390
10-22-80

Ar. 1921

DOE/NOAA/OTEC-17

MASTER

OTEC CURRENT STUDY

Final Report

March 1979

Work Performed Under Contract No. EG-77-A-29-1078

Ocean Facilities Engineering and Construction Project Office
Naval Facilities Engineering Command
Washington, D. C.

64

U.S. Department of Energy

Solar Energy

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DISCLAIMER

"This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $7.00
Microfiche $3.50

DOE/NOAA/OTEC-17
Distribution Category UC-64

OTEC CURRENT STUDY
FINAL REPORT

FPO-1-79(7)
MARCH 1979

OCEAN FACILITIES ENGINEERING AND CONSTRUCTION PROJECT OFFICE
CHESAPEAKE DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
WASHINGTON, D. C. 20374

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

LIST OF FIGURES

1.0 BACKGROUND

A fundamental element of all currently proposed Ocean Thermal Energy Conversion (OTEC) systems is a long, large diameter pipe which will serve as a conduit for cold water from the ocean depths to a heat exchanger at or near the surface. This cold water pipe (CWP), for a 100 megawatt OTEC plant may be as large as 60 feet in diameter and extend to a depth of 3000 feet. Smaller CWPs are planned for testing OTEC system components; these may be as small as 8 or 9 feet in diameter but 3000 foot lengths will be required to reach water temperatures low enough to supply the needed temperature difference to the condenser elements of the system.

There will be various environmental forces acting upon the CWP. Those of primary concern are on the wave action on the CWP suspension system at the surface, and the ocean current hydrodynamic forces on the pipe itself throughout its length. The latter is the subject of this report.

Under a contract with the Applied Physics Laboratory of John Hopkins University, the firm Deep Oil Technology, Inc. planned and carried out a verification test on a model CWP to investigate the potential effect of some of these environmental forces in a true ocean environment. The plans for this experiment were published in Reference 1 in June 1978. The dimensions of the model CWP were 5 feet in diameter and 800 feet long; the pipe was made up of 20-foot lengths of 3/16-inch steel pipe with flanges at either end that were bolted together to form the total test length. This model CWP was suspended from the *Deep Oil X-1* which was moored in 1000 feet of water about two miles south of Santa Catalina Island in the Pacific Ocean during December 1978.

The Ocean Engineering and Construction Project Office of the Chesapeake Division, Naval Facilities Engineering Command (CHESNAVFACENGCOM) was tasked in October 1978 by the National Oceanic and Atmospheric Administration (NOAA) to provide current data in conjunction with this OTEC Cold Water Pipe experiment off the seaward side of Santa Catalina Island. The location of the test site is shown in a section of the chart for this area, Figure 1.

2.0 INSTALLATION PREPARATION

Upon receipt of the tasking assignment from NOAA a string of current

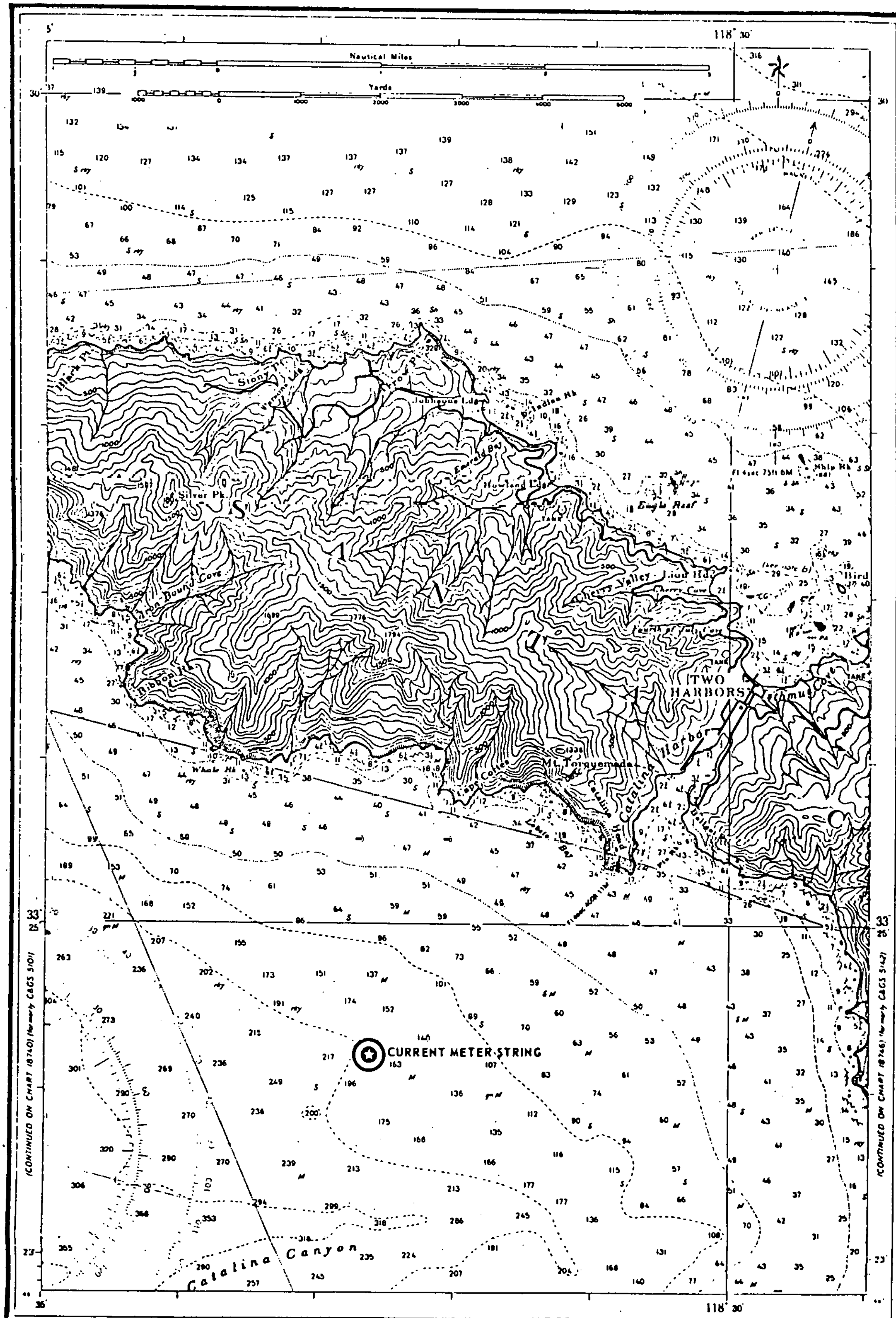


CHART SHOWING LOCATION OF THE TEST SITE AND CURRENT METER STRING

FIGURE 1

meters with the necessary buoy and anchor accessories was designed and a project execution plan, Reference 2, was prepared. The basic design was quite simple. It comprised eight Aanderaa current meters, 100 feet apart, suspended from a 40 inch diameter subsurface buoy and anchored to the bottom as shown in Figure 2. The current meters were acquired from the Naval Oceanographic Office (NAVOCEANO). The actual instrument numbers are shown on Figure 2 to tie in the specific instrument location with the data presented in later sections of this report.

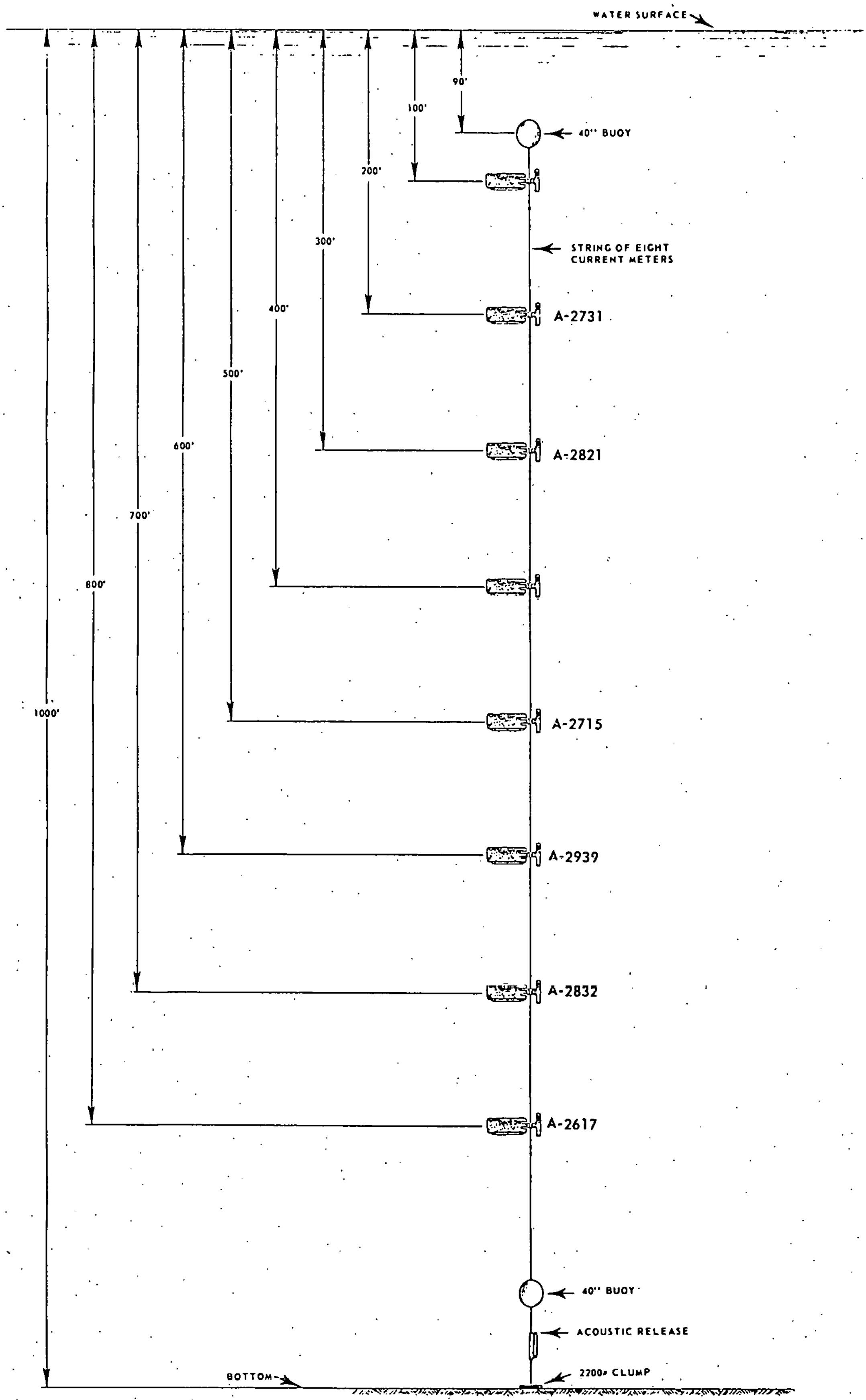
Additional details of the current meter string design are given in Figure 3. It can be seen that the individual meters are connected by a few links of chain and a length of 3/4 inch Sampson Single Braid sized to stretch under load to place the meters at the prescribed 100 foot separation. A second 40 inch diameter buoy is fitted at the bottom of the string to aid in retrieval. This is connected to the 2200 pound steel clump anchor through an acoustic release so that the entire string can float to the surface when the release is actuated.

All the necessary equipment was selected from the CHESNAVFACENGCOM Ocean Construction Equipment Inventory and the Naval Oceanographic Office and shipped to the Civil Engineering Laboratory in Port Hueneme, California. Assembly of the current meter string was completed by the first week in November and ready to be installed when Deep Oil Technology, Inc. (DOT) installed its test platform. The current meters were to be installed at the same time as the platform. This was necessary to take advantage of the ship assets available and used by DOT for the platform installation.

CHESNAVFACENGCOM was supported in the installation by personnel from the Civil Engineering Laboratory (CEL) of the Naval Construction Battalion Center in Port Hueneme, California. All equipment was checked out in Port Hueneme and CHESNAVFACENGCOM and CEL personnel were ready to install the current meters when DOT advised they were ready on 15 November 1978. However, delays occurred relative to the DOT schedule thus delaying installation and CHESNAVFACENGCOM personnel returned to Washington, D. C.

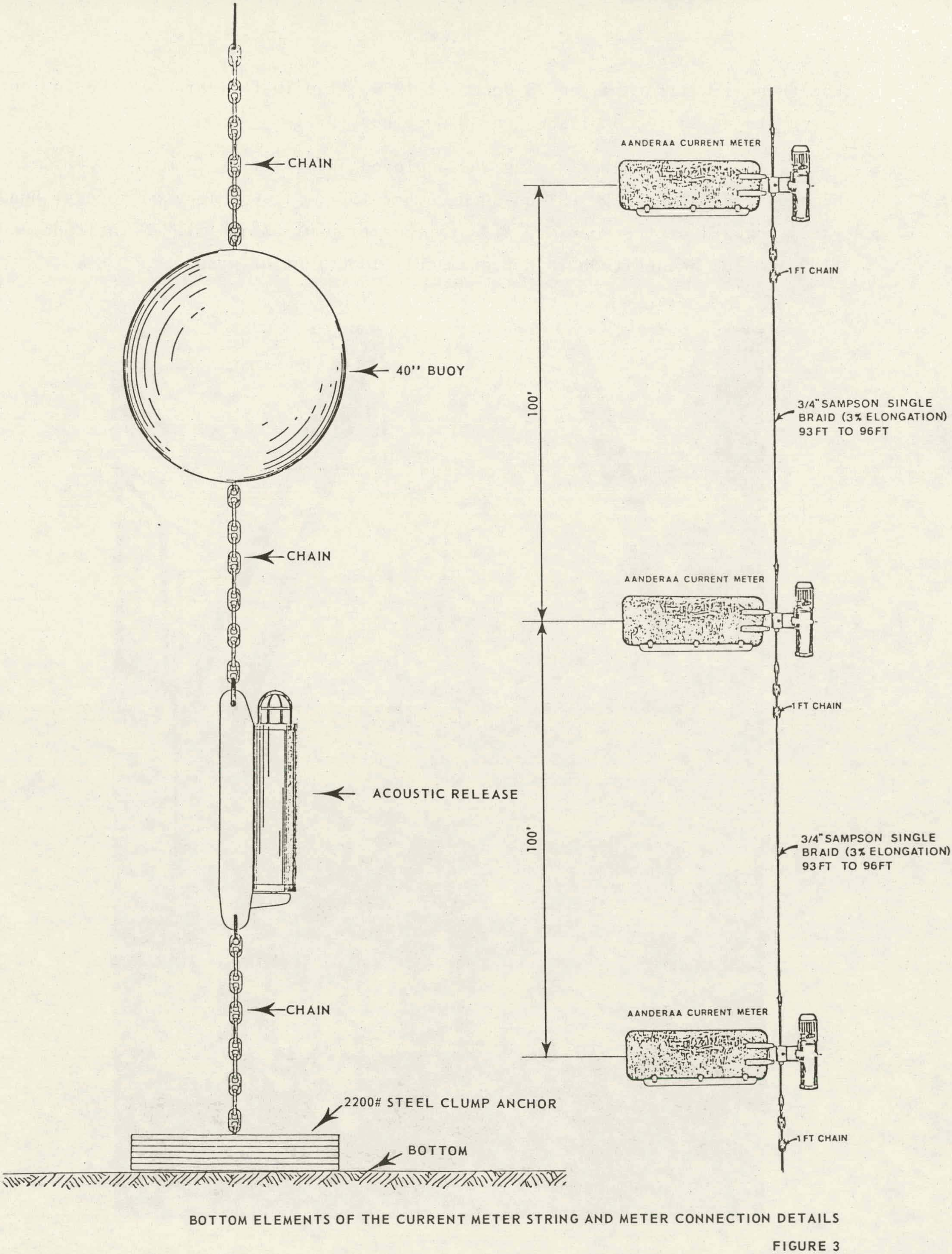
3.0 INSTALLATION OF THE CURRENT METER STRING

