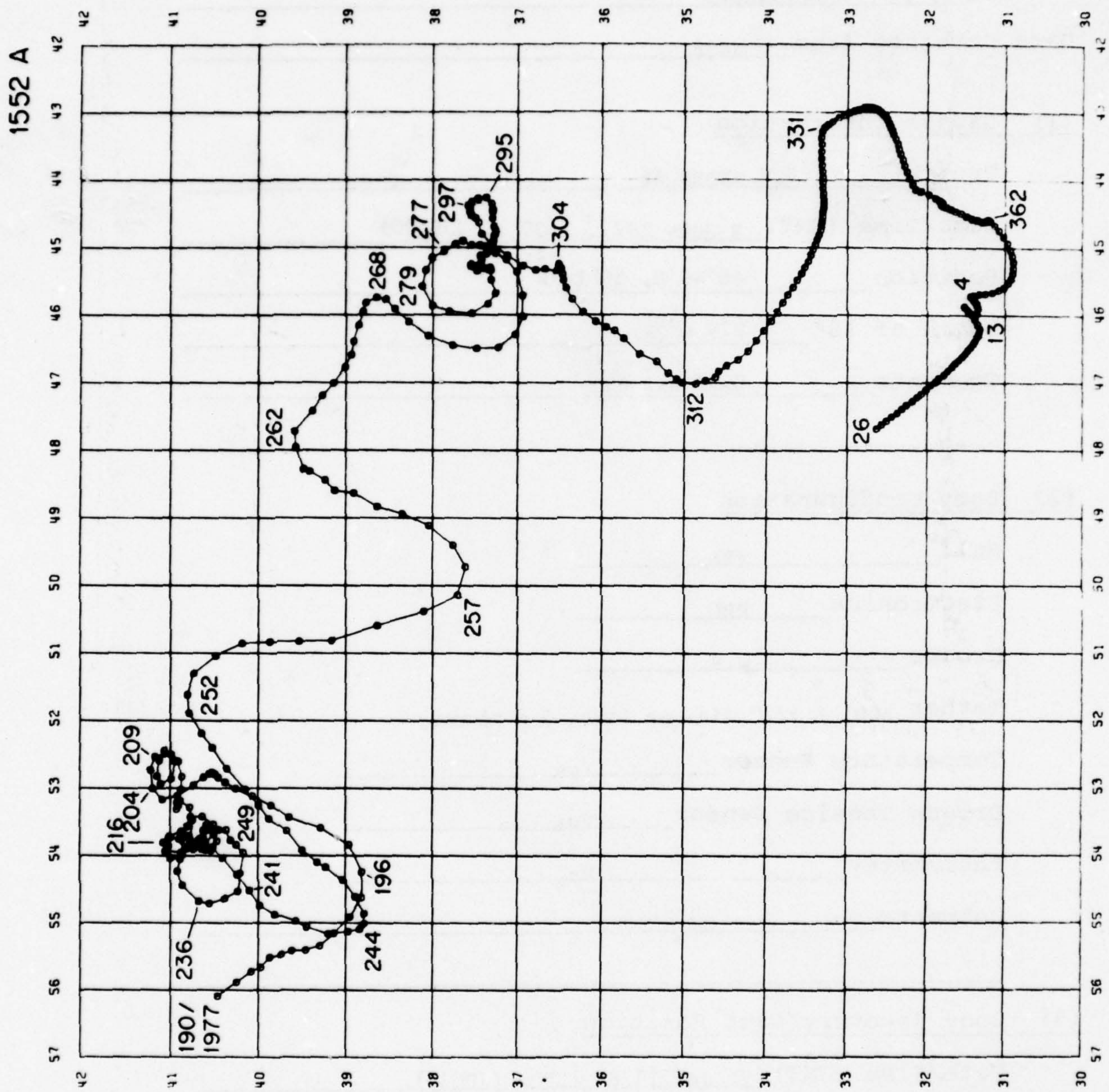
Date/Time (GMT) 26 Jan 1978, 1350z (JD026)

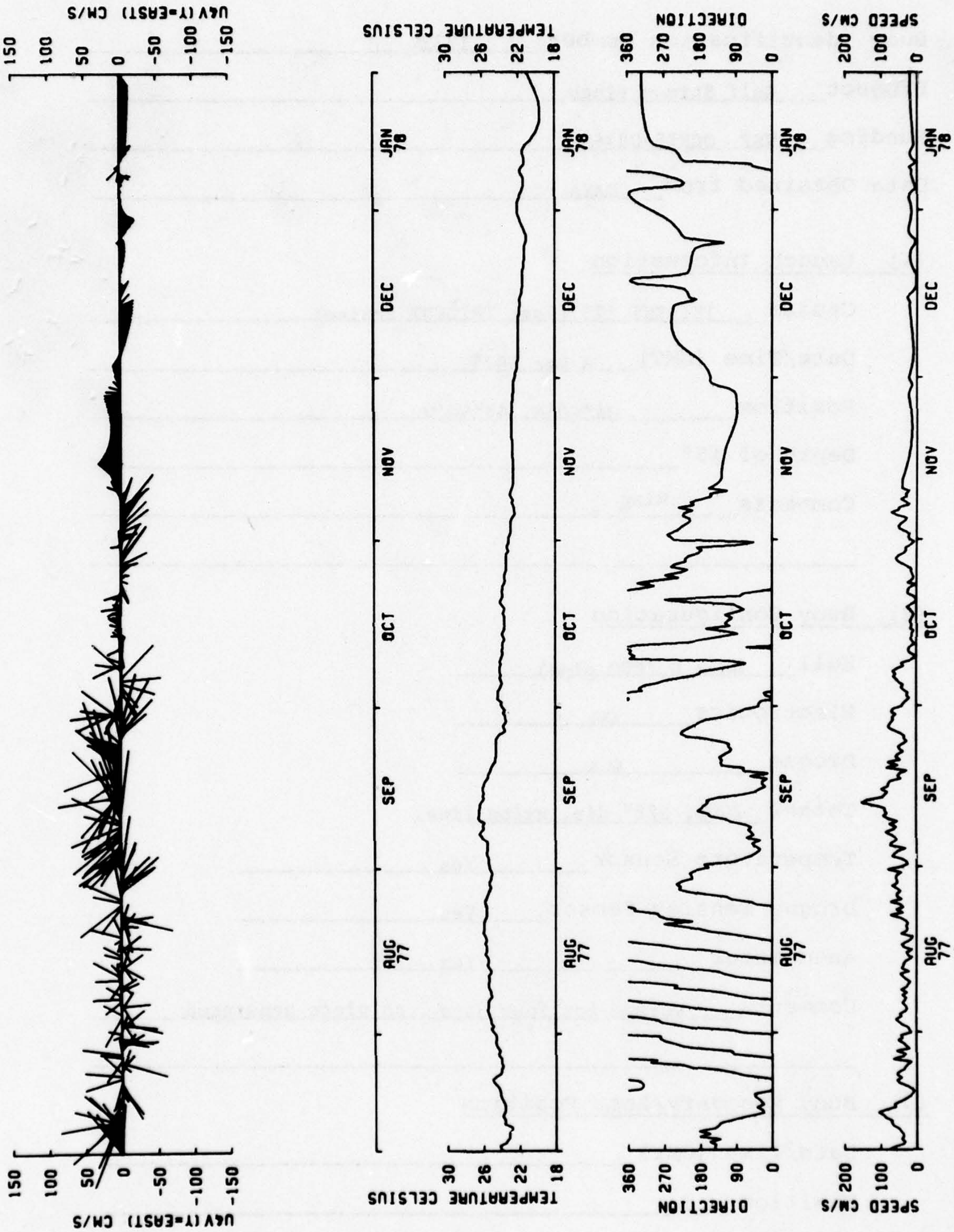
Position 32°39', 47°41'W

Life of Buoy (days) 202

Depth 15°C

Date Drogue came off


1552 A
42
41
40
39
38
37
36
35
34
33
32
31
30
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
331
295
297
277
304
362
268
279
4
13
312
26
262
257
252
209
204
216
249
241
196
236
244
190/
1977


U4V(Y=EAST) CM/S
150 100 50 0 -50 -100 -150
TEMPERATURE CELSIUS
30 26 22 18
DIRECTION
360 270 180 90 0
SPEED CM/S
200 100 0
AUG 77
SEP
OCT
NOV
DEC
JAN 78

1552 A

Buoy Identification Number 1773A

Project Gulf Stream rings

Funding NSF OCE75-08765

Data Obtained from NASA

(1) Launch Information

Cruise TRIDENT 175 (last TRIDENT cruise)

Date/Time (GMT) 8 Dec 1975.

Position 34°40'M. 65°50'W

Depth of 15°

Comments Ring

(2) Buoy Configuration

Hull Nova U (PVC pipe)

Electronics AEL

Drogue W.S.

Tether 200m. 5/8" dia. nylon line.

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer Yes

Comments worked for four days . no plots generated

(3) Buoy Recovery/Last Position

Date/Time (GMT)

Position

Life of Buoy (days) 4

Depth 15°C

Date Drogue came off

APPENDIX B

Supplemental Buoy Data

This Appendix contains information sheets and the plots of trajectory and velocity of five buoys. The data was generously provided by J. Fornshell, E. Kerut, D. Kirwan, and R. Weir.

Buoy Identification Number 0177 A See U.S. Coast Guard (1978) .

Project Ice Patrol Survey

Funding

Data Obtained from Coast Guard Ice Patrol (R. Weir)

(1) Launch Information

Cruise EVERGREEN

Date/Time (GMT) 4 April 1976, 1900 z, (JD095)

Position 46°59'N, 47°15'W

Depth of 15°

Comments Labrador Current

(2) Buoy Configuration

Hull Nova II (FG) ?

Electronics AEL ?