DOT announced it was ready to install the CWP in late December 1978. CHESNAVFACENGCOM and CEL personnel along with all the equipment were on site in



CONFIGURATION OF CURRENT METER STRING
AND IDENTIFICATION OF ACTIVE CURRENT METERS

FIGURE 2

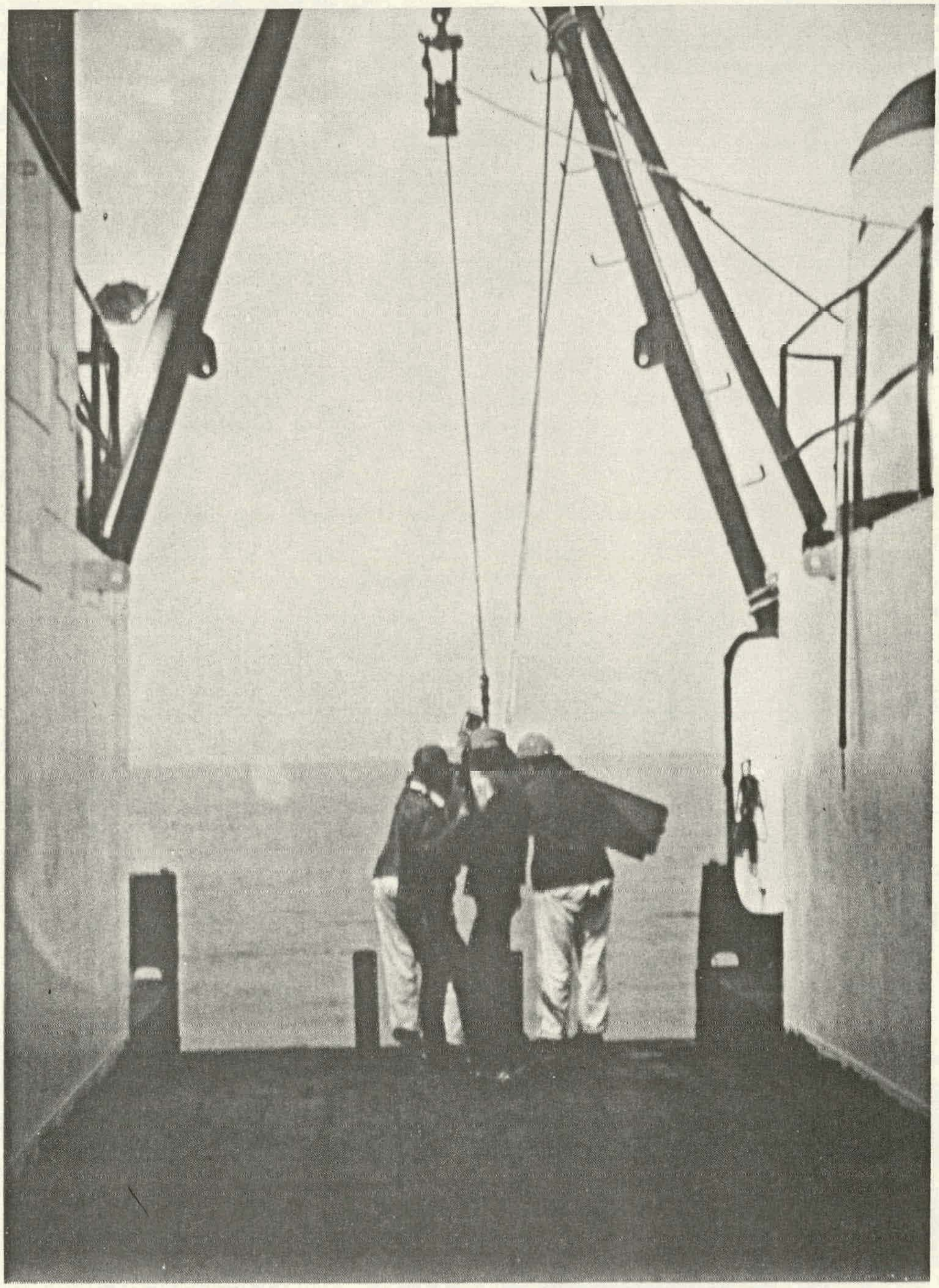


BOTTOM ELEMENTS OF THE CURRENT METER STRING AND METER CONNECTION DETAILS

FIGURE 3

Long Beach, California, on 28 December 1978. The installation of the current meter string was accomplished on 30 December 1978.

The current meter string was deployed anchor-first from the *M.V. Calcasieu*, Figure 4, at about 1 PM PST on 30 December 1978. It was located several hundred yards seaward of the *Deep Oil X-1* at a position of 33° 24' 10" N latitude and 118° 32' 10" W longitude in approximately 1000 feet of water.



LOWERING THE METER STRING OVER THE STERN OF THE M. V. CALCASIEU

FIGURE 4

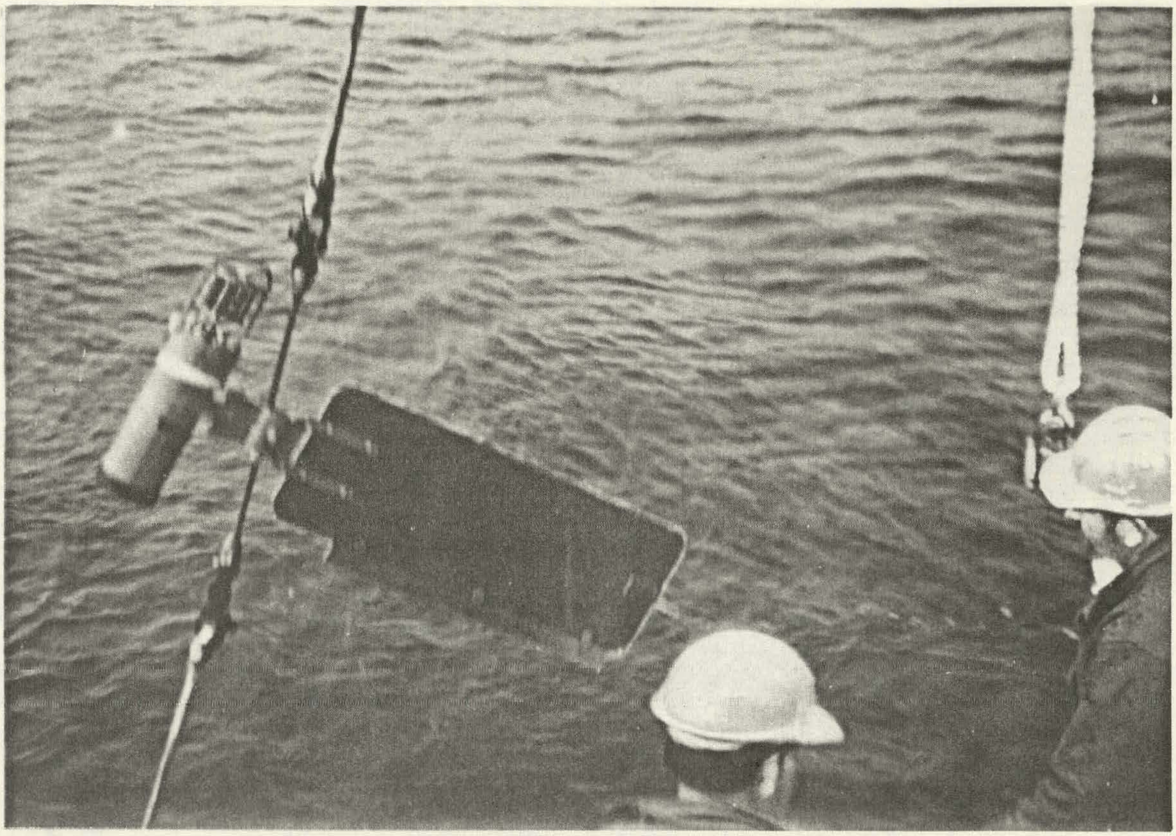
The preassembled line, less meters, buoys and acoustic release, was spooled on the winch. The deployment entailed lowering the anchor to the position of the acoustic release and stopping off the line while the release was inserted between two preinserted shackles. The string was then lowered to the buoy position where it was inserted similarly. This procedure was then repeated for each meter. The operations are depicted in Figures 5 and 6. The subsurface buoy was then added and the entire string was lowered into position using a lowering line. When the anchor reached the bottom, the lowering line went slack. When the lowering line was slacked, a Raymond release hook was actuated so the release hook and lowering line could be recovered.

4.0 CURRENT METER CHARACTERISTICS AND OPERATION

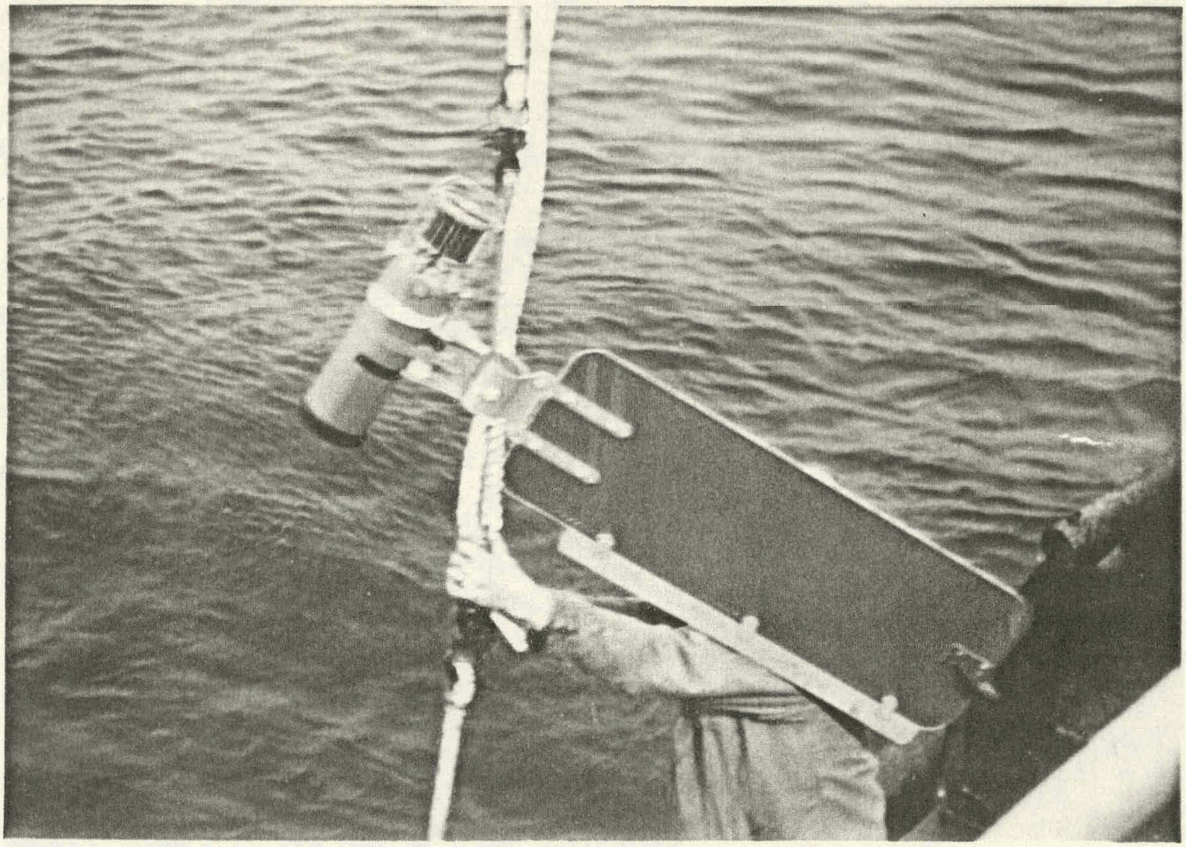
The Aanderaa, RCM-5 Current Meter is a self-contained instrument for recording speed, direction, and temperature of ocean currents. Operation of the current meter is based upon a rotor-type current velocity sensor, a magnetic compass for direction determination, and a thermistor for temperature sensing. The instrument consists of two main parts, the recording unit and the vane assembly. The vane assembly has a spindle which can be shackled onto the mooring line of a surface or subsurface buoy. The motion of the velocity sensing rotor is transmitted through the case of the recording unit via a magnetic coupling. The magnetic compass is housed inside the recording unit. The velocity measurement is in integrated form while the direction measurement is instantaneous. Power is provided by batteries capable of up to 12-months operation, depending upon sampling intervals.

The current meter is capable of performing the following measurements in a single measuring cycle: Reference, temperature, pressure, direction, and current speed. An electro-mechanical encoder samples and converts the measurements to binary digital signals which are then recorded on 1/4-inch magnetic tape. The binary signals are also transmitted to the surface by means of an acoustic transducer, thus permitting on-site monitoring. An internal quartz crystal clock actuates the instrument at regular intervals. The magnetic tape from this instrument can be read by the model 2103 Tape Reader and can be converted to punched paper tape.

The Aanderaa meter shown in Figure 7 has an overall length of 136.0 cm (53.5 in.). The cylindrical recording unit has a diameter of 12.8 cm (5.0 in.) and weighs 13 kg (28.6 lbs) in air. The vane is 37 x 100 cm



AANDERAA CURRENT METER AND STOPPER LINE
FIGURE 5



STOPPING OFF THE LINE
FIGURE 6

(14.6 x 39.4 in.) and weighs 12 kg (26.5 lbs) in air. In water, both the vane and recording unit have a weight of 7.5 kg (16.5 lbs) and thus are weight balanced to hang level when rotating around the vertical spindle. The position of the weight at the bottom of the vane can be adjusted to maintain an accurate moment balance.

The meters were set to collect data at 10 minute intervals for a 30-day period. All meters recorded temperature, current speed,and current direction. The two uppermost meters also measured pressure to monitor any vertical movement of the current meter string.