Drogue WS

Tether 75m

Temperature Sensor Yes, did not work

Drogue Tension Sensor Yes, did not work

Anemometer Yes, did not work

Comments intermittent fixes after day 129

(3) Buoy Recovery/Last Position

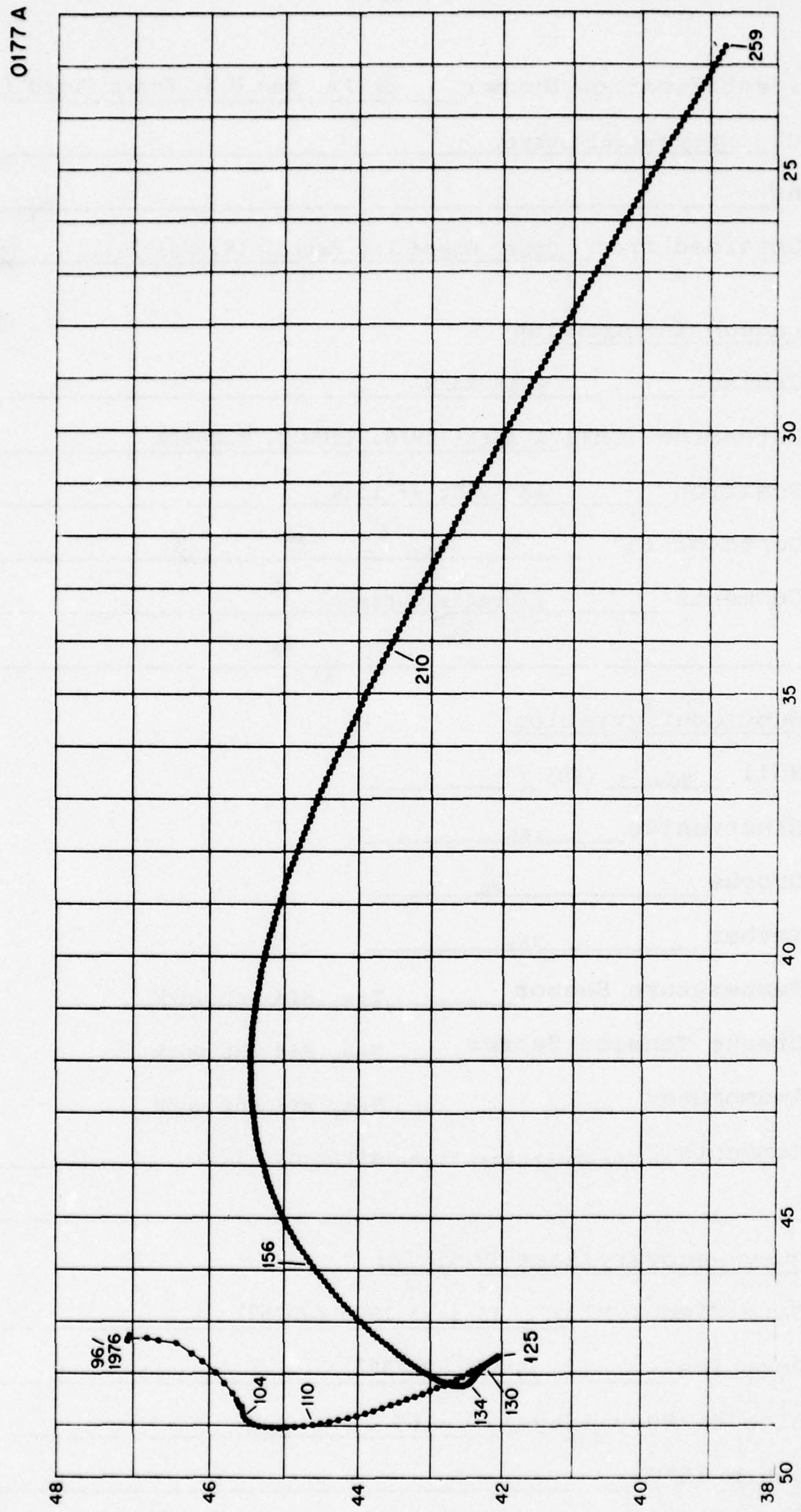
Date/Time (GMT) 15 Sept 1976 (JD259)

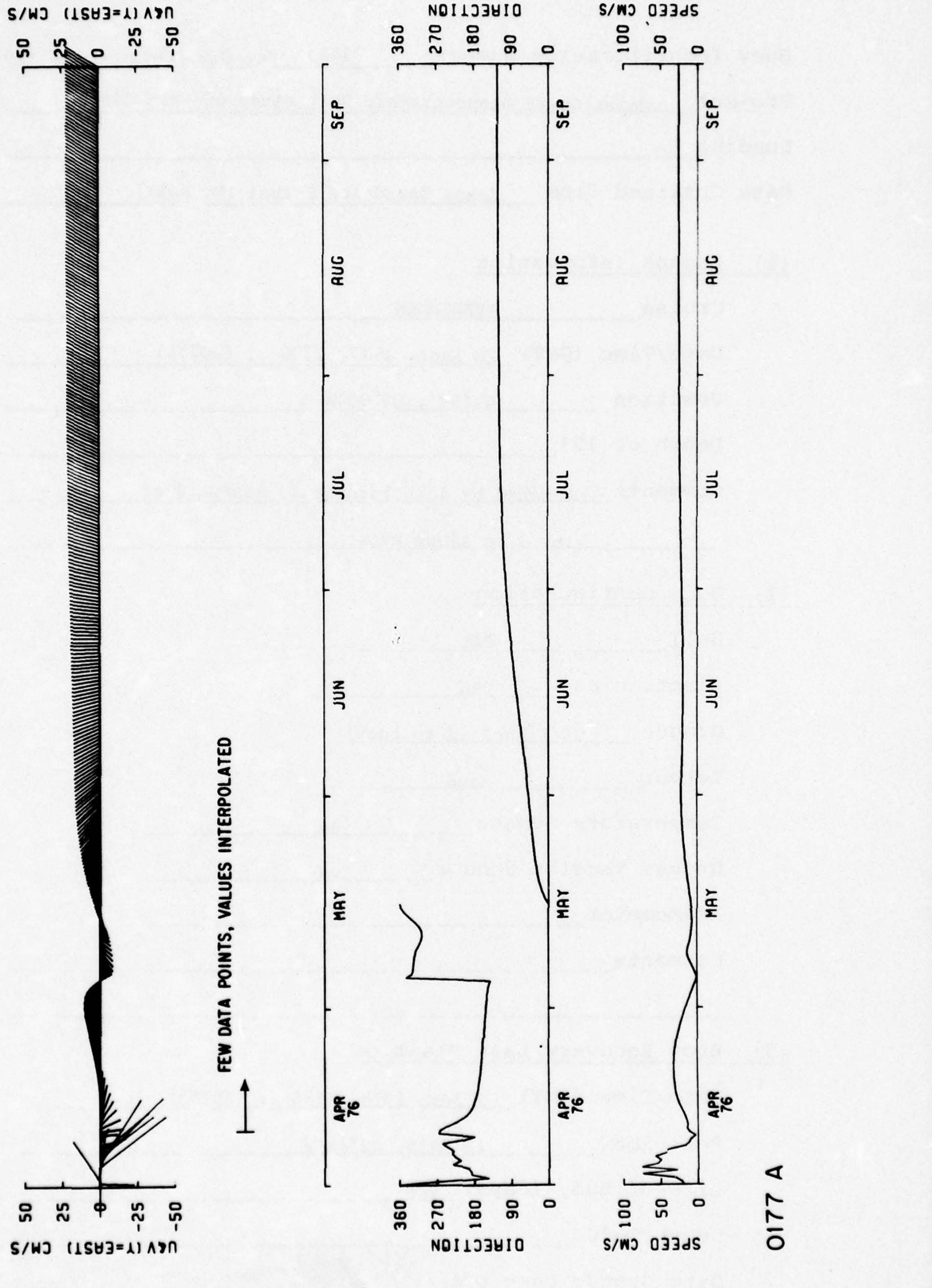
Position 38°46', 22°38'

Life of Buoy (days) 165

Depth 15°C

Date Drogue came off


0177 A
259
25
30
210
35
40
45
156
96/
1976
104
110
134
130
125
50
48
46
44
42
40
38


U+V (V=EAST) CM/S
50
25
0
-25
-50
FEW DATA POINTS, VALUES INTERPOLATED
DIRECTION
360
270
180
90
0
SPEED CM/S
100
50
0
APR 76
MAY
JUN
JUL
AUG
SEP
0177 A

Buoy Identification Number 0271A See U.S. Coast Guard (1978).

Project Coast Guard Oceanographic Unit study of warm rings

Funding

Data Obtained from Coast Guard Ice Patrol (R. Weir)

(1) Launch Information

Cruise EVERGREEN

Date/Time (GMT) 28 Sept. 1977, 1300 z, (JD271)

Position 41°59', 65°00'W

Depth of 15°

Comments Launched by John Fornshell, eastward of ring Q in slope water

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue WS (shackled to buoy)

Tether none

Temperature Sensor Yes

Drogue Tension Sensor Yes

Anemometer No

Comments

(3) Buoy Recovery/Last Position

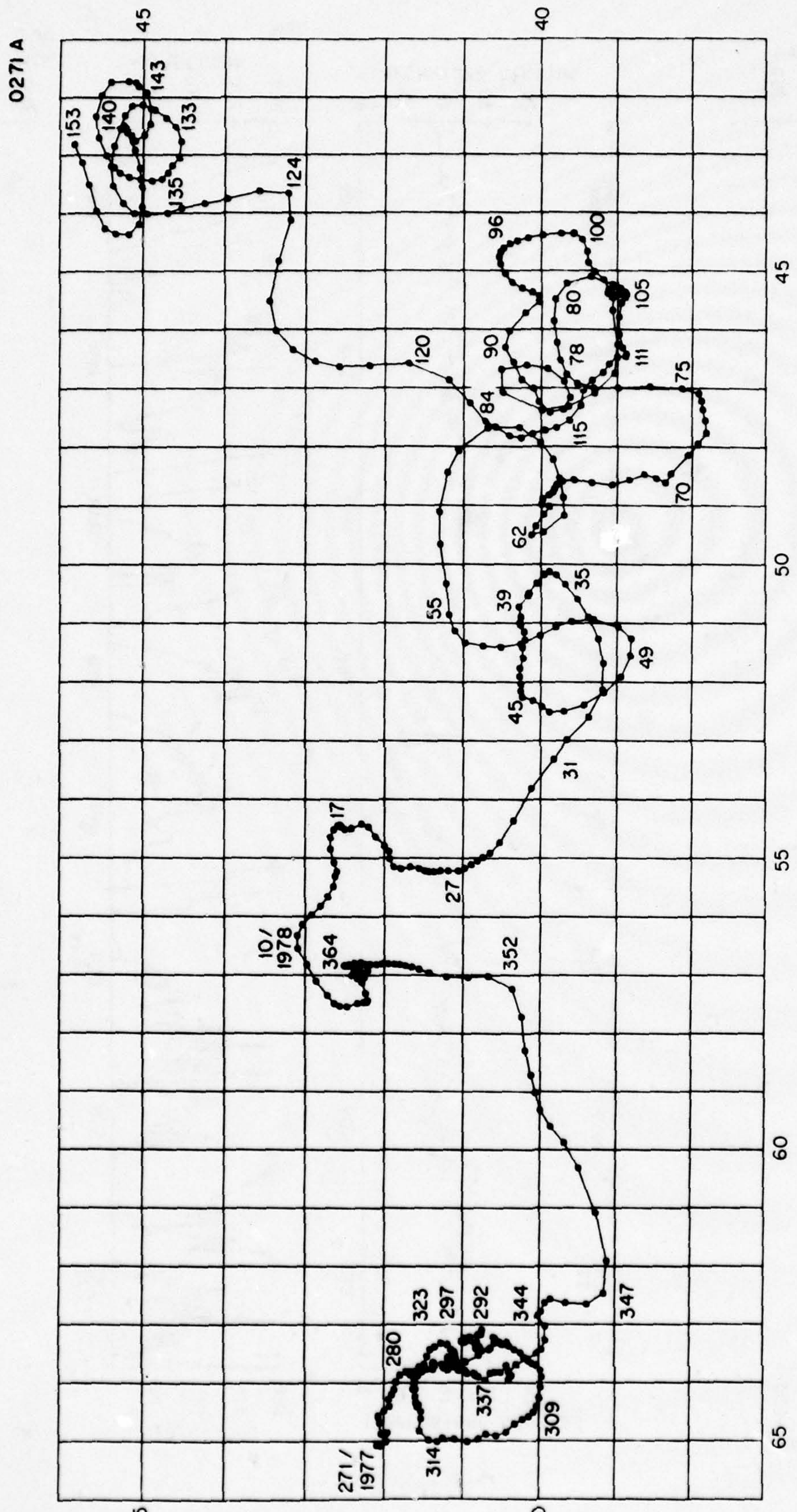
Date/Time (GMT) 2 June 1978, 1235 z, (JD153)

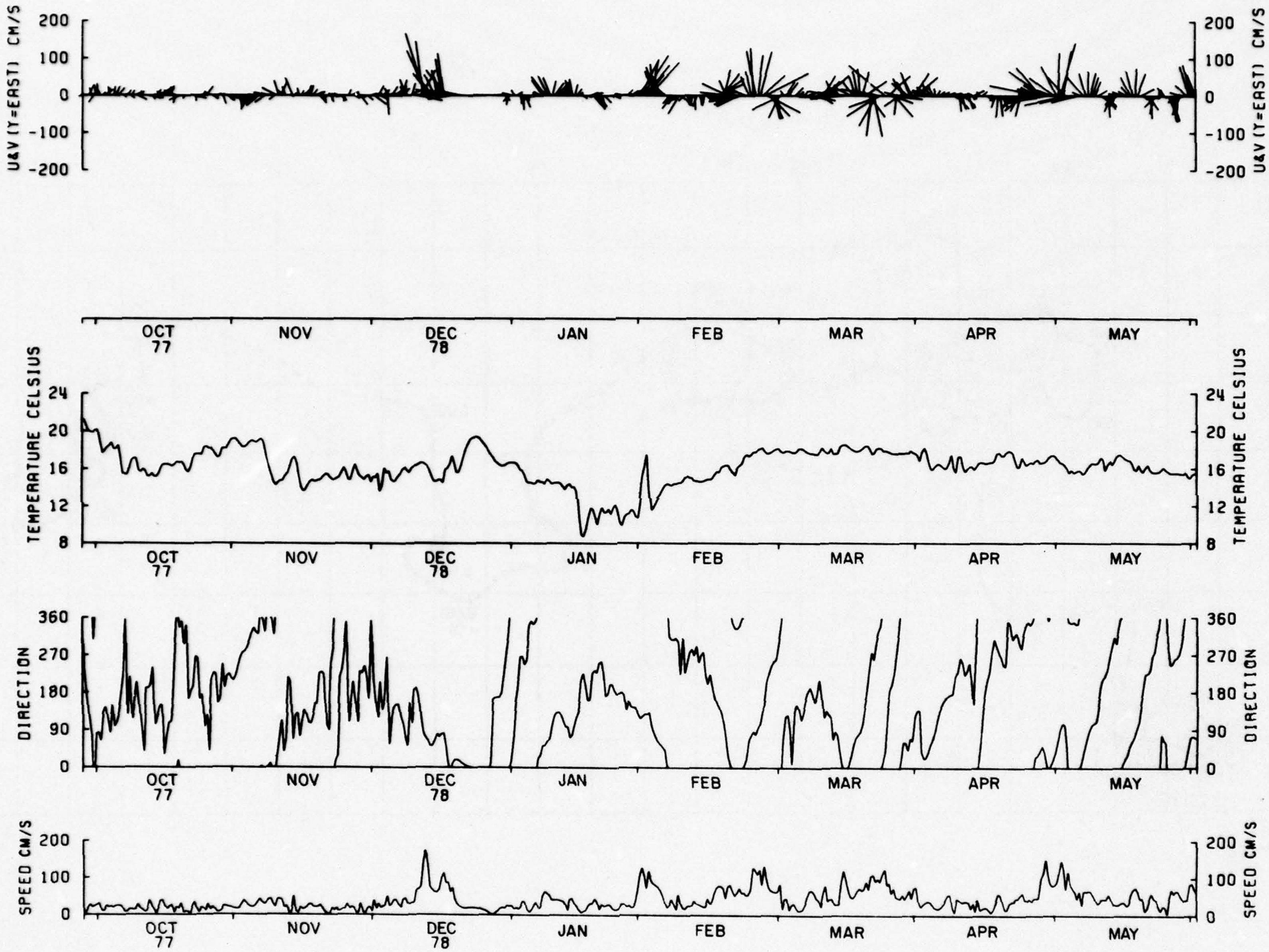
Position 45°39'N, 42°48'W

Life of Buoy (days) 248

Depth 15°C

Date Drogue came off


0271 A
45
40
45
50
55
60
65
45
40
153
140
143
133
135
124
120
96
100
105
80
90
78
111
75
84
115
70
62
55
39
35
49
45
31
17
27
10/
1978
364
352
347
323
297
292
344
280
337
309
314
271/
1977


U&V (Y=EAST) CM/S
200
100
0
-100
-200
OCT 77
NOV
DEC 78
JAN
FEB
MAR
APR
MAY
TEMPERATURE CELSIUS
24
20
16
12
8
DIRECTION
360
270
180
90
0
SPEED CM/S
200
100
0

0271 A

Buoy Identification Number 0343A

Project Argo Merchant oil spill observations

Funding

Data Obtained from NDBO

(1) Launch Information

Cruise U.S. Coast Guard H-3 Helicopter

Date/Time (GMT) 1 Jan. 1977, 0317 z, (JD001)

Position 39°58'N, 66°47'W

Depth of 15°

Comments Launched in 35 x 75 foot pancake of oil

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue None

Tether None

Temperature Sensor

Drogue Tension Sensor

Anemometer

Comments

(3) Buoy Recovery/Last Position

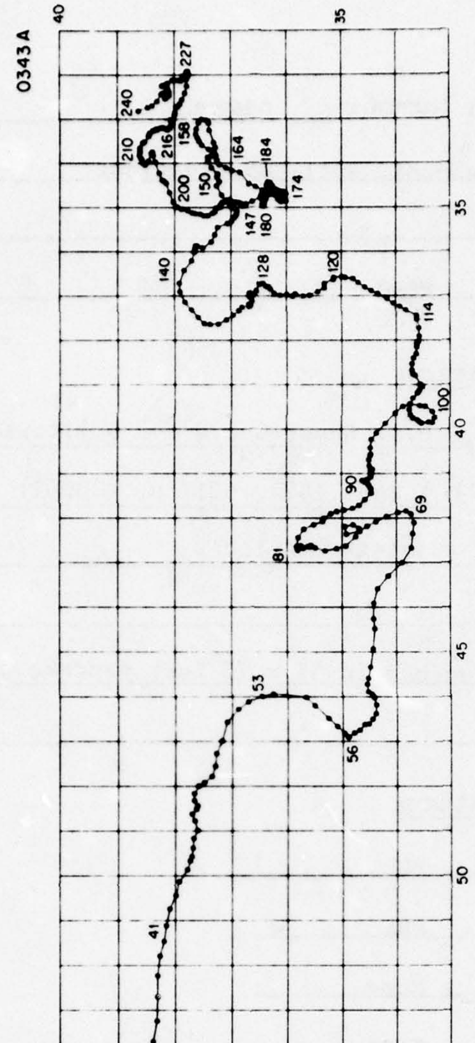
Date/Time (GMT) 28 August 1977 (JD240)

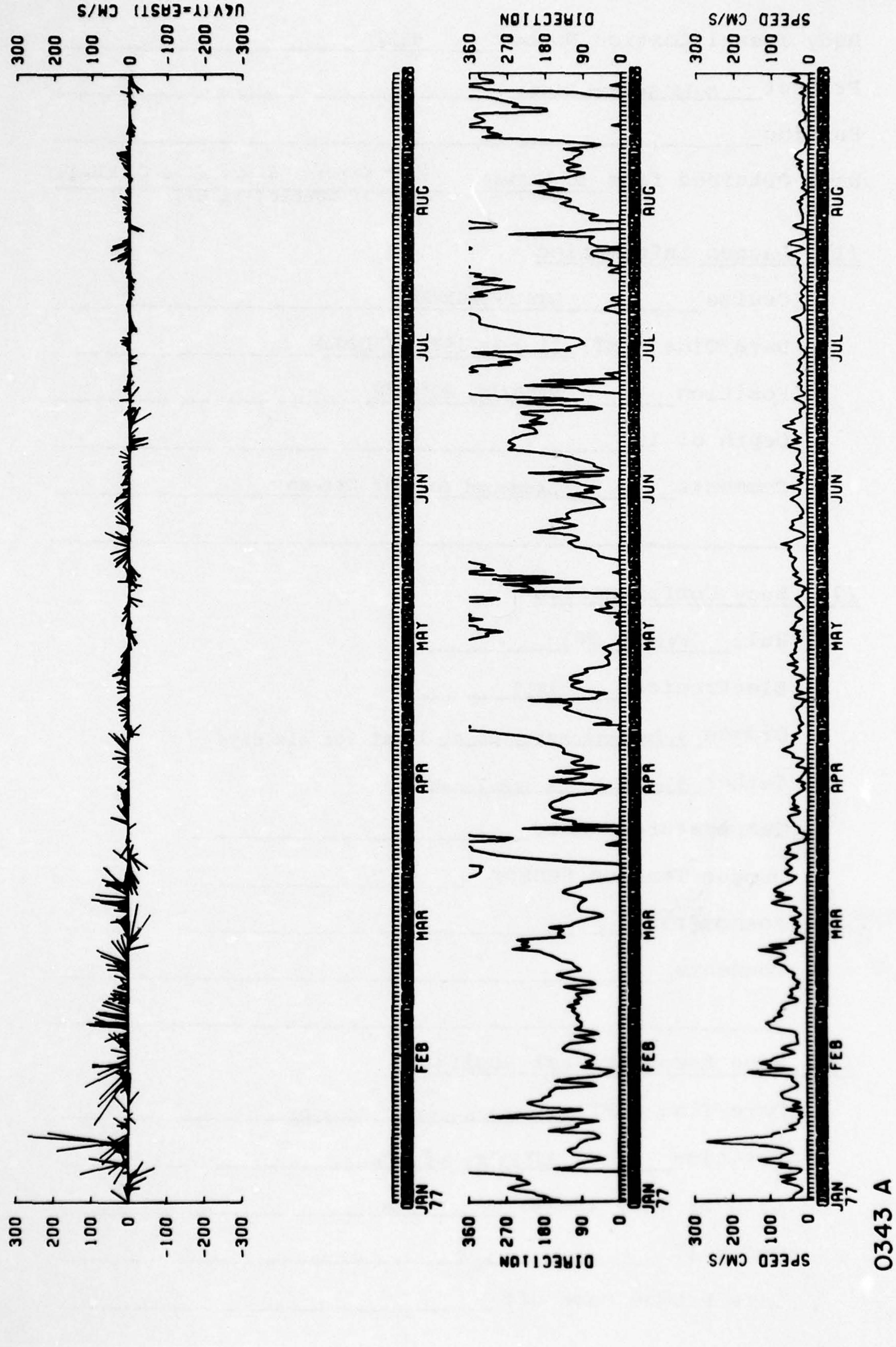
Position 38°40'N, 32°50'W

Life of Buoy (days) 240

Depth 15°C

Date Drogue came off


0343 A
1/1977
11
8
27
29
37
41
53
56
69
81
90
100
114
120
128
140
147
150
158
164
174
180
184
200
210
216
227
240
40
35
40
45
50
55
60
65