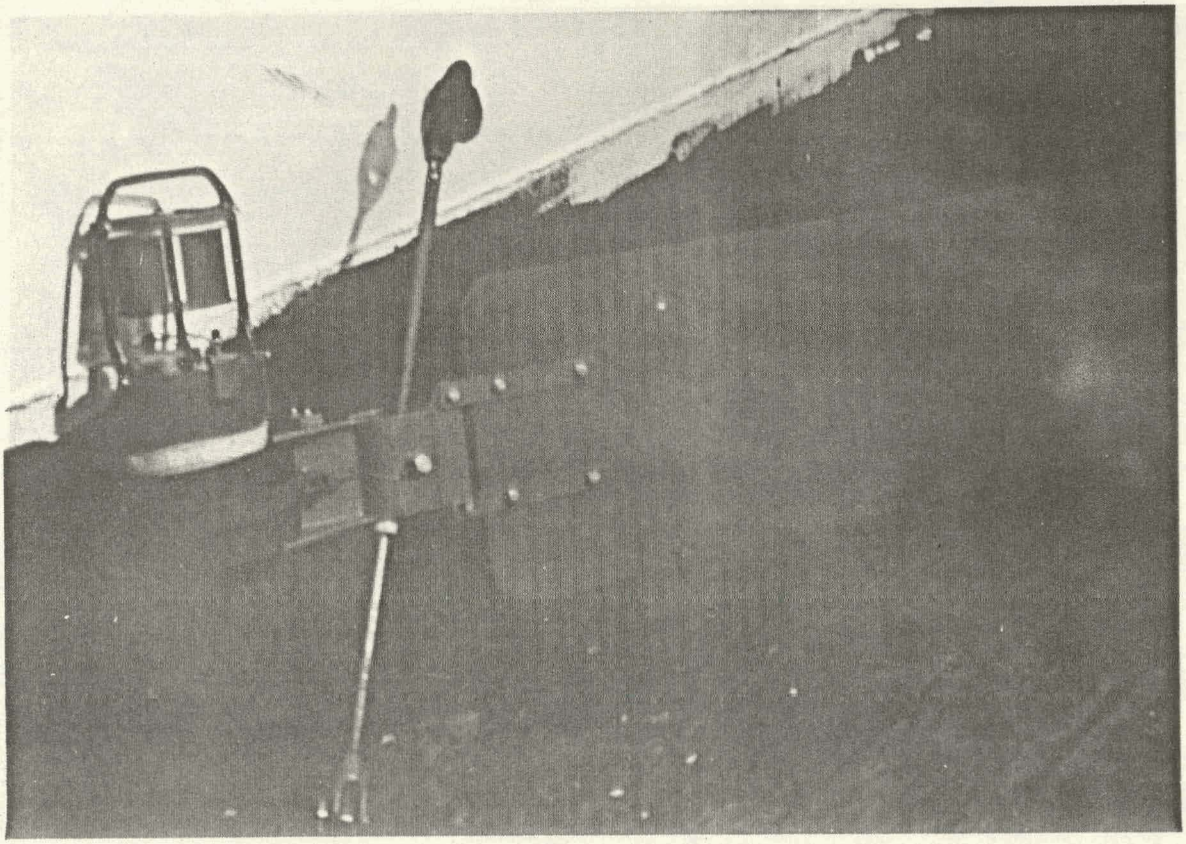
5.0 RECOVERY AND INSPECTION OF THE CURRENT METERS

Recovery of the meters occurred on 23 January 1979 at dusk, once again using the *M.V. Calcasieu* for the operation. The recovery went flawlessly and was completed in about 30 minutes. The current meter string was called to the surface by activating an acoustic release located between the clump and the string. Once the release was fired and the buoys brought the string to the surface, a lifting line was attached to the subsurface float, Figure 8, and the string was lifted aboard the *Calcasieu* in a reverse order to the installation procedure. An air tugger on the *Calcasieu* was utilized for this instead of the winch.

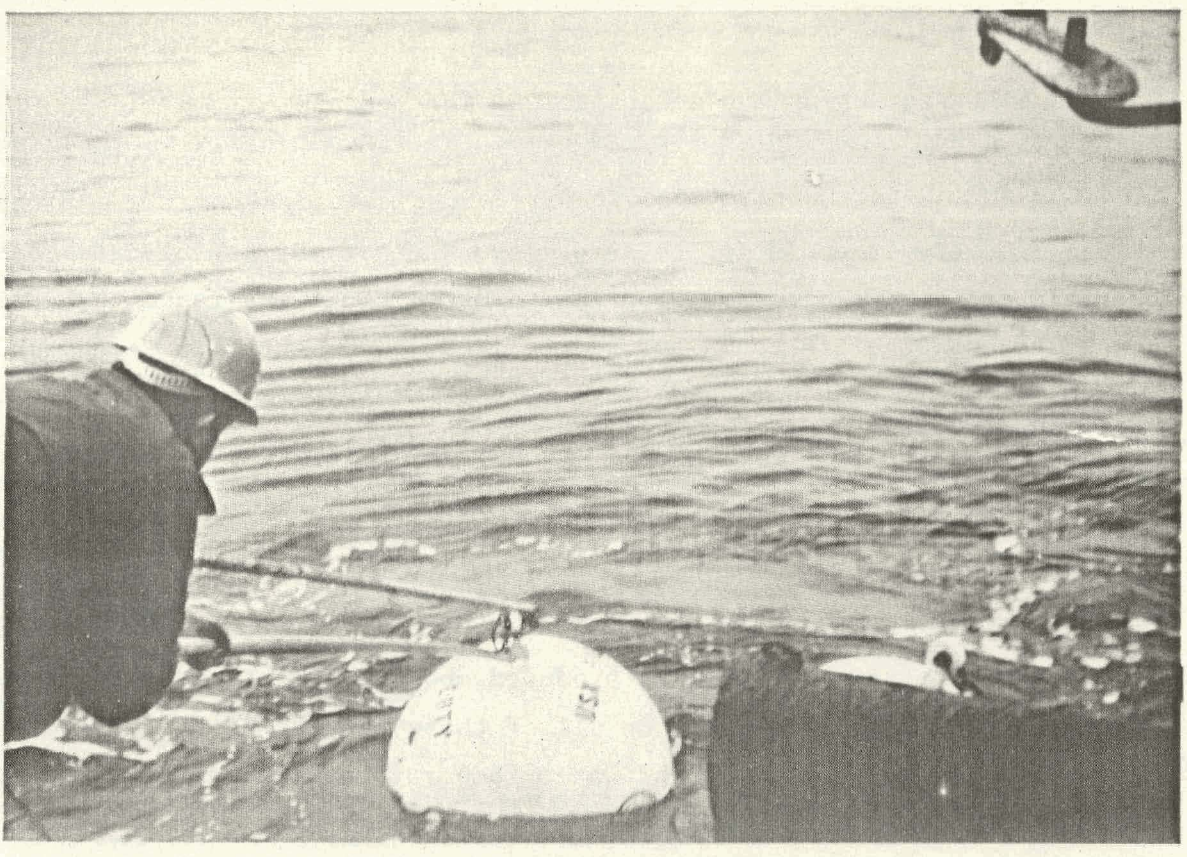
After returning the meters to CEL for removal of the tapes, two problems were revealed. The 100' meter had evidently flooded early in the experiment and the 400' meter malfunctioned and recorded data irregularly. At the time of their recovery it could not be determined whether any useful data could be derived from these meters. Upon later analysis, it was found that the data from these two meters could not be utilized. This meant that one set of hydrostatic pressure data and two sets each of temperature and current velocity and direction data were not available for analysis.

6.0 PROCESSED RESULTS OF MEASURED DATA

The valid measurements obtained during the 30-day period that the meters were installed off Santa Catalina included data taken at ten minute intervals for about 580 hours. This produced about 3480 sets of readings on each of six Aanderaa current meters. On all of these meters, recordings were made of current speed and direction and water temperature. On one of the six, located at 61 m (200 ft) below the surface, the hydrostatic pressure also was recorded at these same intervals.



DETAILS OF THE AANDERAA CURRENT METER
FIGURE 7



RECOVERY OF THE SUBSURFACE BUOY
FIGURE 8

The data processing was done by NAVOCEANO in Bay St. Louis, Mississippi and completed on 13 March 1979. The first step in the processing comprised the playback and printout of all of the data points. A sample printout is given in Figure 9 together with identifying designations for the various columns of figures.

READING NUMBER	U (CM/SEC)	V (CM/SEC)	TEMP (°C)	NOT USED	PRESSURE (DECIBARS)	NOT USED
50	-8.500	5.075	14.25	.0000	58.60	.0000
51	-6.719	8.017	14.31	.0000	58.60	.0000
52	-4.580	10.33	14.50	.0000	58.50	.0000
53	-5.345	9.316	14.39	.0000	58.50	.0000
54	-5.426	9.592	14.42	.0000	58.50	.0000
55	-3.553	10.73	14.47	.0000	58.60	.0000
56	-2.757	10.67	14.36	.0000	58.60	.0000
57	-4.629	10.61	14.31	.0000	58.60	.0000
58	-4.885	10.50	14.31	.0000	58.79	.0000
59	-1.952	11.98	14.34	.0000	58.98	.0000
60	.4431	13.25	14.42	.0000	58.98	.0000
61	.9466	13.51	14.39	.0000	58.98	.0000
62	4.334	12.83	14.42	.0000	59.17	.0000
63	4.800	12.66	14.39	.0000	59.35	.0000
64	5.911	14.03	14.67	.0000	59.36	.0000
65	5.803	13.77	14.69	.0000	59.36	.0000
66	7.976	11.29	14.69	.0000	59.36	.0000
67	6.272	10.07	14.75	.0000	59.36	.0000
68	6.634	9.148	14.72	.0000	59.55	.0000
69	6.874	7.124	14.61	.0000	59.73	.0000
70	7.171	7.615	14.64	.0000	59.73	.0000
71	7.072	6.102	14.64	.0000	59.73	.0000
72	7.823	5.102	14.61	.0000	59.73	.0000
73	7.930	4.382	14.64	.0000	59.73	.0000
74	8.079	2.641	14.64	.0000	59.92	.0000
75	8.075	1.537	14.54	.0000	60.11	.0000
76	9.196	1.634	14.77	.0000	60.11	.0000
77	8.357	-1.551	14.61	.0000	60.11	.0000
78	6.856	-1.844	14.58	.0000	60.11	.0000
79	5.952	-2.709	14.39	.0000	60.11	.0000

TABULATED DATA FROM CURRENT METER A-2731
AT DEPTH OF 61 METERS (200 FEET)

FIGURE 9

In addition to the tabulation of the recorded data a series of analyses were made to aid in data interpretation. These included the development of the following plots.

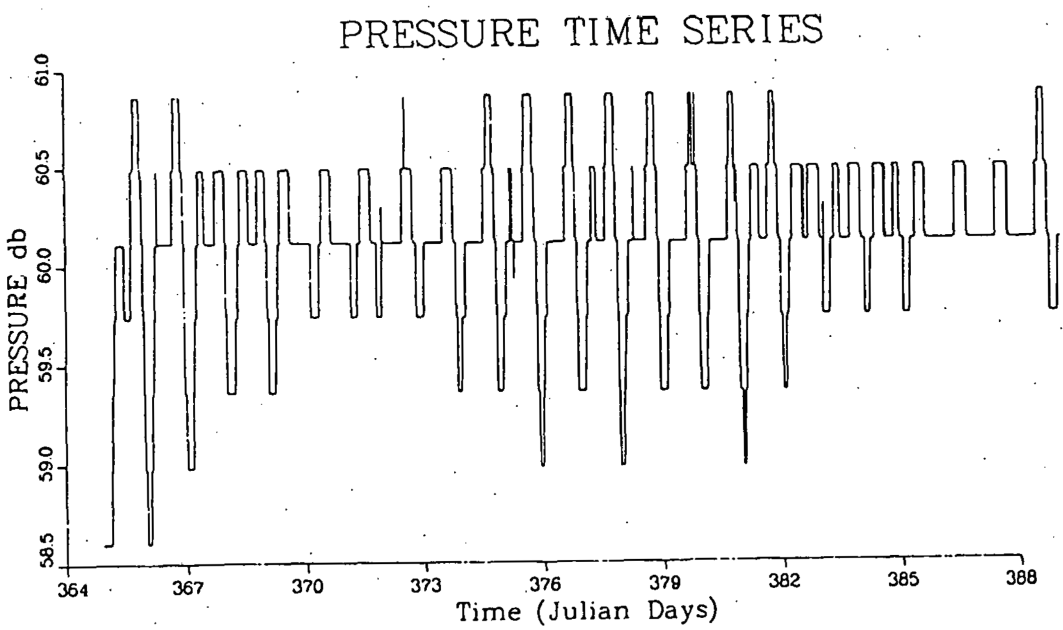
- Pressure versus time for one depth
- Temperature versus time for six depths

- U- and V-Components of current velocity, direction, and resultant velocity versus time for six depths
- Progressive Vector Diagrams for six depths
- U-Component Current Spectra for six depths
- V-Component Current Spectra for six depths
- Rotary Current Spectra for six depths
- Current Vector Diagrams for six depths

These various forms of data analysis are discussed on the following pages and the plotted data are presented. It may be noted that time is expressed in all plots in Julian Days. The first reading is arbitrarily started at Julian Day 365 and each successive day represents the accumulation of an additional 144 readings from the initial reading. Referring back to Figure 9, the first reading of the series shown that corresponds with Julian Day 365 was reading No. 25 taken at 2116Z on 30 December 1978 when the current meter string anchor first touched bottom.

6.1 PRESSURE AND TEMPERATURE DATA

The pressure-time plot of the data recorded from the 61 m depth meter is given in Figure 10. The pressure is given in decibars, i.e. one-tenth of



File:	AA1278		Array :	1
Meter:	A-2731		Depth :	61 M
Latitude :	33-24-10 N		Deployed :	30 DEC 1978
Longitude:	118-32-10 W		Recovered:	24 JAN 1979

FIGURE 10

an atmosphere. The digital steps indicated in the plot are each equivalent to about 38 cm (1.25 ft) of head of sea water. Since the time interval of measurement is 10 minutes, the pressure reading does not respond to waves or swell and reflects primarily the mean head of sea water above the transducer. Thus, the results are indicative of the vertical tidal movement in the Catalina Island area which ranges from a maximum of 230 cm (7.5 ft) total head difference to a minimum of 75 cm (2.5 ft). The results check fairly closely with the Los Angeles Outer Harbor tide gage for this period. These data may be of future use in relating tidal current movements to the measured current data.

The temperature-time plots give temperature in degrees Celsius versus time in Julian Days. These are included here as Appendix A. It may be noted that the temperature measurement system of Meter A-2939 was performing somewhat erratically and therefore the temperature measurements at the 183 m (600 ft) depth are of questionable validity. Also Meter A-2715 at the 153 m (500 ft) depth, although it showed temperature variations that fit the pattern of those from other meters, gave extremely low temperature values which do not appear reasonable. Thus, only four sets of valid temperature data are available.

The primary use of the temperature data would be to obtain a series of temperature profiles for use in deriving kinematic viscosities and mass densities of the water to be employed along the current velocities in getting Reynolds Numbers for estimating the drag coefficients and forces acting on the CWP. It is suggested that this task be held in abeyance until it is determined under just what conditions such calculations are to be made since mass processing of data with so many gaps may lead to erroneous conclusions.

6.2 CURRENT VELOCITY AND DIRECTION

The six illustrations in Appendix B show plots of current magnitude and direction at the six levels where the current meters were operational. In addition to speed and direction the U and V velocity components are shown in the two lower plots with the velocities given in centimeters per second plotted against time in Julian Days. These are the north-south and east-west components of the current velocities obtained by conversion of the velocity vectors and current directions recorded by each current meter. The top plot gives the magnitude of the resultant velocity vector and the next plot gives the current direction in degrees magnetic. The zero value represents magnetic north with the positive values to the east and negative values to the west. If required, a conversion to true north can be made using the compass rose shown in the upper corner of Figure 1.

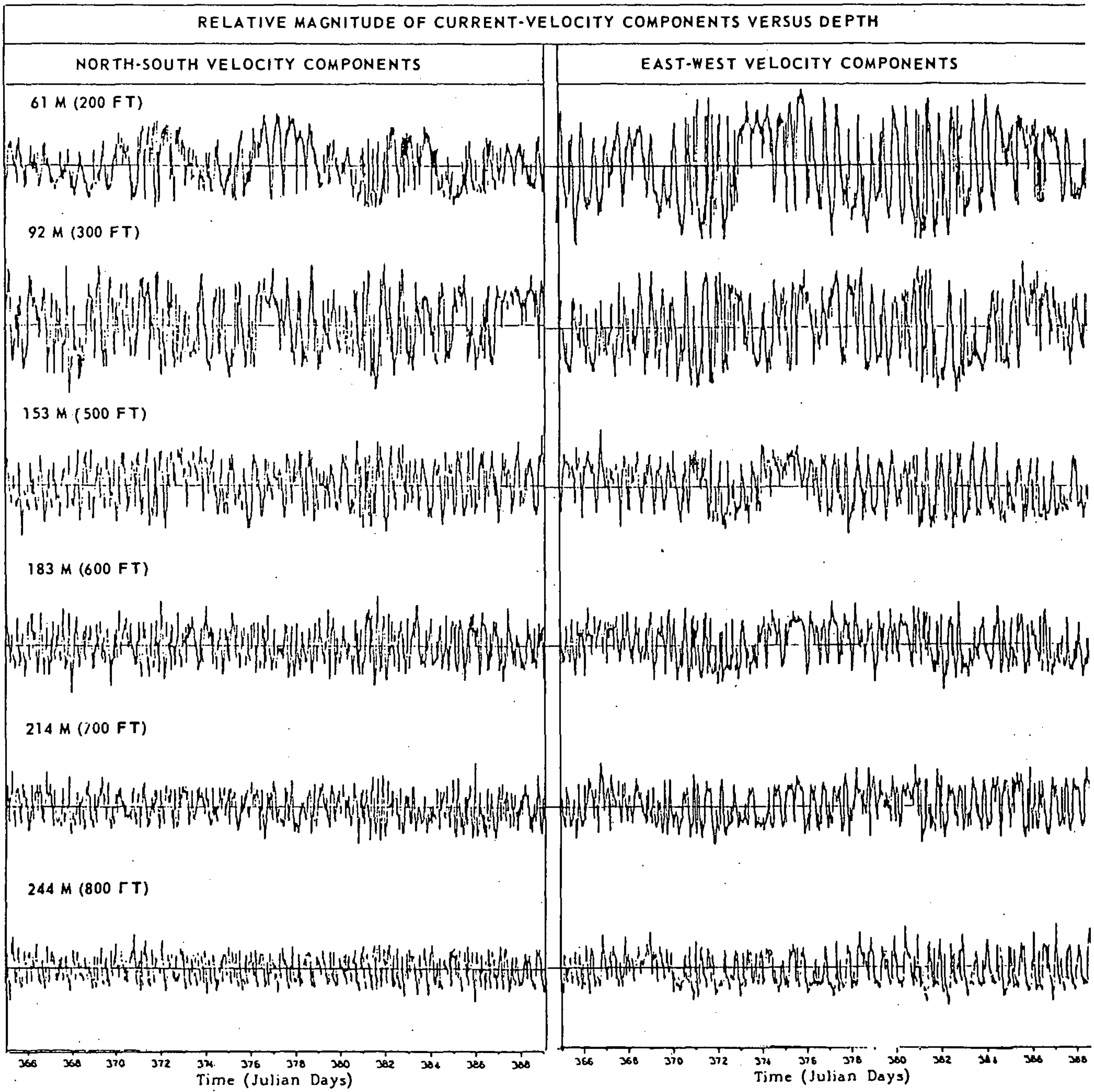


FIGURE 11

It is somewhat difficult to interpret from these plots any information that can be used directly in developing current profiles for the area of the CWP test site. More detailed analyses are needed to extract a workable picture of the actual current patterns as will be illustrated in subsequent sections. However, to illustrate the variation of current with time and with depth, Figure 11 is included. This shows the U and V components of the current velocity plotted against time for all six active current meters.

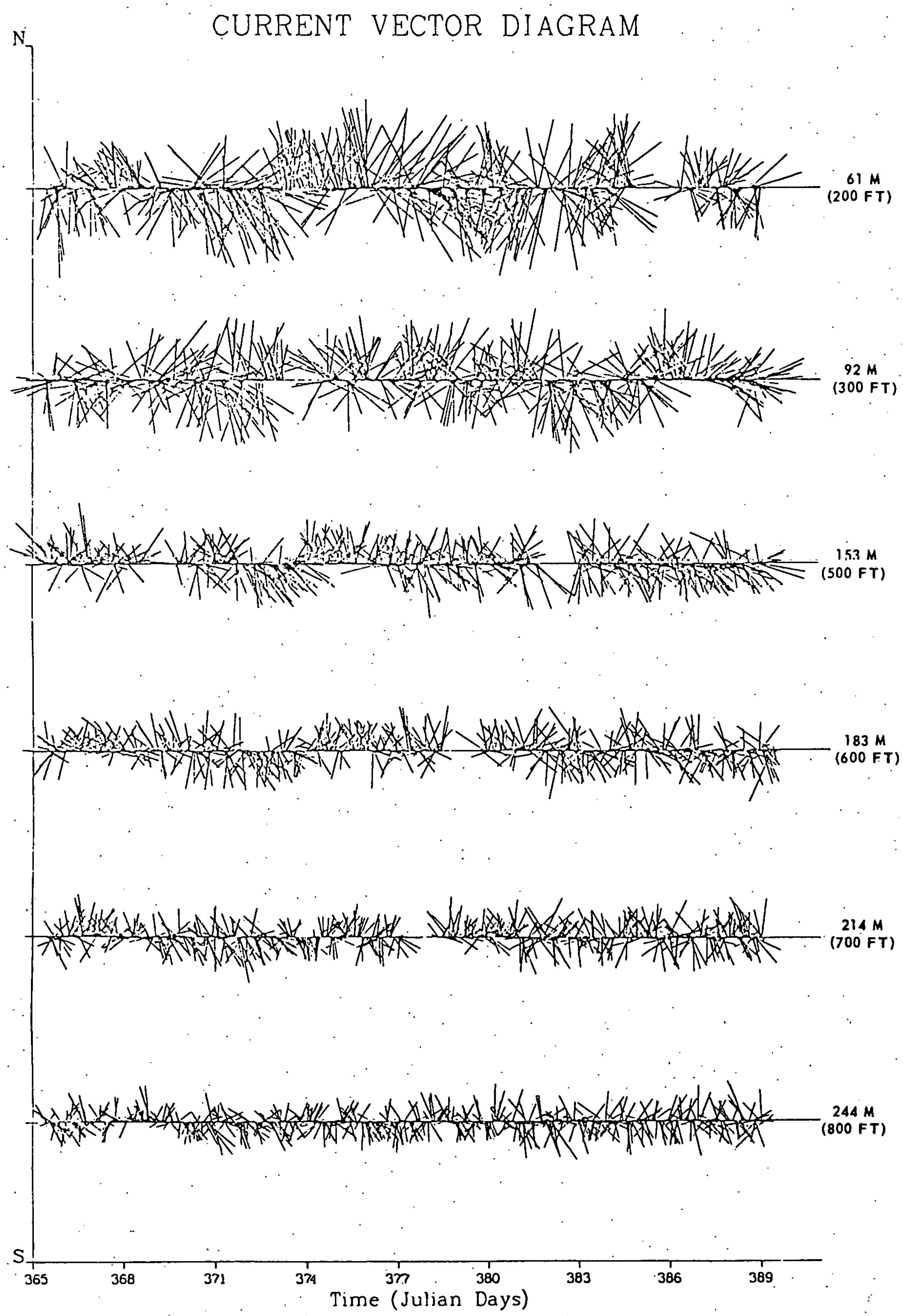
6.3 VECTOR DIAGRAMS OF CURRENT AT VARIOUS DEPTHS

The next series of analysis diagrams prepared by NAVOCEANO, Appendix C, comprise the magnitude of the resultant current velocities as averaged for each full hour of the total test period. The ordinate of each diagram is the north-south component of each velocity vector and the vectors are shown in their true angular orientation relative to the vertical north-south line. The horizontal spacing is one hour. It may be noted that some blank regions appear where no current vectors are shown. These are computer parity errors and not periods devoid of current. Since these current velocity vectors are all drawn to the same scale, the composite plot versus depth of Figure 12 gives a somewhat realistic version of the relative magnitude of the current from the surface to the bottom of the pipe.

Another way of displaying the current velocity magnitude and direction is to integrate the movement of an imaginary neutrally buoyant object as it moves with the subsurface currents at each level where measurements were made. This is done in the illustrations of Appendix D. Starting at 0000 on Julian Day 366, the ten minute distances travelled by the imaginary object are summarized for each 24-hour period in both the north-south direction and in the east-west direction. Each elemental ten minute distance is 600 times the measured mean velocity in centimeters per second; the summation of 144 of these elemental distances constitutes the movement per day in centimeters.

Referring to the first of these, which at 61 meters depth represents the highest velocities measured, the integrated travel seldom exceeds five kilometers per day. This is equivalent to an average current velocity of about 5.8 cm/sec or 0.11 knots. Actually the intermediate velocities may be considerably greater since this diurnal integration includes flow in opposite directions. This is the type of movement that would be obtained from 24-hour drift data; for actual velocities that might act upon the CWP at any instant of time, another form of analysis is required that deals with the oscillating flow phenomena.

Another interesting point is illustrated in these Progressive Vector Diagrams. Again referring to the Progressive Vector Diagram at the 61 meter depth, it can be seen that the total movement in the twenty days between Julian Days 369 and 389 is 23 kilometers, an average drift rate of only 1.33 cm/sec to the east. It can be concluded from this, and from the lesser total movements of the deeper measurements, that there was very little net



COMPOSITE OF CURRENT VECTOR DIAGRAMS AS A FUNCTION OF DEPTH

FIGURE 12

translational current over the time period of the measurements. The only significant currents are periodic and thus are related to tidal movements rather than wind drift,down sea wave action, or circulation within the Pacific Ocean basin.

6.4 SPECTRUM ANALYSIS OF CURRENT VELOCITIES

When dealing with oscillatory motions, a conventional means of analysis is to consider the total pattern as an infinite series of superimposed sinusoidal waves of different frequencies and amplitudes. A fourier analysis is then made of the composite pattern to approximate the spectrum of these sinusoidal components. This too was a part of the analysis performed by NAVOCEANO on the recorded current measurements.

In Appendix E, the spectra for the current velocity components in the north-south direction at each depth are plotted. The ordinates are the squares of the current amplitudes divided by the frequency; the abscissa for each spectrum is the frequency in cycles per hour. In Appendix F are similar plots for the east-west current velocity components.

In these velocity component spectra the frequencies of the predominant amplitudes have been identified as K_1 at 0.041 cycles per hour, f at 0.045 cycles per hour, and M_2 at 0.080 cycles per hour. These correspond to periods of 24.39, 22.22, and 12.50 hours respectively. Referring back to Figure 9 it can be seen that these periods identify quite precisely with the the daily and twice daily tidal cycles; this is evidence that the current movements are predominantly due to tidal action.

The figures in Appendix G are entitled Rotary Spectra. These are essentially plots of the resultant current vector amplitude against frequency. Each plot contains two spectra labelled CW and CCW. A clockwise spectrum is obtained when the phase angle of the east-west current velocity component sinusoid leads the north-south component sinusoid by approximately 90°. The counterclockwise spectrum is obtained when the V component lags the U component.

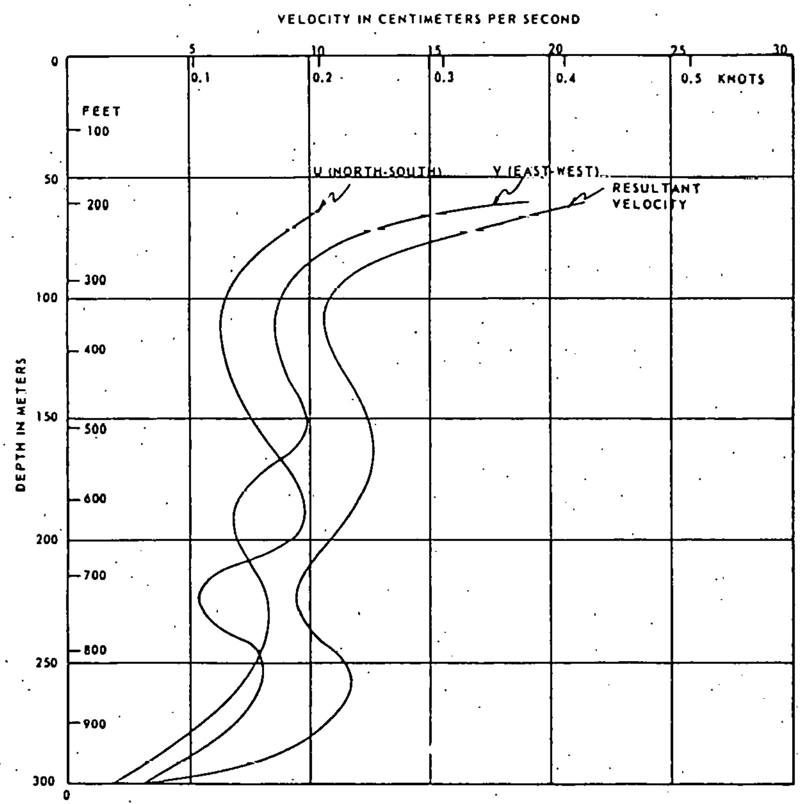
7.0 INTERPRETATION OF THE PLOTTED AND TABULATED DATA

In discussing the various analyses performed by NAVOCEANO it has been pointed out that the currents acting in the test site area are dominated almost completely by tidal flow. Since the current loading on the test CWP is proportional to the square of the current velocity, it is the maximum current encountered at each depth that is of primary concern. It can be noted in the preceding series of figures that this maximum value occurs consistently at the frequency M_2 which is the twice daily tidal variation. These values can therefore be extracted from the current spectra to develop a current profile. This is done in the following table.

DEPTH METERS	DEPTH FEET	U-VARIANCE $(CM/SEC)^2/CPH$	U-VARIANCE CM/SEC	V-VARIANCE $(CM/SEC)^2/CPH$	V-VARIANCE CM/SEC	RESULTANT CM/SEC
61	200	1300	10.20	4500	18.97	21.54
92	300	520	6.45	1000	8.94	11.03
153	500	810	8.05	1200	9.80	12.68
183	600	1200	9.80	600	6.93	12.00
214	700	380	5.51	800	8.00	9.72
244	800	750	7.75	800	8.00	11.14

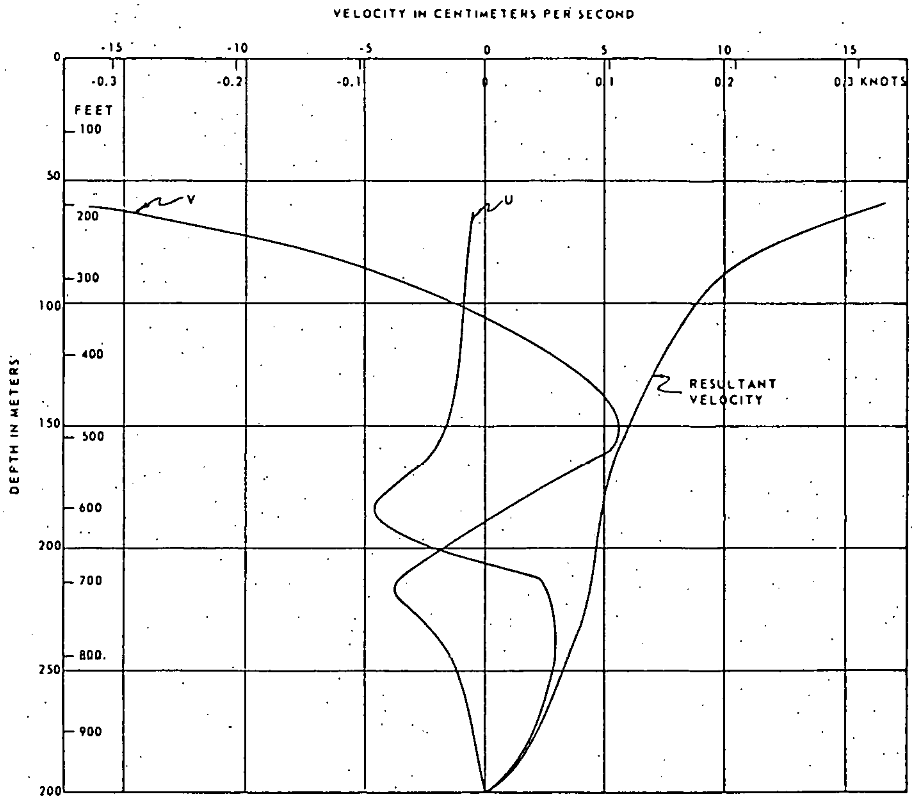
The U and V velocity components and the resultant current velocities obtained from this tabulation are plotted in Figure 13. This represents the best estimate of the maximum current profile at the test site that can be derived from the test data.