U&V(Y=EAST) CM/S
300
200
100
0
-100
-200
-300
DIRECTION
360
270
180
90
0
SPEED CM/S
300
200
100
0
JAN 77
FEB
MAR
APR
MAY
JUN
JUL
AUG
0343 A

Buoy Identification Number 0357A

Project Gulf Stream Rings

Funding

Data Obtained from D. Kirwan (See Kirwan A.D., Jr., G.McNally and J. Coehlo; 1976).

(1) Launch Information

Cruise USS PRESERVER

Date/Time (GMT) 21 July 1975 (JD202)

Position 29°02'N, 80°01'W

Depth of 15°

Comments Launched in Gulf Stream

(2) Buoy Configuration

Hull Nova U (FG)

Electronics AEL?

Drogue 9.2m parachute, on at least for six days

Tether 35m, 1.18 cm steel cable

Temperature Sensor

Drogue Tension Sensor

Anemometer

Comments

(3) Buoy Recovery/Last Position

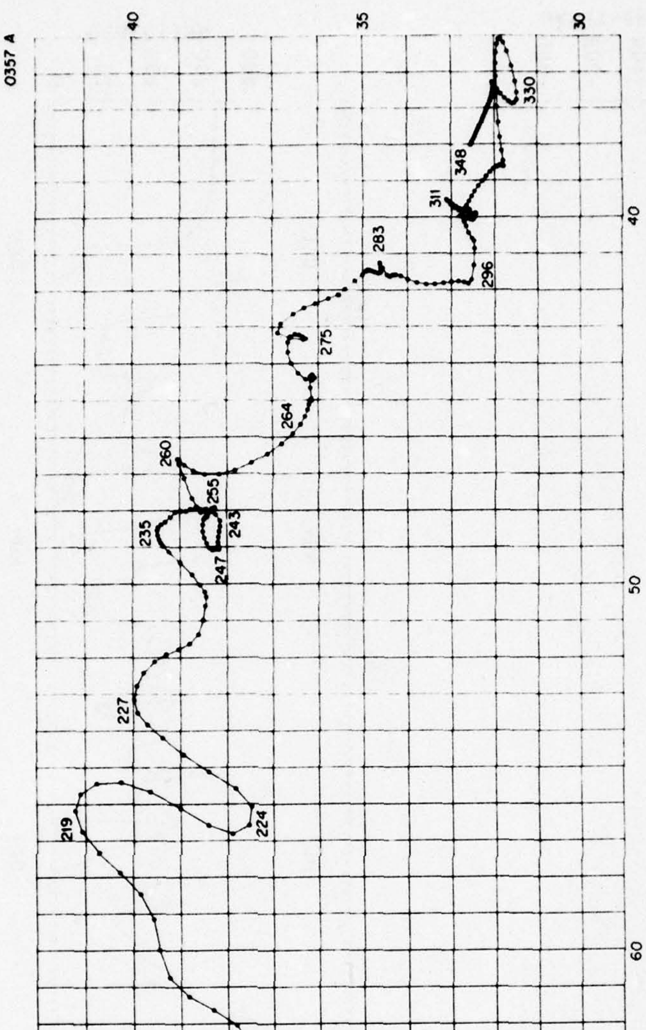
Date/Time (GMT) 16 Dec 1975 (JD350)

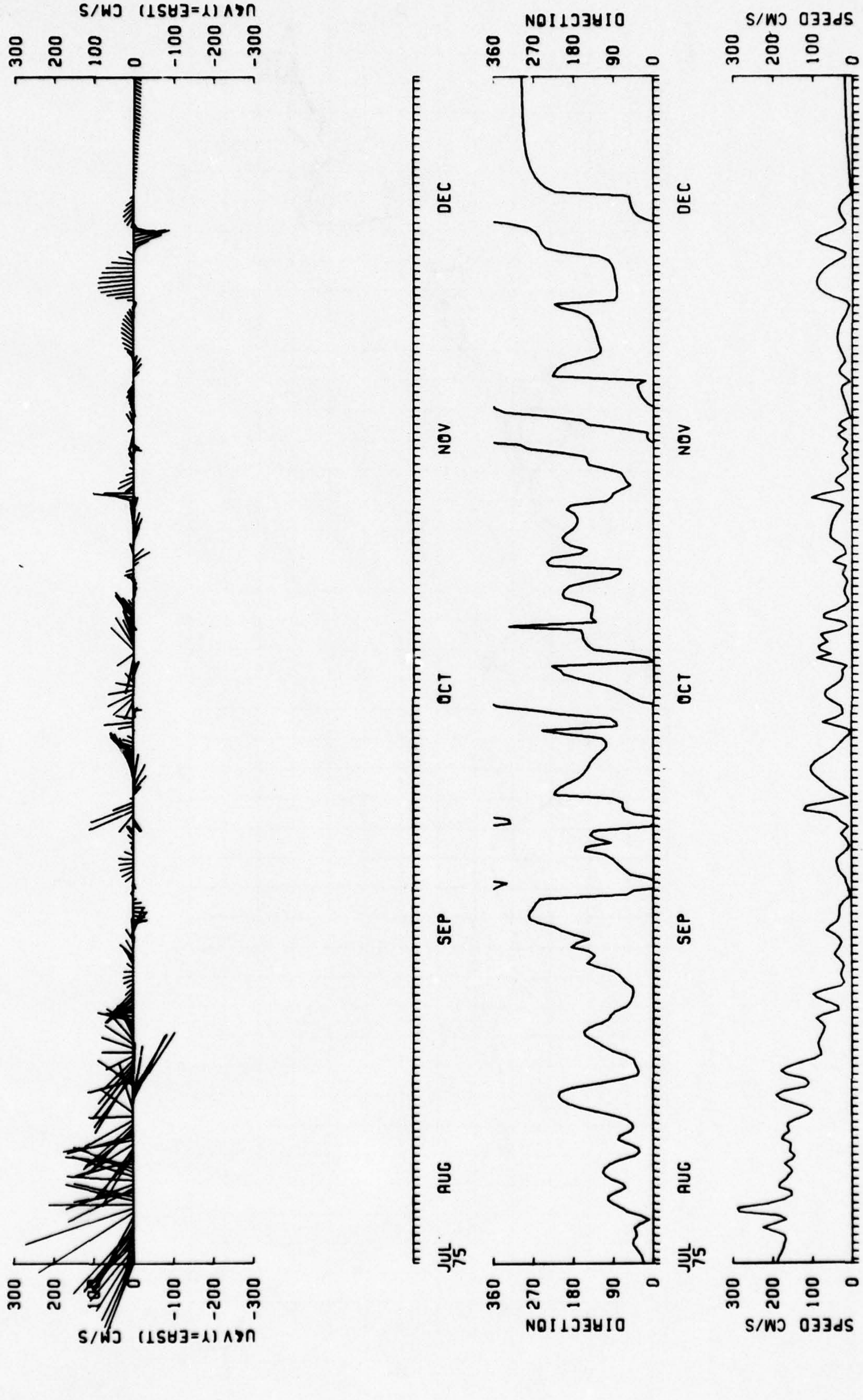
Position 32°33'N, 38°02'W

Life of Buoy (days) 149

Depth 15°C

Date Drogue came off


0357 A
40
35
30
40
50
60
70
80
1975
201
205
208
211
219
224
227
235
243
247
255
260
264
275
283
296
311
348
330


U&V(Y=EAST) CM/S
300
200
100
0
-100
-200
-300
DIRECTION
360
270
180
90
0
SPEED CM/S
300
200
100
0
JUL
75
AUG
SEP
OCT
NOV
DEC

0357 A

Buoy Identification Number 0373 A

Project MESA

Funding

Data Obtained from NDBO

(1) Launch Information

Cruise USCGC DALLAS

Date/Time (GMT) 29 Dec 1976, 1728 z (JD364)

Position 39°29'N, 70°32'W

Depth of 15°

Comments Launched near the continental shelf

(2) Buoy Configuration

Hull PRL

Electronics PRL

Drogue ?

Tether ?

Temperature Sensor ?

Drogue Tension Sensor ?

Anemometer No

Comments

(3) Buoy Recovery/Last Position

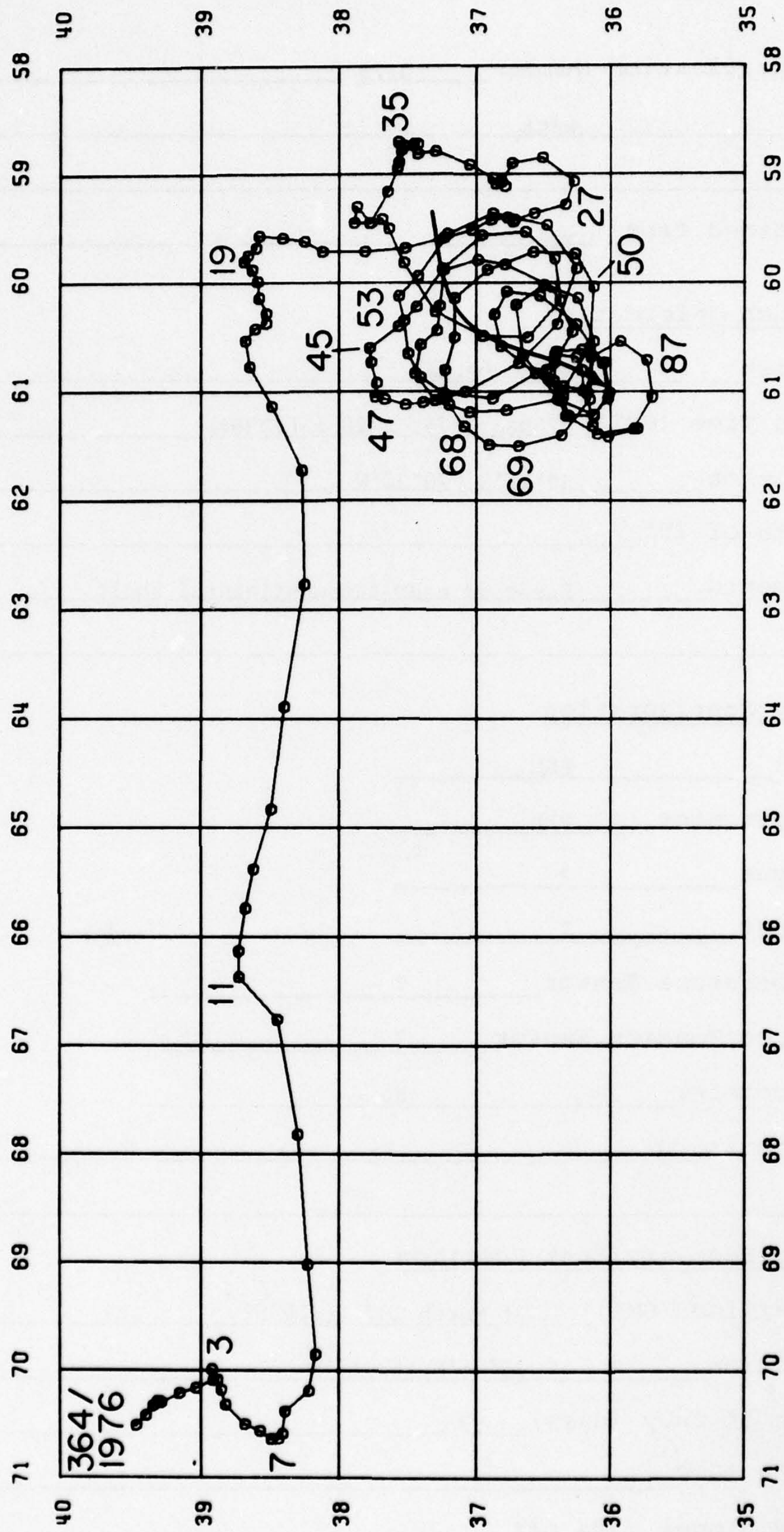
Date/Time (GMT) 31 March 1977 (JD090)

Position 35°46'N, 61°19'W

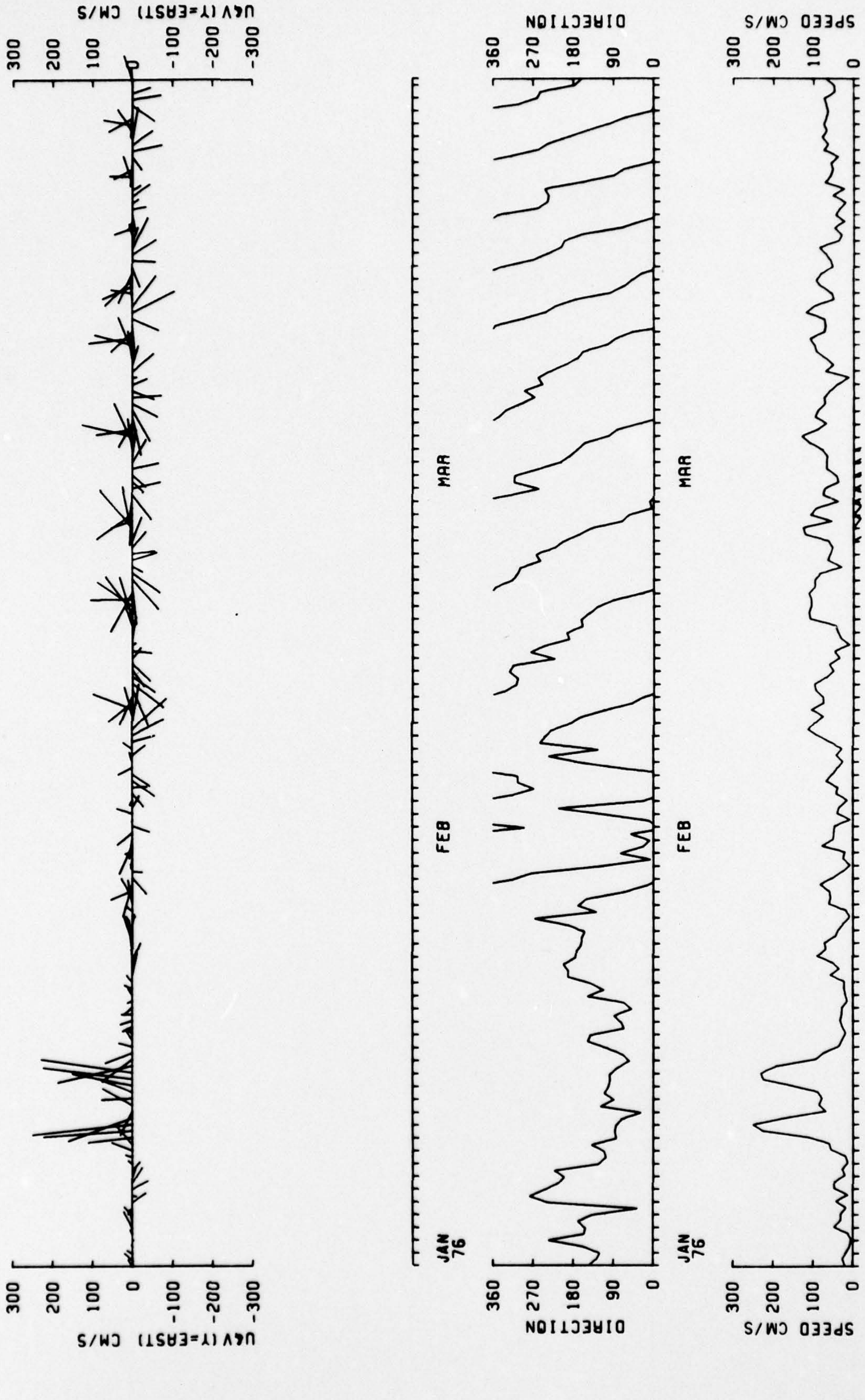
Life of Buoy (days) 93

Depth 15°C

Date Drogue came off



0373 A
364/
1976
3
7
11
19
35
27
50
53
45
47
68
69
87
40
39
38
37
36
35
58
59
60
61
62
63
64
65
66
67
68
69
70
71


U&V(Y=EAST) CM/S
300
200
100
0
-100
-200
-300
DIRECTION
360
270
180
90
0
SPEED CM/S
300
200
100
0
JAN
76
FEB
MAR

0373 A

APPENDIX C

Buoy Position Error and Data Editing

ABSTRACT

Errors associated with satellite fixes of drifting buoys were investigated by analyzing 364 buoy fixes at a known location. The relationship between fix errors and four fix quality parameters provided by NASA were determined. By means of the quality parameters the data were subdivided into four groups: the excellent data (mean error 1.3 km), the good data (mean error 1.5 km), the marginal data (mean error 2.3 km), and the rejected data (mean error 190 km). The marginal, good and excellent data, when combined comprise 75% of the total data and have a mean error of 1.6 km. This value indicates that the retained positions have smaller errors than the ±5km suggested by NASA as being representative of the Nimbus 6 satellite fixes.

INTRODUCTION

A significant number of buoy positions provided by NASA were found to have medium to large errors. In order to be able to eliminate poor fixes we investigated a series of fixes obtained while the buoys were at a known location. The error of each fix was compared to several fix quality parameters and a system was developed to classify the quality of fixes. This system was then used to edit our data; we selected two good fixes per day a half day apart for each buoy. Because of its potential benefit to other Nimbus F users we have described the data, analysis and classification system in considerable detail.

DATA

The data were obtained from six COSRAMS buoys (ID's: 264, 557, 731, 1224, 1307, 1406) that were left on the WHOI dock while transmitting for periods ranging from four to seventy days. These buoys provided 364 fixes with an average of 2.3 fixes per buoy per day. Data were provided by NASA in the form of computer printouts (Fig. C-1), and are also available on magnetic tape and computer cards.

EXAMPLES OF BUOY POSITION DATA PROVIDED BY NASA

TWO PASS FIX

POSITION

EI

```
ORBIT=12501 01101110 ENTERED BY S/M  12/31/77 14.05.52 0731 12501 00000326
  PLATFORM ID= 0731  TIME= 365/14/17/04/254    EARTH RADIUS= 6369.5 KM   ALTITUDE= -0.1STD ERR INDEX= 50
TWO PASS POS   VELOCITY-M/S TOT  F PLT  TIME               DATA                        F PLT  TIME               DATA
LAT    LONG    NORTH EAST   MSGS L ID   DDD/HH/MM/SS/MMM L M WD1 WD2 WD3 WD4 L ID   DDD/HH/MM/SS/MMM L M WD1 WD2 WD3 WD4
41.52  289.32   0.1  0.3     17 0 0731 365/14/17/04/254 4 3 325 000 000 000 0 0731 365/14/18/06/054 6 3 325 000 000 000
46.47  306.33  S/C SUBPT        0 0731 365/14/19/07/854 0 3 325 000 000 000 0 0731 365/14/21/11/554 1 3 326 000 000 000
PER PASS DATA                   0 0731 365/14/22/13/354 5 3 326 000 000 000 0 0731 365/14/24/16/954 3 3 325 000 000 000
ITEM         PASS 1  PASS 2     0 0731 365/14/25/18/854 5 3 325 000 000 000 0 0731 365/14/26/20/654 1 3 325 000 000 000
PT OF INF     YES     YES       0 0731 365/14/27/22/454 3 3 325 000 000 000 0 0731 365/16/04/13/654 4 3 326 000 000 000
MSGS USED      9       8        0 0731 365/16/05/15/454 7 3 326 000 000 000 0 0731 365/16/06/17/354 1 3 326 000 000 000
BIAS(HZ)      63      63        0 0731 365/16/08/20/954 1 3 326 000 000 000 0 0731 365/16/09/22/754 0 3 326 000 000 000
                                0 0731 365/16/10/24/554 0 3 326 000 000 000 0 0731 365/16/12/28/254 4 3 325 000 000 000
                                0 0731 365/16/13/30/054 1 3 325 000 000 000
```