It should be recognized that Figure 13 represents the maximum flow velocities that can be acting upon the pipe and that these will not necessarily



MEAN CURRENT VELOCITIES VERSUS DEPTH FOR DECEMBER-JANUARY TEST PERIOD OFF SANTA CATALINA

FIGURE 13

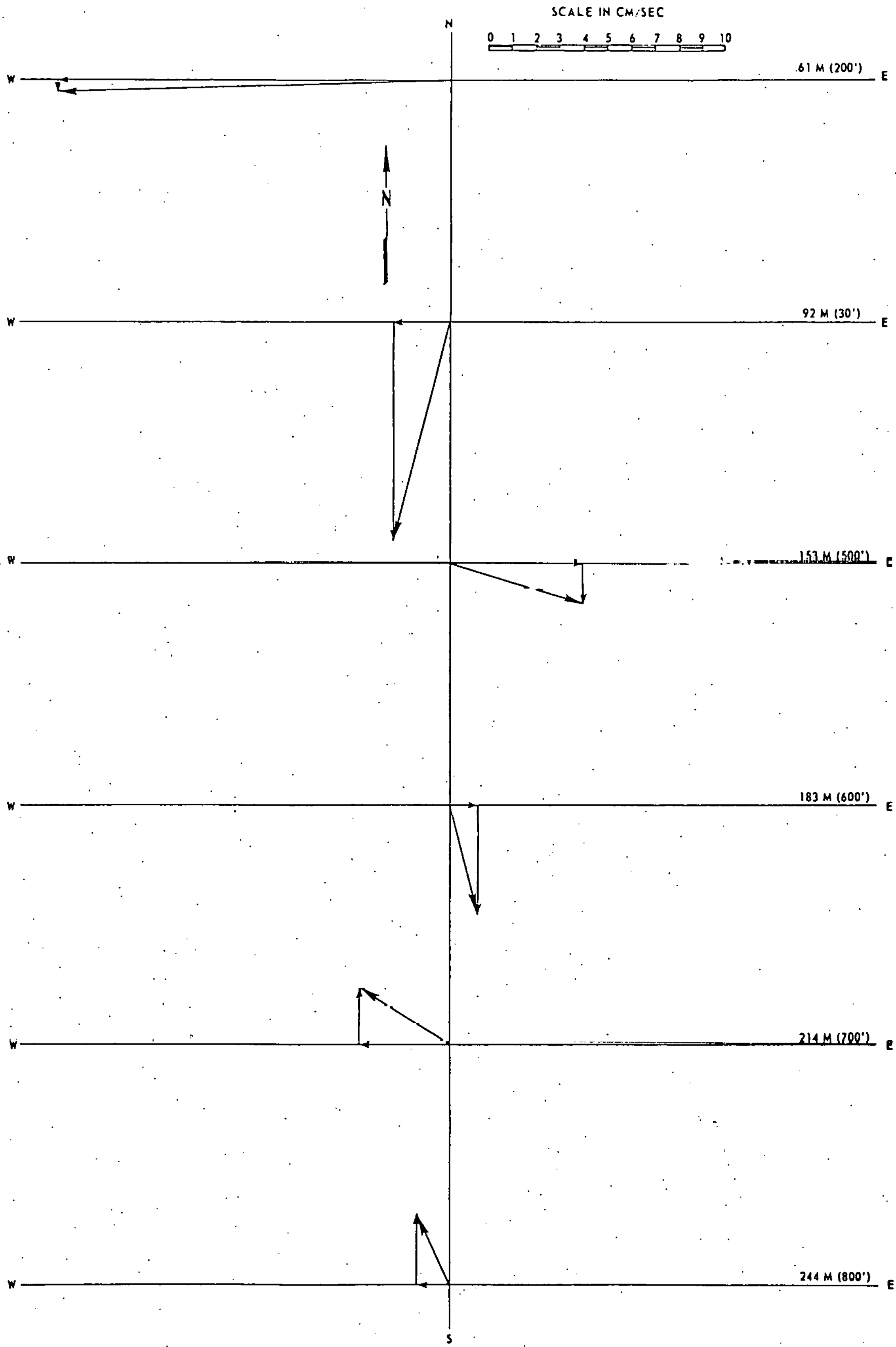


MEAN VELOCITIES VERSUS DEPTH FOR ONE HOUR PERIOD CENTERED AT 23 HOURS AFTER START OF MEASUREMENTS

FIGURE 14

be imposed at any specific time nor will they all be acting in the same direction. As an example of the kinds of variations that may appear, averages for a single hour during the test period have been obtained for the north-south, east-west, and resultant velocities at the various depths. The particular period selected was one where the 61 meter depth east-west velocities approached the maximum in the westerly direction; this was a one hour period that occurred 23 hours after the measurement process was begun. The mean U and V components and the mean resultant velocity for this period are shown in Figure 14. It can be seen that these relatively instantaneous values vary considerably from the maximum velocities given in Figure 13.

It is also evident that the current flow is by no means all acting in the same direction from the top to the bottom of the CWP. At this particular point the east-west current is moving west at 16.5 cm/sec at the 61 m depth and is moving east at 5.5 cm/sec at the 153 m depth; at 214 m it again reverses direction. These changes of direction with depth are quite apparent in the current vector presentation of Figure 15. Each of these reversals creates a change in direction of the force acting on the CWP which in turn creates one or more bending moments in the pipe thus stressing the outer fibers of the



MEAN VELOCITY VECTORS AND RESULTANTS FOR ONE HOUR PERIOD
CENTERED AT 23 HOURS AFTER START OF MEASUREMENTS

FIGURE 15

pipe structure. To extract from the available data the maximum shear forces and bending moments acting on the CWP requires a considerably more detailed analysis than has been possible in this limited study.

It is quite evident that the east and west tidal flow, as it passes around Santa Catalina Island, generates a series of vortices in both horizontal and vertical planes that create a disturbed flow pattern in the area where the test CWP was anchored. The mean resultant flow velocity magnitude is a function of the ebbing and flowing of the tide during its diurnal cycles but the direction of flow at any given geographical position and at any specific depth is highly unpredictable.

The maximum current velocities plotted against depth in Figure 13 are considered to be reasonably valid for the test period, but it should be expected that flows of these velocities might occur in opposite directions at many points in time; therefore, high levels of shear force and bending moment could have been applied to the test cold water pipe during the period when it was suspended in this environment.

8.0 REFERENCES

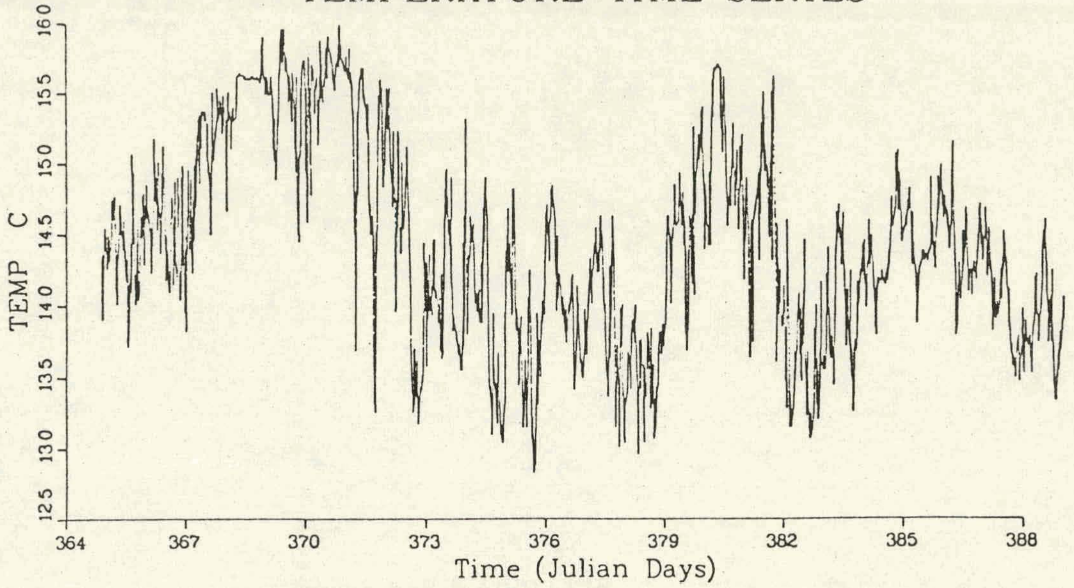
1. "Engineering Tasks Related to the 'Verification Test for OTEC Cold Water Pipe'", prepared for the Applied Physics Laboratory of The Johns Hopkins University (APL Contract No. 600833) by Deep Oil Technology, Inc., June 21, 1978.

2. Project Execution Plan for OTEC Current Study, FPO-1(2), November 1978.

APPENDIX A

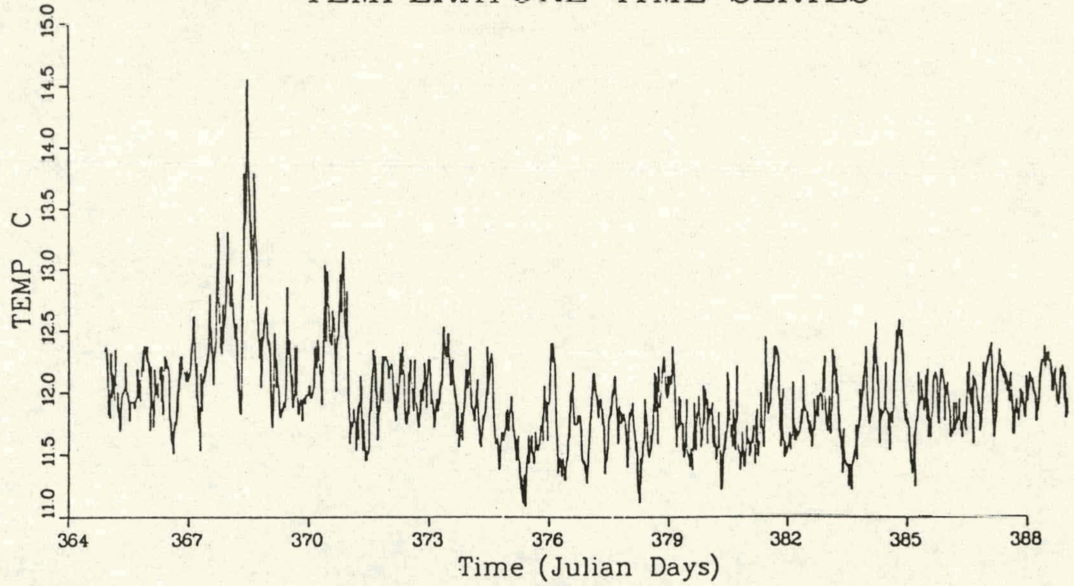
TEMPERATURE-TIME PLOTS FOR SIX ACTIVE CURRENT METERS

TEMPERATURE TIME SERIES

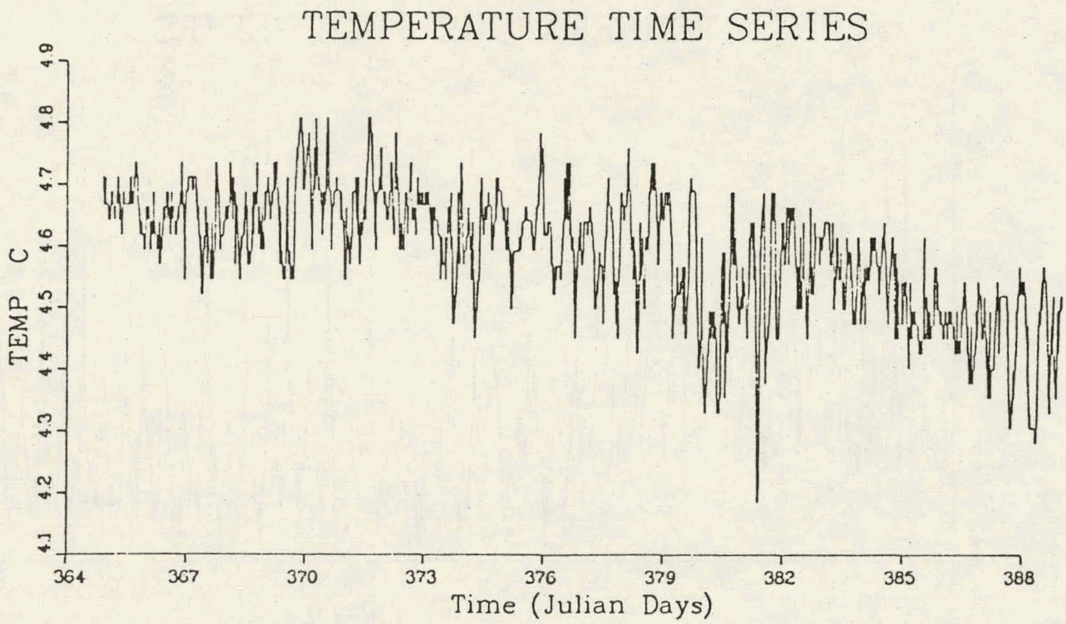


File:	AA1278	Array :	1
Meter:	A-2731	Depth :	61 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979

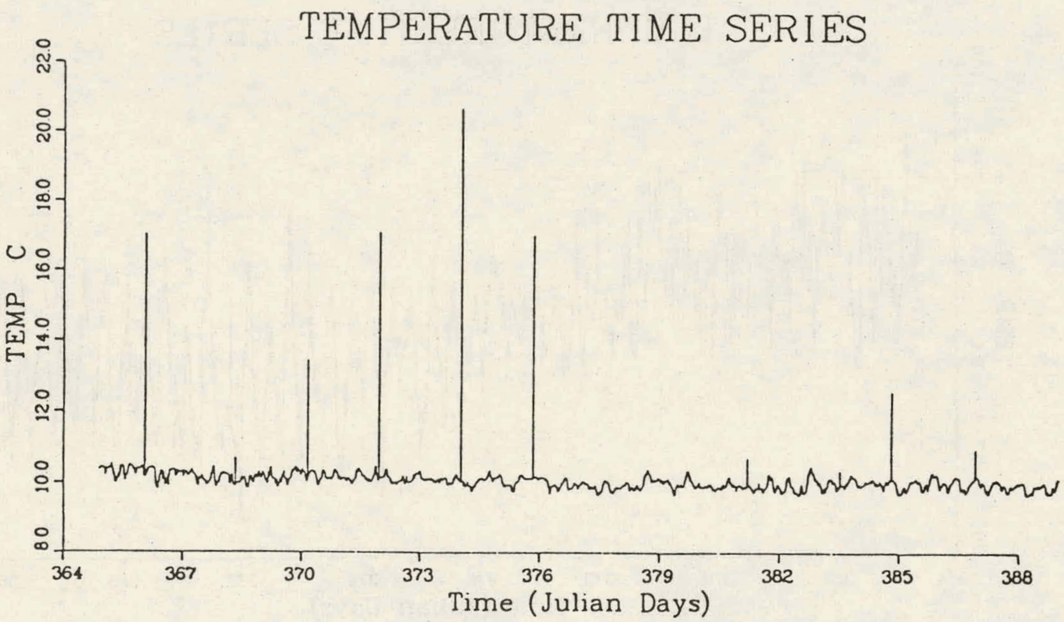
TEMPERATURE TIME SERIES



File:	AA1278	Array :	1
Meter:	A-2821	Depth :	92 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979

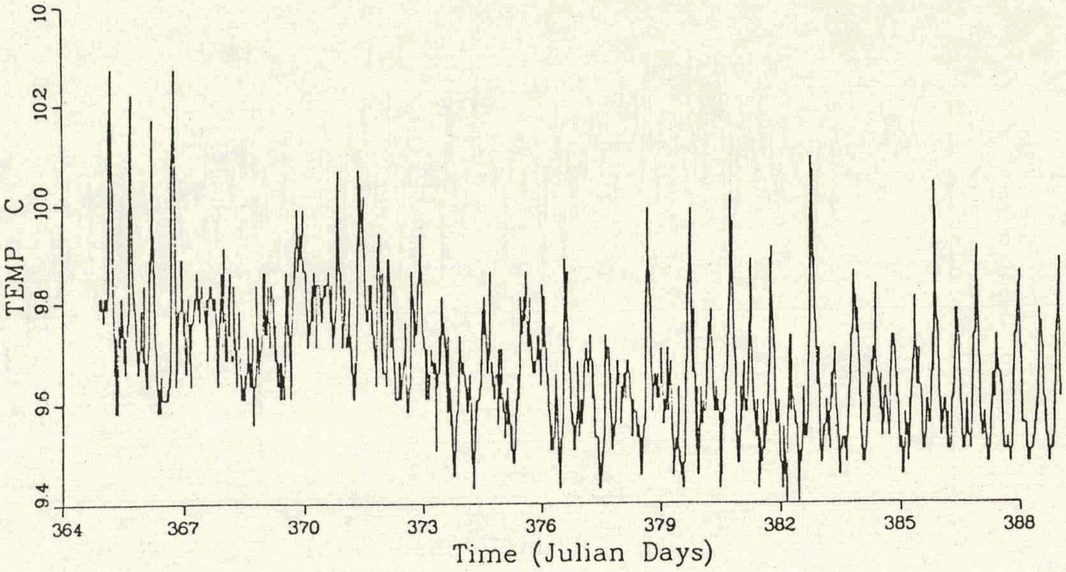


File:	AA1278	Array :	1
Meter:	A-2715	Depth :	153 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979



File:	AA1278	Array :	1
Meter:	A-2939	Depth :	183 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979

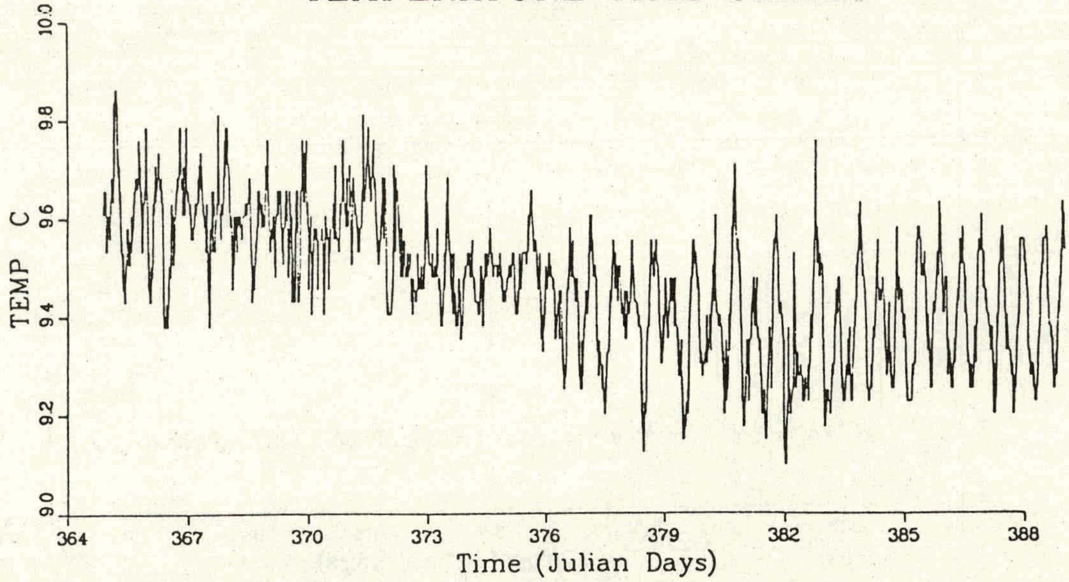
TEMPERATURE TIME SERIES



File: AA1278
Meter: A-2822
Latitude : 33-24-10 N
Longitude: 118-32-10 W

Array : 1
Depth : 214 M
Deployed : 30 DEC 1978
Recovered: 24 JAN 1979

TEMPERATURE TIME SERIES

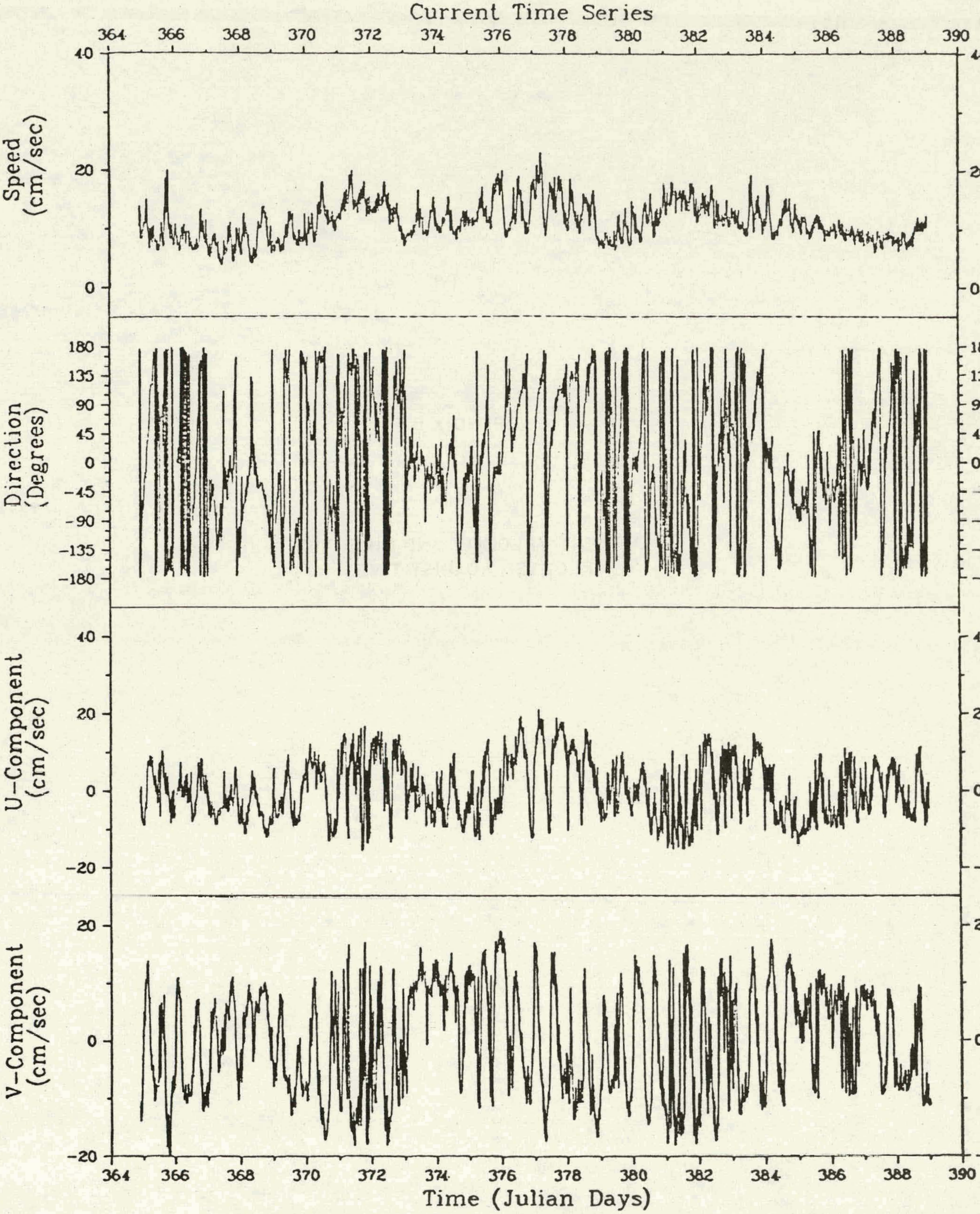


File: AA1278
Meter: A-2617
Latitude : 33-24-10 N
Longitude: 118-32-10 W

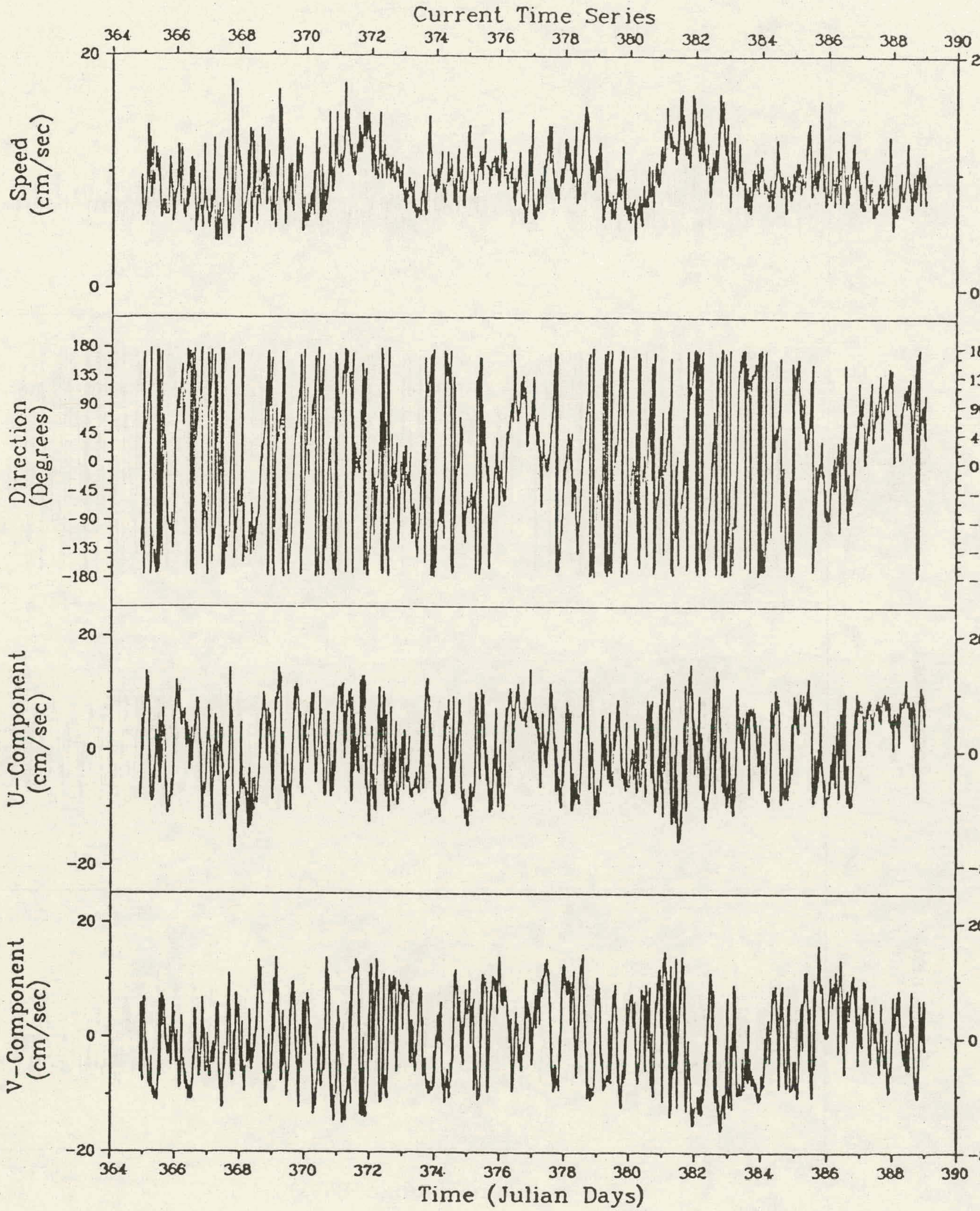
Array : 1
Depth : 244 M
Deployed : 30 DEC 1978
Recovered: 24 JAN 1979