MESSAGES

SATELLITE SUBPOINT

ONE PASS FIX

POSITION

F VALUE

```
ORBIT=12500 01101130 ENTERED BY S/M  12/31/77 09.35.51 1040 12500 00000172
  PLATFORM ID= 1040  TIME= 365/12/33/34/462    EARTH RADIUS= 6366.7 KM   ALTITUDE= -0.1 FVALUE= 91.7
ONE PASS POS   STD ERR      TOT  F PLT  TIME               DATA                        F PLT  TIME               DATA
LAT    LONG    IND/PREF     MSGS L ID   DDD/HH/MM/SS/MMM L M WD1 WD2 WD3 WD4 L ID   DDD/HH/MM/SS/MMM L M WD1 WD2 WD3 WD4
49.72    7.90   45            6 0 1040 365/12/33/34/462 7 3 075 000 000 000 0 1040 365/12/34/36/262 4 3 075 000 000 000
35.24  302.56   49 *            0 1040 365/12/36/39/962 4 3 075 000 000 000 0 1040 365/12/37/41/762 7 3 075 000 000 000
47.68  332.65  S/C SUBPT        0 1040 365/12/38/43/662 1 3 075 000 000 000 0 1040 365/12/39/45/462 1 3 075 000 000 000
PT OF INF     YES
MSGS USED      6
BIAS(HZ)     -805   -719
```

EI

MESSAGES

SATELLITE SUBPOINT

Figure C-1

The fixes provided by NASA on computer printouts are rounded to the nearest .01 degree which corresponds to 1.11 km for latitude and .83 km for longitude at Woods Hole, Mass. The estimated rms radial error* due to this roundoff is 0.5 km. The average position of the dock given by 224 of the best data points is 41.522°N and 289.324, and since 96% of these points came from buoys within 0.10 km of the Port Office at 41. 524°N and 289.328°E, the mean error is .002° in latitude and .004 in longitude, a radial distance of about 0.4 km. This value (0.4 km) reflects the overall accuracy of the system. In this study we are more concerned with the precision of individual fixes, the scatter of fixes about the known location.

Two types of fixes are given by NASA: one-pass and two-pass fixes (Fig. C-1). A two-pass fix is one calculated from two successive satellite passes separated in time by 108 minutes. For a one-pass fix, two possible positions are computed, one on each side of the satellite path. For each of these possible positions a standard Error Index (EI) is computed. The EI is a measure of the fit of the raw data to a theoretical doppler curve on a scale of 0 to 100. The position with the highest EI is marked with an asterisk indicating that it is probably the correct position and another parameter, the F value, gives the estimated reliability of that choice in percent. In this error analysis NASA's choice was always used even when it was obvious that the other position was better. Two-pass fixes consist of only one position and, therefore, no F value. They do have EI's, however (listed in the same place as the one pass F value). In addition to the EI and F value, two other parameters were used in this analysis. One of these parameters is the number of messages used to calculate the fix; the number of messages ranges from 4 to 15. The final parameter was the great circle angle (GCA) between the computed buoy position and the subpoint of the satellite's closest approach to the buoy. The GCA ranges from 0° to 26° corresponding to a range in elevation angle, the angle of the satellite measured from the horizon at the buoy's position, of 90° to 6° (Fig. C-2).

*The radial error refers to the radial distance of the fix from the known location of the buoy on the dock.

SATELLITE ELEVATION ANGLE vs. GREAT CIRCLE ANGLE BETWEEN SATELLITE SUBPOINT AND BUOY POSITION

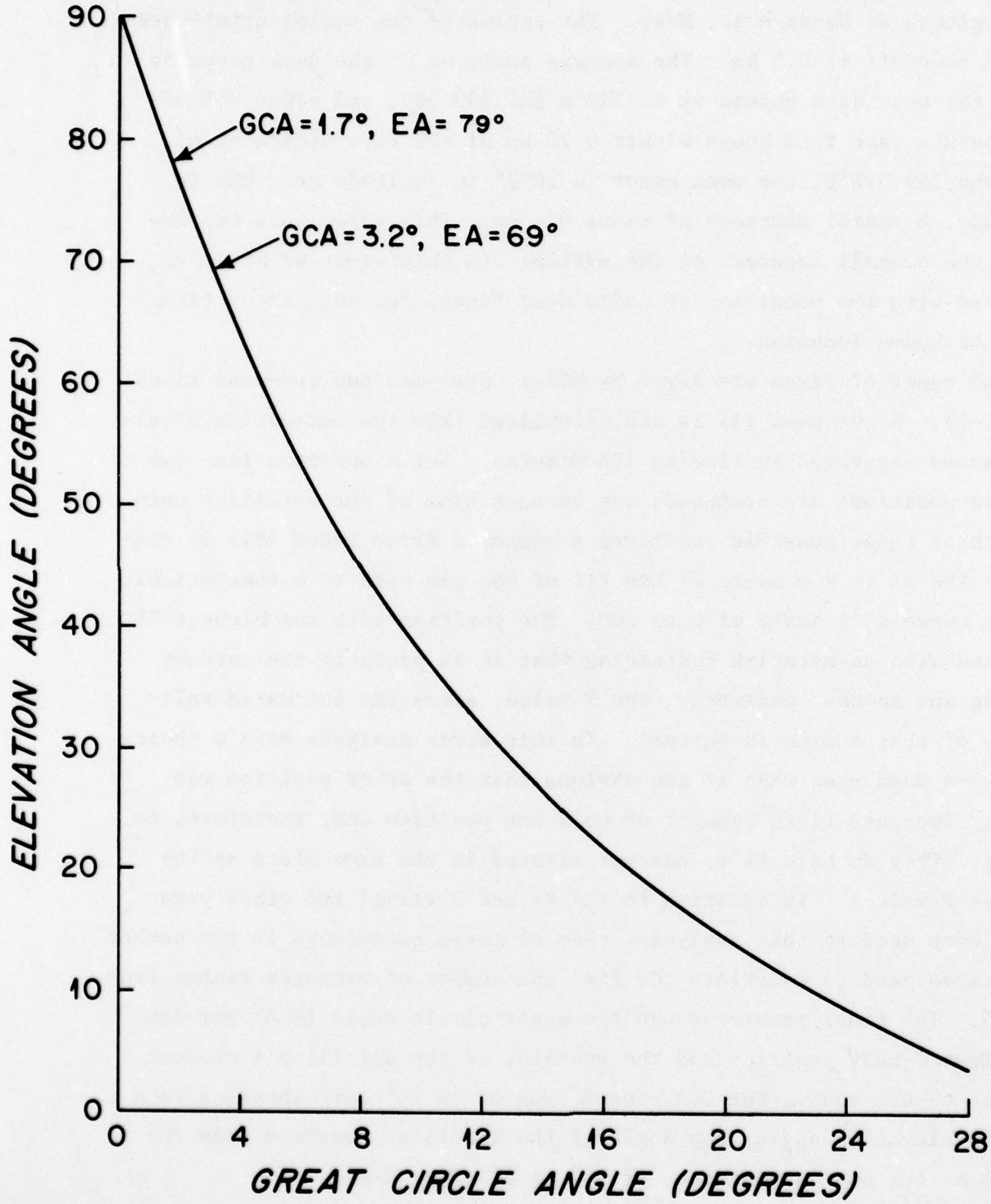


Figure C-2

Fix errors were computed and compared to the four parameters (GCA, EI, F value, and messages) provided by NASA for the 364 fixes. Most of the fixes had small errors; 75% had errors less than 3 km. However, 10% of the fixes had errors greater than 20 km.

METHODS

Several techniques were used to develop an error estimation and data editing scheme. First the data were abstracted from the NASA print-outs and the fix errors from the WHOI Port Office calculated. Next, several scatter plots were made to search for relationships between the errors and parameters. The only scatter plot that revealed a functional relationship was the plot of error vs. great circle angle (Fig. C-3). A clear correlation between the elevation angle and the number of messages received by the satellite was also observed. Examination of the scatter plots led to the development of an editing system which eliminated bad data. A multiple regression analysis was used in an attempt to extract a more definite functional relationship between the error and all four quality criteria. The Statistical Package for the Social Sciences (Nie *et al.*, 1975) was used for the multiple regression analysis, to produce scatter plots, to classify the data and to compute statistics that were very helpful during the development of the editing system.

RESULTS

The main result is that the fixes could be subdivided into four quality classes, excellent, good, marginal, and poor on the basis of the size of their errors and the values of the parameters (Table C-1, Fig. C-4). The best fixes (excellent) were those two-pass fixes with EI's of at least 45, GCA's greater than 3.2° (elevation angles less than 69°) and more than five messages. The mean error for these fixes was 1.34±.08 km, the 68th percentile error was 1.66 km, and the standard deviation was 1.37 km*. Twenty-five percent of the data fell into the excellent category.

The second best class of fixes (good) included those one-pass

*Distances given are distances of the fixes from the WHOI dock.