APPENDIX B

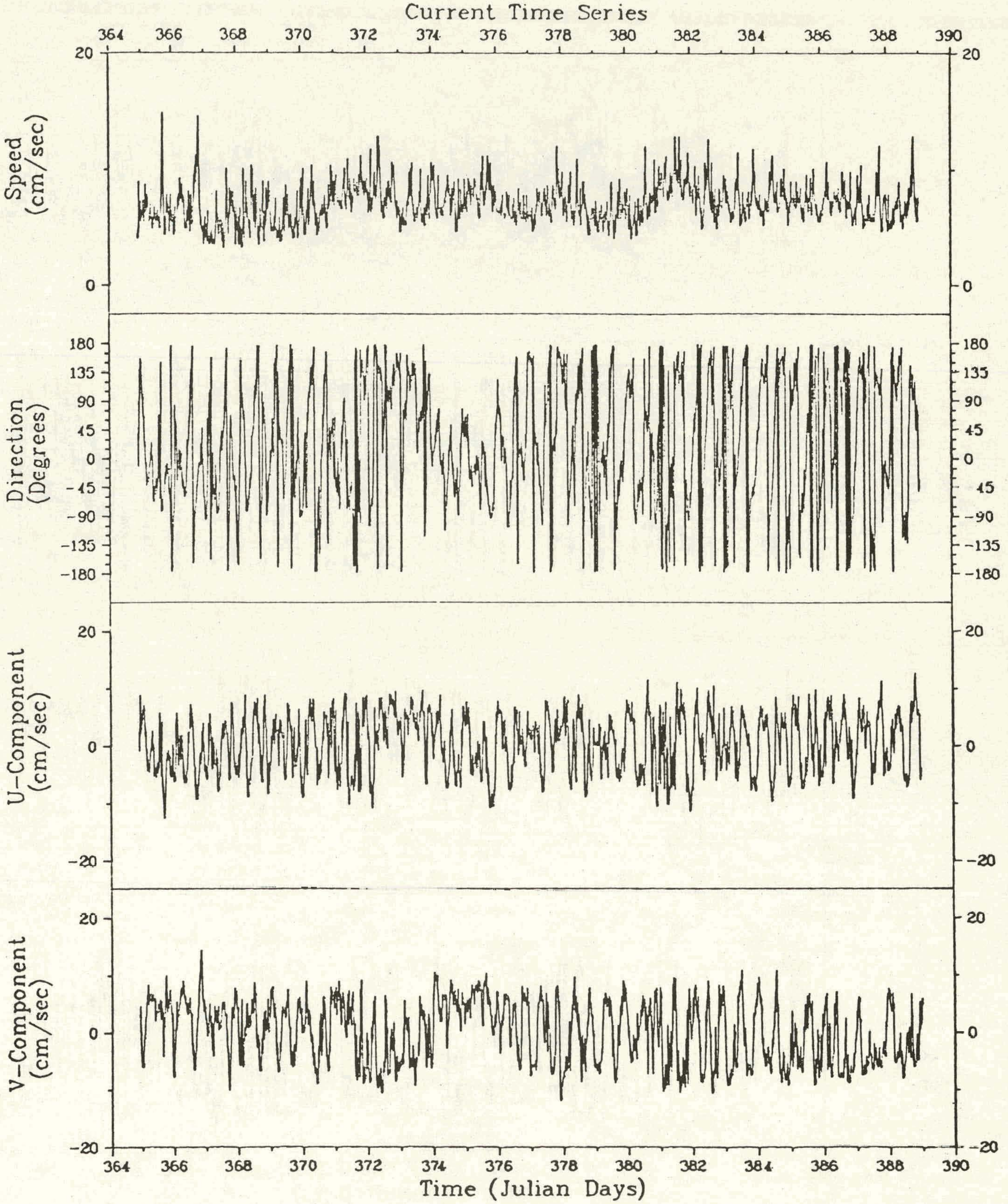
CURRENT VELOCITY AND DIRECTION PLOTTED AGAINST TIME



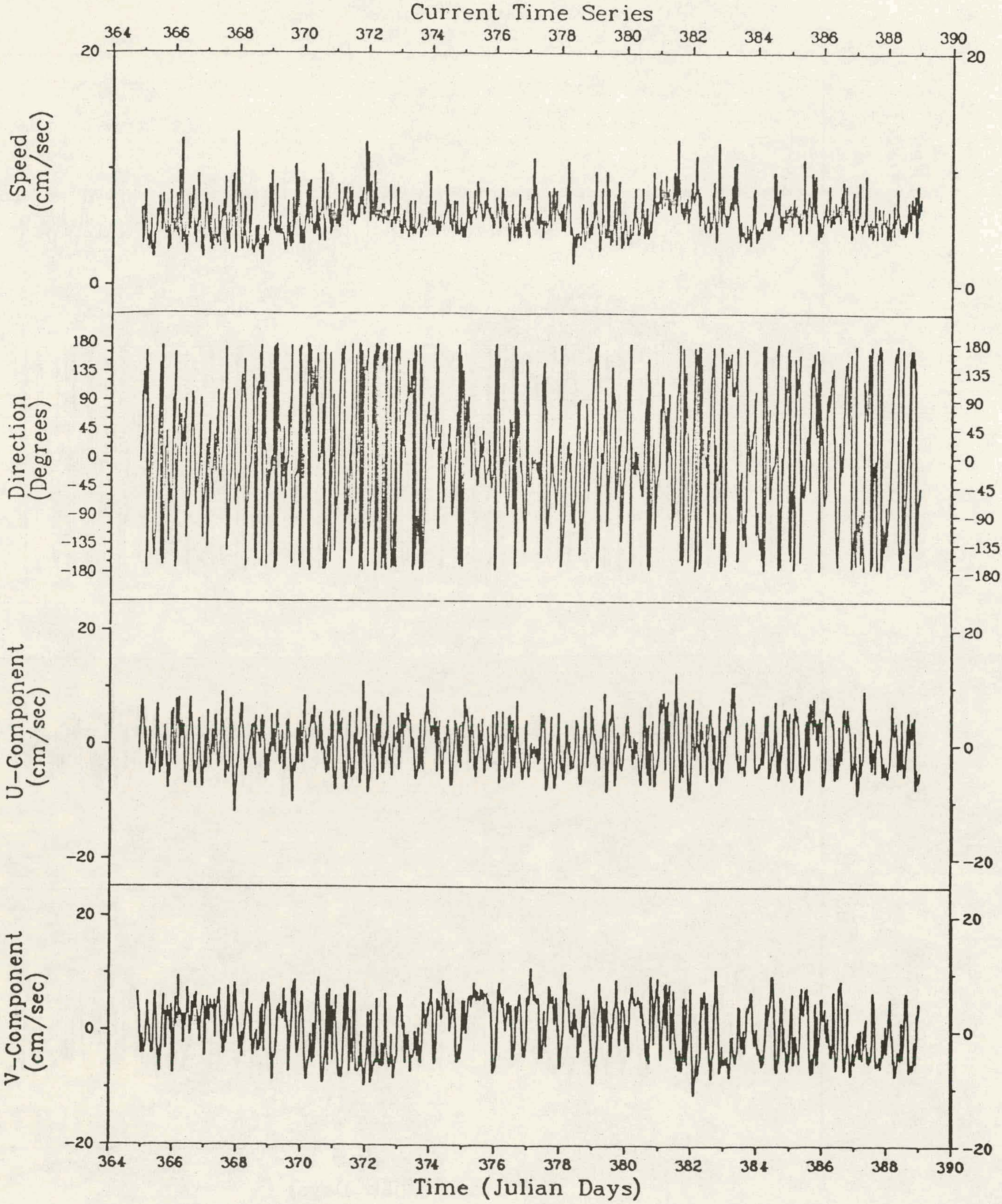
File:	AA1278	Array :	1
Meter:	A-2731	Depth :	61 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979



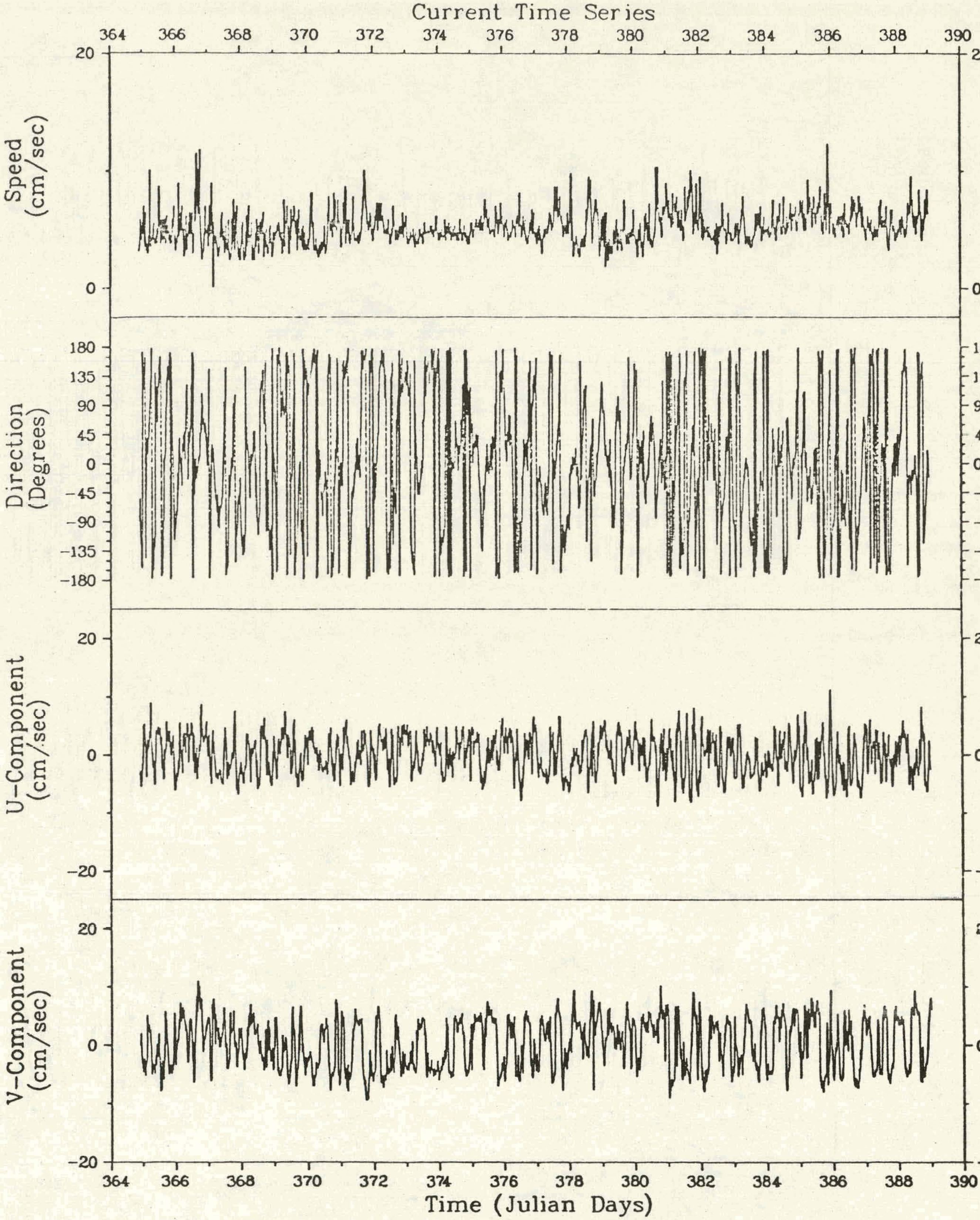
File:	AA1278	Array :	1
Meter:	A-2821	Depth :	92 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979



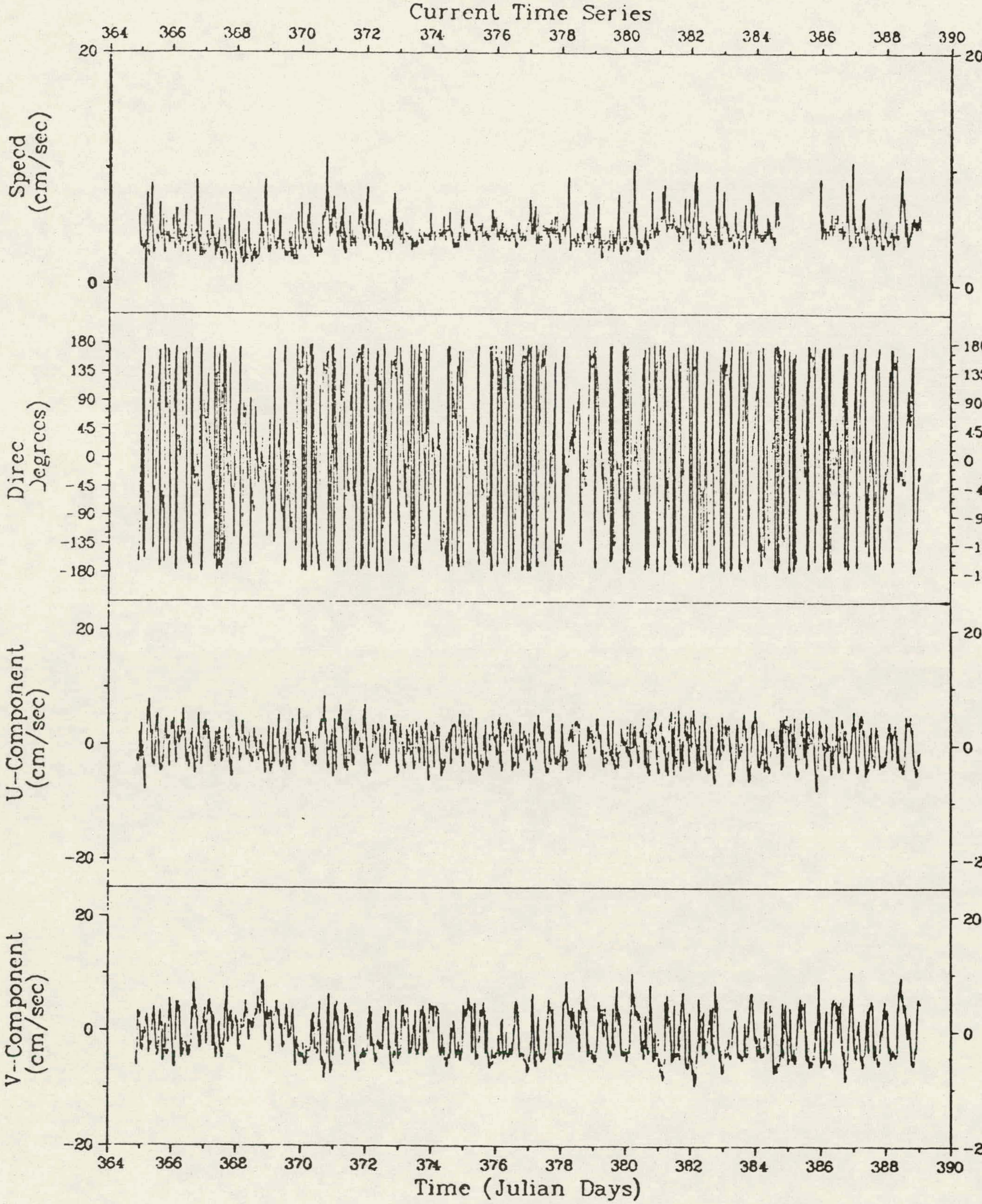
File:	AA1278	Array :	1
Meter:	A-2715	Depth :	153 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979



File:	AA1278	Array :	1
Meter:	A-2939	Depth :	183 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979



File:	AA1278	Array :	1
Meter:	A-2822	Depth :	214 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979

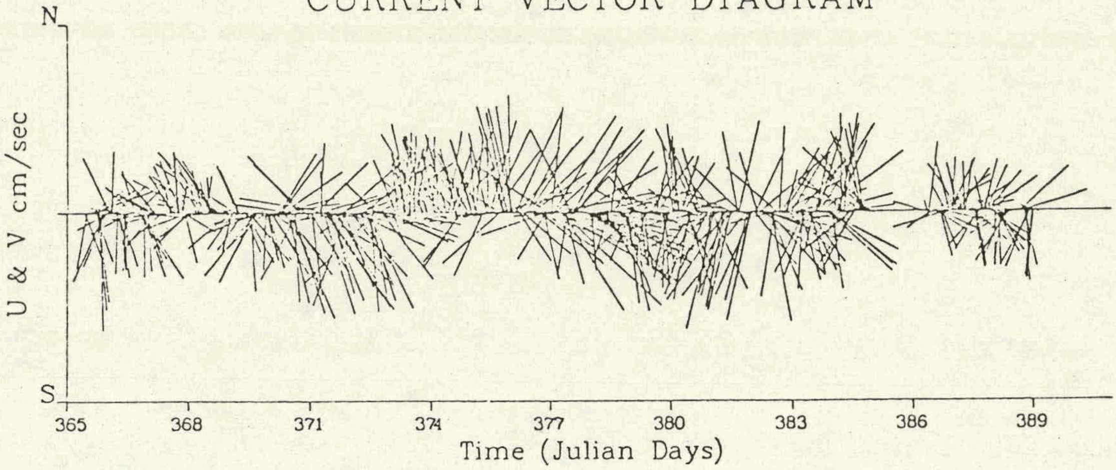


File:	AA1278	Array :	1
Meter:	A-2617	Depth :	244 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979

APPENDIX C

CURRENT VECTOR DIAGRAMS
PLOTTED AGAINST TIME

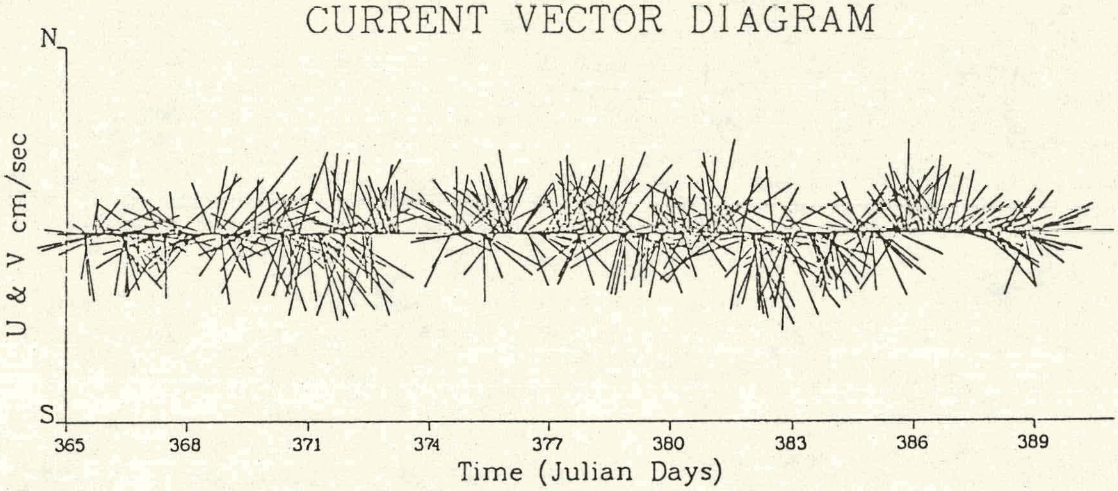
CURRENT VECTOR DIAGRAM



Scale: 300 cm/sec

File:	AA1278	Array :	1
Meter:	A-2731	Depth :	61 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979
Time Interval:	1.0000 Hours		