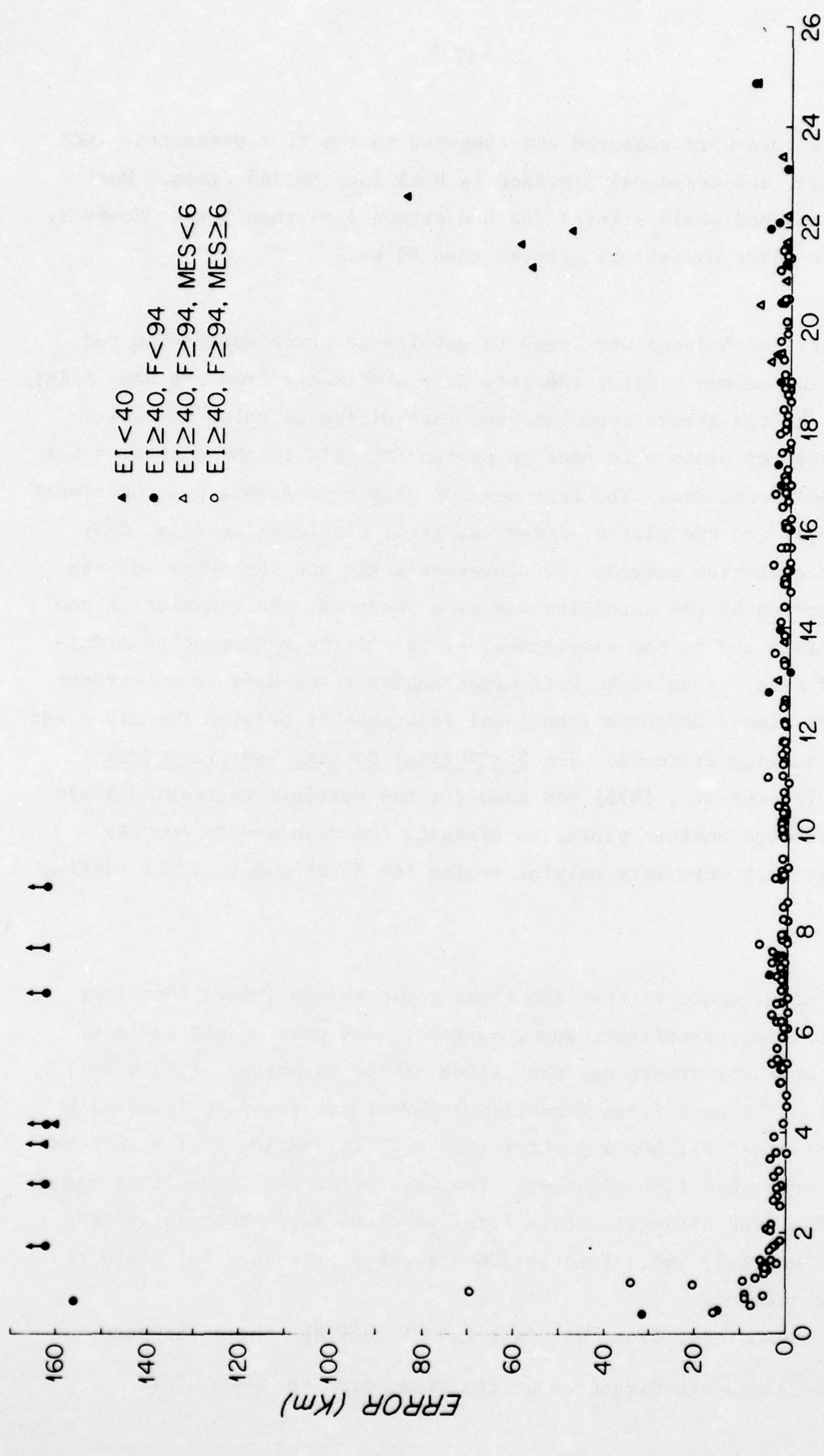

EI < 40
EI ≥ 40, F < 94
EI ≥ 40, F ≥ 94, MES < 6
EI ≥ 40, F ≥ 94, MES ≥ 6
ERROR (Km)
0
20
40
60
80
100
120
140
160
GREAT CIRCLE ANGLE (DEGREES)
0
2
4
6
8
10
12
14
16
18
20
22
24
26

Figure C-3

fixes with EI's of at least 45, F values greater than or equal to 90 and GCA's greater than 3.2°. This group included 36% of the data and has a mean error of 1.52±.08 km. When this class was combined with the first (62% of the data) the mean error became 1.45±.08 km.

Marginal fixes included two-pass fixes with GCA's greater than 1.7° and EI's of at least 40 that were not included in the first category as well as one-pass fixes that met the requirements of the good class with the exception that their angles were between 1.7° and 3.2°. The mean error for the marginal fixes was 2.24±.10 km and these fixes included 13% of the data. The first three classes were combined in a group of acceptable fixes (75% of the fixes) and their mean error was 1.59± .08 km.

The final group of fixes was the rejected fixes which included all the remaining fixes (25%). The mean error for this group was 190±50 km and the 68th percentile is at 33 km. A more complete presentation of the fix quality classes is given in Table C-1 and Figure C-4.

The error in buoy fixes was used to estimate errors in velocity calculated from successive buoy fixes. When the velocity was calculated from two fixes 108 minutes apart, a 1.5 km position error was found to lead to a 23 cm/sec velocity error. For the case of relatively high velocity (100 cm/sec) a 1.5 km fix error gives a bearing error of 13°. During the normal data editing process, in order to reduce the velocity errors, two fixes per day a half-day apart were retained. The expected speed error of these is 3.5 cm/sec. For a slow moving buoy (10 cm/sec) the expected bearing error is 19°, a faster buoy (100 cm/sec) has an expected bearing error of 2°.

DISCUSSION

The relationship between the EI and the error is not a very clear one. The sparse information given by NASA on the EI implies that the EI provides a measurement of the accuracy of a fix on a scale ranging from 0 to 100. The EI's in this study all fell within a range from 25 to 67, 85% fell between 45 and 55. Once the EI's below 45 were dis-

Table C-1

Subdivision of Fixes into Quality Classes

Classification of fixes	% of Total Fixes	Errors of the fixes (a) Mean (km)	Median (km)	68th percentile (km)	Quality parameters from NASA (see text) one or two pass fixes	EI	F Value	Number of messages	GCA
Excellent	25	1.34 ±.08(d)	1.11	1.66	2	≥45	None	≥6	≥3.2 (c)
Good & Excellent	62	1.45 ±.08	1.41	1.67	1	≥45	90	all	≥3.2
					2	≥45	None	≥6	≥3.2
Acceptable marginal + good + excellent	75	1.59 ±.08	1.56	1.71	1	≥45	90	all	≥1.7 (c)
					2	≥40	None	all	≥1.7
Rejected	25	190(b)± 50	7.50	33.15	1	<45	or<90	all	or<1.7
					2	<40	None	all	or≤1.7
All data	100	49(b)± 19	1.66	2.34	all	all	all	all	all
Good	36	1.52 ±.08	1.42	1.68	1	≥45	≥90	all	≥3.2
Marginal	13	2.27 ±.10	1.94	2.59	1	≥45	≥90	all	≥1.7
					2	<45,≥40	None	all	>1.7
						or>40	None	≤6	≤3.2 ≥1.7

(a) These values refer to the distance of the fixes from the known position of the buoys.

(b) These values include two fixes with errors greater than 4000 km. With these two eliminated the mean error is 25±5 km for all the data and 93±15 km for the rejected data.

(c) Great circle angles ≥ 3.2° and ≥ 1.7° correspond to elevation angles ≤ 69° and ≤ 79° respectively.

(d) The standard deviation of excellent fixes was 1.37 km.

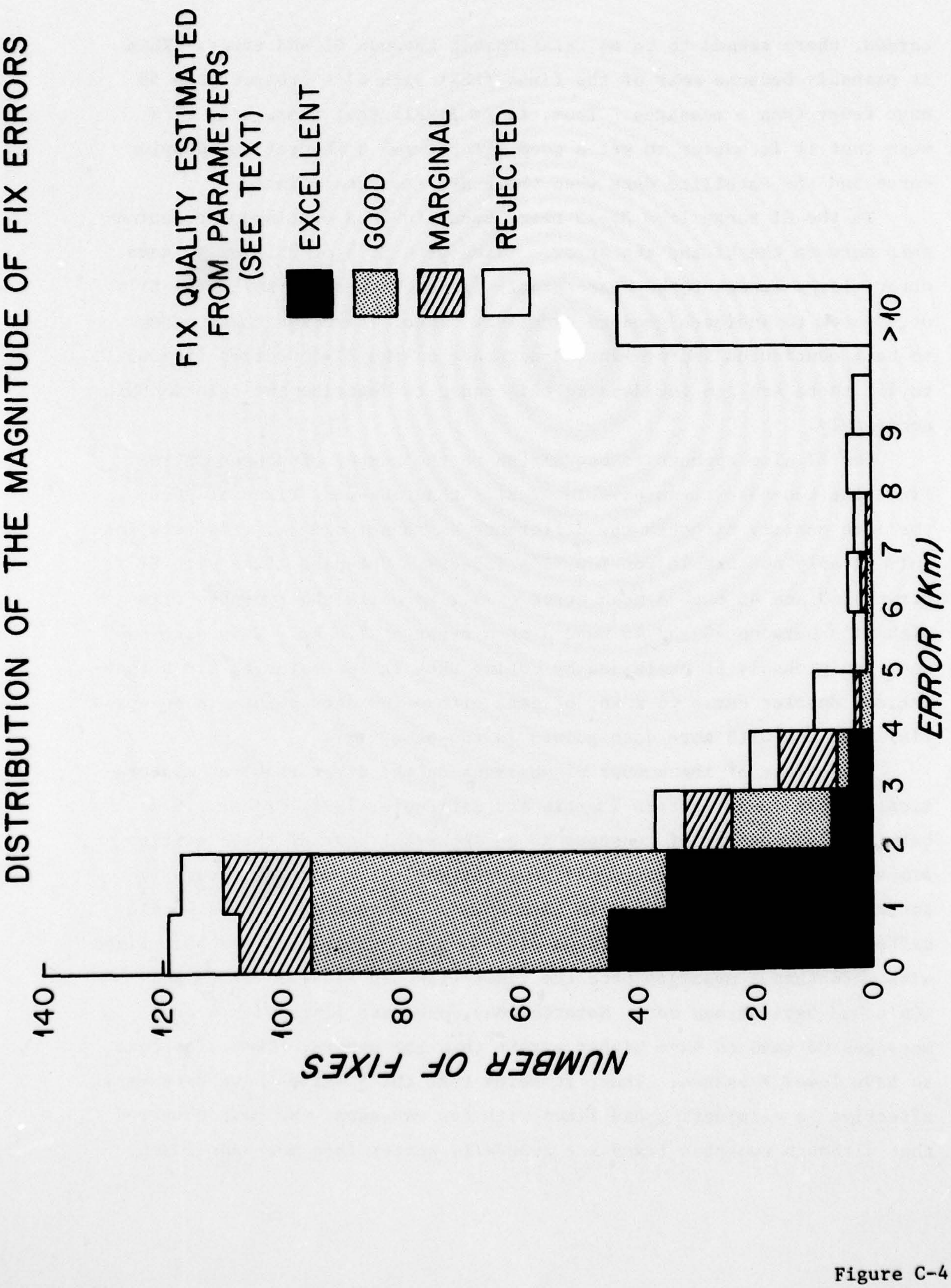

DISTRIBUTION OF THE MAGNITUDE OF FIX ERRORS
FIX QUALITY ESTIMATED FROM PARAMETERS (SEE TEXT)
EXCELLENT
GOOD
MARGINAL
REJECTED
NUMBER OF FIXES
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
>10
ERROR (Km)

Figure C-4

carded, there seemed to be no relationship between EI and error. This is probably because most of the fixes (88%) with EI's greater than 55 have fewer than 8 messages. Thus, it is likely that these high EI's mean that it is easier to get a good fit between a theoretical doppler curve and the satellite data when there are few data points.

In the EI range from 35-45 there seems to be a continuous relationship between the EI and the error. Fixes with EI's of 35 seem to have errors large enough to be unacceptable (greater than 6-7 km) while EI's of 45 seem to indicate good to excellent fixes. Although there seems to be a continuous improvement in accuracy as the EI increases from 35 to 45, there are too few data in this range to describe the relationship accurately.

The EI also appears to be related to the number of passes in the fix. The two-pass fixes have lower EI's than one-pass fixes of about the same quality although the difference is rather slight; this relationship is only noticeable for low EI's (35-45). One-pass fixes with EI's between 40 and 45 have a mean error of 5.2 km while the two-pass fixes with EI's between 40 and 45 have a mean error of 1.6 km. This discrepancy can probably be explained by noting that it is easier to fit a theoretical doppler curve to a set of data with a few data points (a one-pass fix) than one with more data points (a two-pass fix).

The effect of the number of messages on the error requires elaboration. Other investigators (Martin and Gillespie, 1978; Greene, 1977) have used the number of messages as an important part of their editing procedure. However, the number of messages was not found to be very important in predicting errors in this study. There seemed to be little difference between one-pass fixes with 4 or 5 messages and one-pass fixes with more than 5 messages once the fixes with bad EI's, F values and GCA's had been thrown out. Nevertheless, one-pass fixes with 4 or 5 messages do tend to have higher errors than the others. They also tend to have lower F values. Thus, it seems that the F values have been very effective in eliminating bad fixes with few messages. We have observed that although two-pass fixes are generally better than one-pass fixes, two-pass fixes with 4 or 5 messages are considerably worse than one-pass fixes. Two-pass fixes with 4 or 5 messages have a mean error of 2.2 km, while one-pass fixes with 4 or 5 messages have a mean error of 1.5 km, and two-pass fixes with 6 or more messages have a mean error of 1.3 km. (These values do not include rejected or poor data.)

Some fixes with elevation angles less than 15°, corresponding to great circle angles greater than about 20°, were found to have large errors (Fig. C-2). However, all these poor fixes were rejected because of low EI's or low F values. Thus, it was not necessary to reject the data on the basis of their large GCA's.

A significant part of the error in fixes could be due to an error in the satellite position. Martin and Gillespie (1978) note that when the errors along the satellite track of the platform are subtracted from drifting buoy fixes, the accuracy of the fixes is significantly improved. Unfortunately, information on the satellite track is only available on the magnetic tape (and possibly card) output from NASA but not on the computer printouts most users receive.

CONCLUSION

The basic purpose of this analysis was to develop a "hands-off" method by which bad fixes could be removed from the drifting buoy data in order that the accuracy of the remaining data would remain within known standards. In order to eliminate low quality fixes, a simple editing system was developed that retains 60-75% of the data and maintains an accuracy (mean error) of 1.3-1.6 km. The 1.3 km and 60% values correspond to the good and excellent data (one-pass fixes with EI $\geq$ 45, messages $\geq$ 6 and GCA $\geq$ 3.2°) while the 1.6 km and 75% values correspond to all the acceptable data, the excellent, good and marginal data (one-pass fixes with EI $\geq$ 45, F value $\geq$ 90 and GCA $\geq$ 1.7°, two-pass fixes with EI $\geq$ 40 and GCA $\geq$ 1.7°). The quality control parameters on which the editing procedure is based are available from the NASA printout used by most Nimbus-6 users; therefore, all users of Nimbus-6 data could easily employ the proposed editing system.

MANDATORY DISTRIBUTION LIST

FOR UNCLASSIFIED TECHNICAL REPORTS, REPRINTS, AND FINAL REPORTS
PUBLISHED BY OCEANOGRAPHIC CONTRACTORS
OF THE OCEAN SCIENCE AND TECHNOLOGY DIVISION
OF THE OFFICE OF NAVAL RESEARCH

(REVISED NOVEMBER 1978)

1 Deputy Under Secretary of Defense
(Research and Advanced Technology)
Military Assistant for Environmental Science
Room 3D129
Washington, D.C. 20301

Office of Naval Research
800 North Quincy Street
Arlington, VA 22217
3 ATTN: Code 483
1 ATTN: Code 460
2 ATTN: 102B

1 CDR J. C. Harlett, (USN)
ONR Representative
Woods Hole Oceanographic Inst.
Woods Hole, MA 02543

Commanding Officer
Naval Research Laboratory
Washington, D.C. 20375
6 ATTN: Library, Code 2627

12 Defense Documentation Center
Cameron Station
Alexandria, VA 22314
ATTN: DCA

Commander
Naval Oceanographic Office
NSTL Station
Bay St. Louis, MS 39522
1 ATTN: Code 8100
1 ATTN: Code 6000
1 ATTN: Code 3300

1 NODC/NOAA
Code D781
Wisconsin Avenue, N.W.
Washington, D.C. 20235

Woods Hole Oceanographic Institution
WHOI-79-4

FREE-DRIFTING BUOY TRAJECTORIES IN THE GULF STREAM SYSTEM (1975-1978) A DATA REPORT by P. L. Richardson, J. J. Wheat and D. Bennett. 158 pages. January 1979. Prepared for the Office of Naval Research under Contract N00014-74-C-0262; NR 083-004 and for the National Science Foundation under Grants OCE 75-08765 and OCE 77-08045.

From 1975-1978, thirty-one satellite-tracked free-drifting surface buoys were launched in the Gulf Stream system. Most of these buoys were launched in cyclonic rings, as part of an interdisciplinary Gulf Stream ring experiment. Other buoys were launched in anticyclonic rings and the Gulf Stream itself; one buoy was launched in a cyclonic Kuroshio ring. The basic data set consists of buoy trajectories and sea surface temperature and velocity measurements along trajectories.

The main results consist of a series of 19 buoy trajectories in rings from which the movement of rings is inferred and a series of 20 buoy trajectories in the Gulf Stream. Rings frequently coalesced with the Gulf Stream; and some reformed as modified rings. the trajectories of buoys in the Stream reveal that at times surface currents are strongly influenced by topographic features such as seamounts and ridges. Most buoys in the Stream continued to move eastward until they reached the vicinity of the Grand Banks (50°W) where they rapidly fanned out, some moving northward, others eastward across the mid-Atlantic Ridge, still others southward and westward.

1. Satellite tracked buoy
2. Trajectories at buoys
3. Gulf Stream System

I. Richardson, P. L.
II. Wheat, J. J.
III. Bennett, D.
IV. N00014-74-C-0262; NR 083-004
V. OCE 75-08765
VI. OCE 77-08045

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
WHOI-79-4

FREE-DRIFTING BUOY TRAJECTORIES IN THE GULF STREAM SYSTEM (1975-1978) A DATA REPORT by P. L. Richardson, J. J. Wheat and D. Bennett. 158 pages. January 1979. Prepared for the Office of Naval Research under Contract N00014-74-C-0262; NR 083-004 and for the National Science Foundation under Grants OCE 75-08765 and OCE 77-08045.

From 1975-1978, thirty-one satellite-tracked free-drifting surface buoys were launched in the Gulf Stream system. Most of these buoys were launched in cyclonic rings, as part of an interdisciplinary Gulf Stream ring experiment. Other buoys were launched in anticyclonic rings and the Gulf Stream itself; one buoy was launched in a cyclonic Kuroshio ring. The basic data set consists of buoy trajectories and sea surface temperature and velocity measurements along trajectories.

The main results consist of a series of 19 buoy trajectories in rings from which the movement of rings is inferred and a series of 20 buoy trajectories in the Gulf Stream. Rings frequently coalesced with the Gulf Stream; and some reformed as modified rings. the trajectories of buoys in the Stream reveal that at times surface currents are strongly influenced by topographic features such as seamounts and ridges. Most buoys in the Stream continued to move eastward until they reached the vicinity of the Grand Banks (50°W) where they rapidly fanned out, some moving northward, others eastward across the mid-Atlantic Ridge, still others southward and westward.

1. Satellite tracked buoy
2. Trajectories at buoys
3. Gulf Stream System

I. Richardson, P. L.
II. Wheat, J. J.
III. Bennett, D.
IV. N00014-74-C-0262; NR 083-004
V. OCE 75-08765
VI. OCE 77-08045

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
WHOI-79-4

FREE-DRIFTING BUOY TRAJECTORIES IN THE GULF STREAM SYSTEM (1975-1978) A DATA REPORT by P. L. Richardson, J. J. Wheat and D. Bennett. 158 pages. January 1979. Prepared for the Office of Naval Research under Contract N00014-74-C-0262; NR 083-004 and for the National Science Foundation under Grants OCE 75-08765 and OCE 77-08045.

From 1975-1978, thirty-one satellite-tracked free-drifting surface buoys were launched in the Gulf Stream system. Most of these buoys were launched in cyclonic rings, as part of an interdisciplinary Gulf Stream ring experiment. Other buoys were launched in anticyclonic rings and the Gulf Stream itself; one buoy was launched in a cyclonic Kuroshio ring. The basic data set consists of buoy trajectories and sea surface temperature and velocity measurements along trajectories.

The main results consist of a series of 19 buoy trajectories in rings from which the movement of rings is inferred and a series of 20 buoy trajectories in the Gulf Stream. Rings frequently coalesced with the Gulf Stream; and some reformed as modified rings. the trajectories of buoys in the Stream reveal that at times surface currents are strongly influenced by topographic features such as seamounts and ridges. Most buoys in the Stream continued to move eastward until they reached the vicinity of the Grand Banks (50°W) where they rapidly fanned out, some moving northward, others eastward across the mid-Atlantic Ridge, still others southward and westward.

1. Satellite tracked buoy
2. Trajectories at buoys
3. Gulf Stream System

I. Richardson, P. L.
II. Wheat, J. J.
III. Bennett, D.
IV. N00014-74-C-0262; NR 083-004
V. OCE 75-08765
VI. OCE 77-08045

This card is UNCLASSIFIED

Woods Hole Oceanographic Institution
WHOI-79-4

FREE-DRIFTING BUOY TRAJECTORIES IN THE GULF STREAM SYSTEM (1975-1978) A DATA REPORT by P. L. Richardson, J. J. Wheat and D. Bennett. 158 pages. January 1979. Prepared for the Office of Naval Research under Contract N00014-74-C-0262; NR 083-004 and for the National Science Foundation under Grants OCE 75-08765 and OCE 77-08045.

From 1975-1978, thirty-one satellite-tracked free-drifting surface buoys were launched in the Gulf Stream system. Most of these buoys were launched in cyclonic rings, as part of an interdisciplinary Gulf Stream ring experiment. Other buoys were launched in anticyclonic rings and the Gulf Stream itself; one buoy was launched in a cyclonic Kuroshio ring. The basic data set consists of buoy trajectories and sea surface temperature and velocity measurements along trajectories.

The main results consist of a series of 19 buoy trajectories in rings from which the movement of rings is inferred and a series of 20 buoy trajectories in the Gulf Stream. Rings frequently coalesced with the Gulf Stream; and some reformed as modified rings. the trajectories of buoys in the Stream reveal that at times surface currents are strongly influenced by topographic features such as seamounts and ridges. Most buoys in the Stream continued to move eastward until they reached the vicinity of the Grand Banks (50°W) where they rapidly fanned out, some moving northward, others eastward across the mid-Atlantic Ridge, still others southward and westward.

1. Satellite tracked buoy
2. Trajectories at buoys
3. Gulf Stream System

I. Richardson, P. L.
II. Wheat, J. J.
III. Bennett, D.
IV. N00014-74-C-0262; NR 083-004
V. OCE 75-08765
VI. OCE 77-08045

This card is UNCLASSIFIED