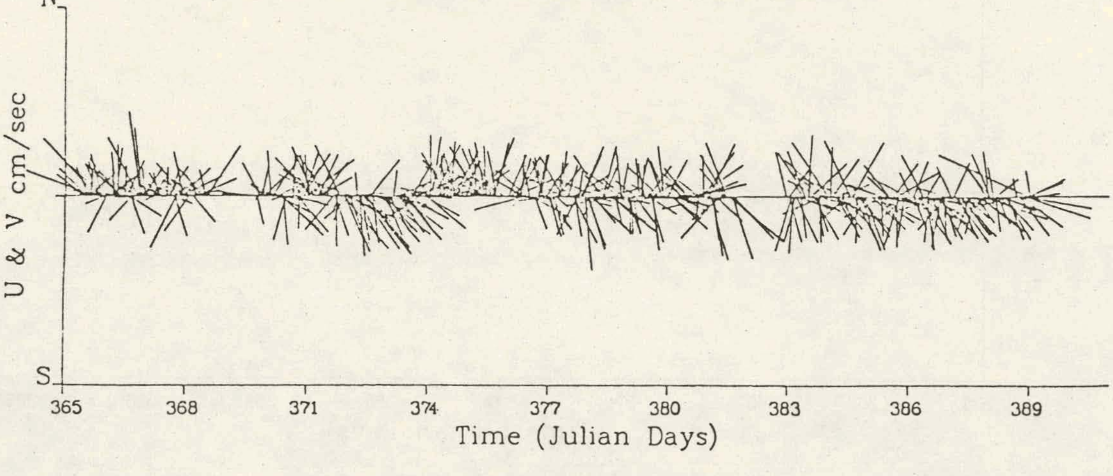
CURRENT VECTOR DIAGRAM



Scale: 300 cm/sec

File:	AA1278	Array :	1
Meter:	A-2821	Depth :	92 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979
Time Interval:	1.0000 Hours		

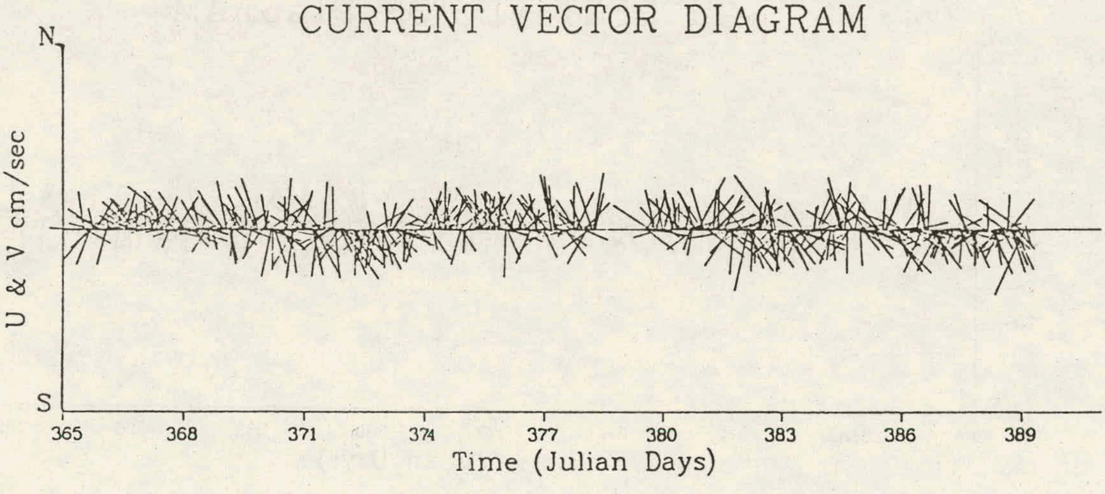
CURRENT VECTOR DIAGRAM



Scale: 30.0 cm/sec

File:	AA1278	Array :	1
Meter:	A-2715	Depth :	153 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979
Time Interval:	1.0000 Hours		

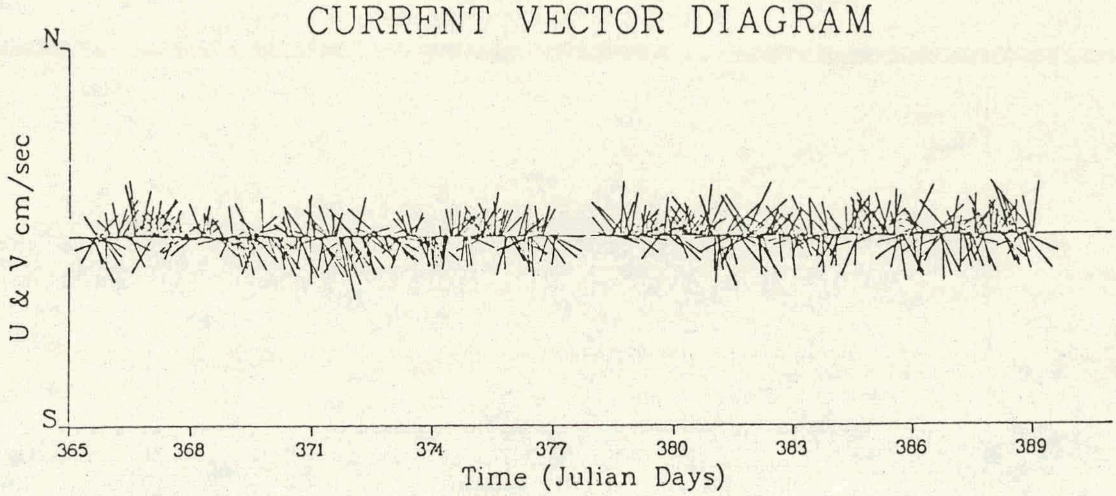
CURRENT VECTOR DIAGRAM



Scale: 30.0 cm/sec

File:	AA1278	Array :	1
Meter:	A-2939	Depth :	183 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979
Time Interval:	1.0000 Hours		

CURRENT VECTOR DIAGRAM

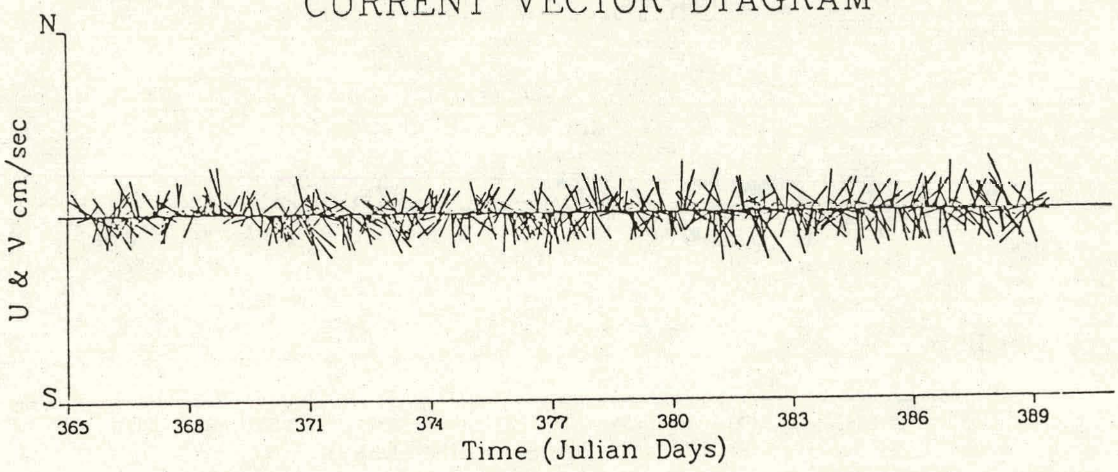


Scale: 30.0 cm/sec

File: AA1278
Meter: A-2822
Latitude : 33-24-10 N
Longitude: 118-32-10 W
Time Interval: 1.0000 Hours

Array : 1
Depth : 214 M
Deployed : 30 DEC 1978
Recovered: 24 JAN 1979

CURRENT VECTOR DIAGRAM



Scale: 30.0 cm/sec

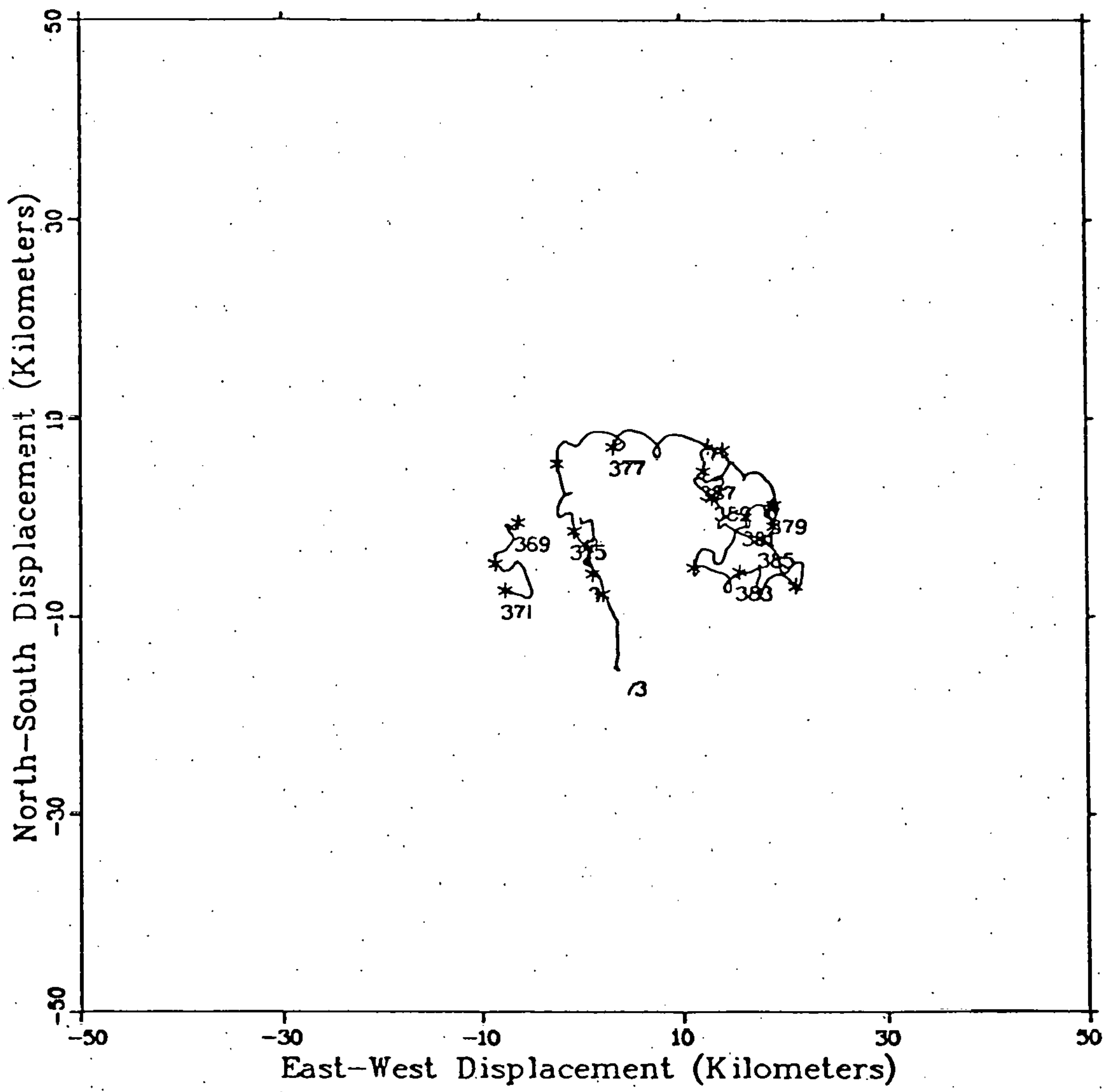
File: AA1278
Meter: A-2617
Latitude : 33-24-10 N
Longitude: 118-32-10 W
Time Interval: 1.0000 Hours

Array : 1
Depth : 244 M
Deployed : 30 DEC 1978
Recovered: 24 JAN 1979

APPENDIX D

PROGRESSIVE VECTOR DIAGRAMS

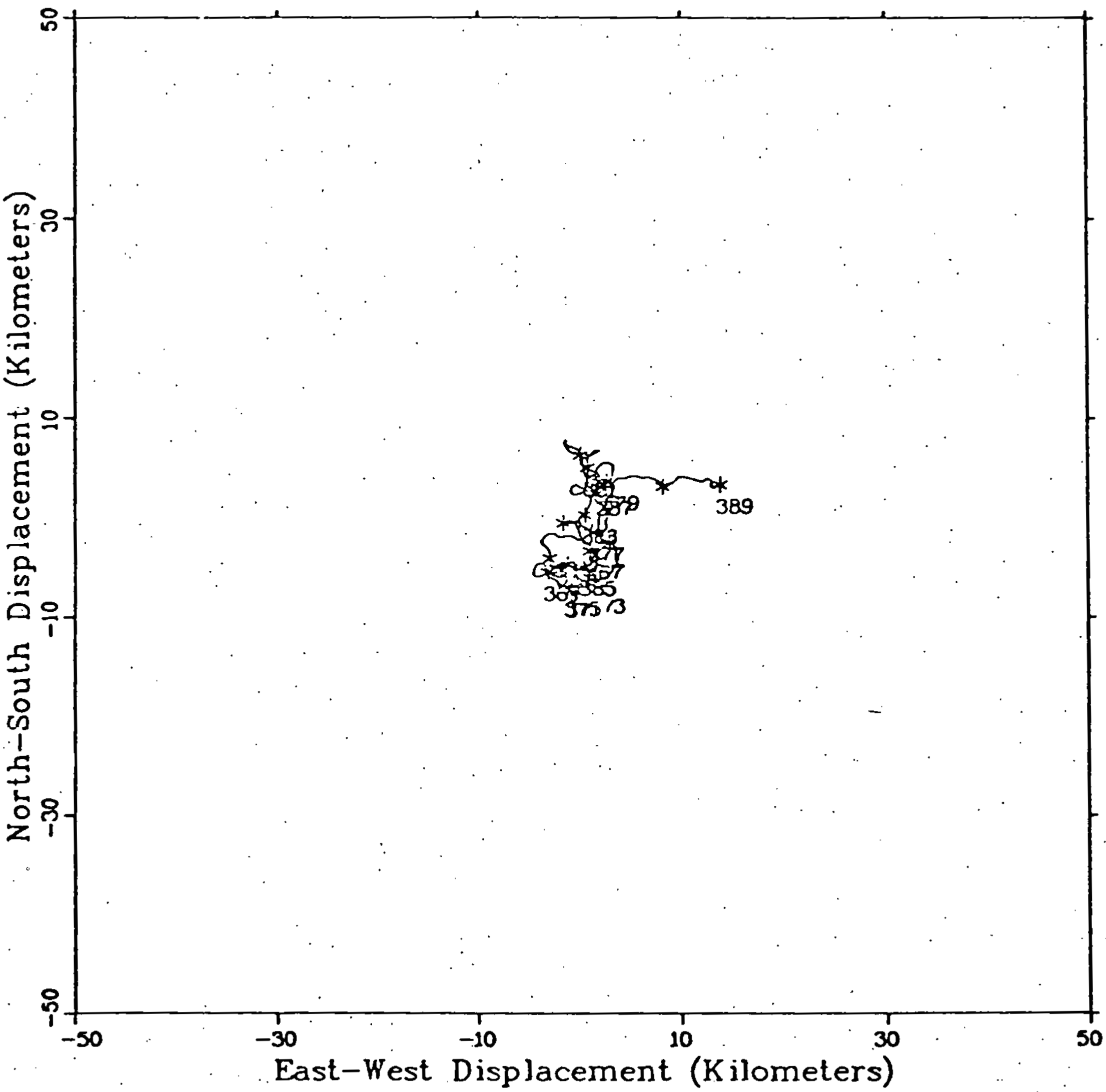
Progressive Vector Diagram



* Every 24 Hours Starting AT 0000, Julian Day 366

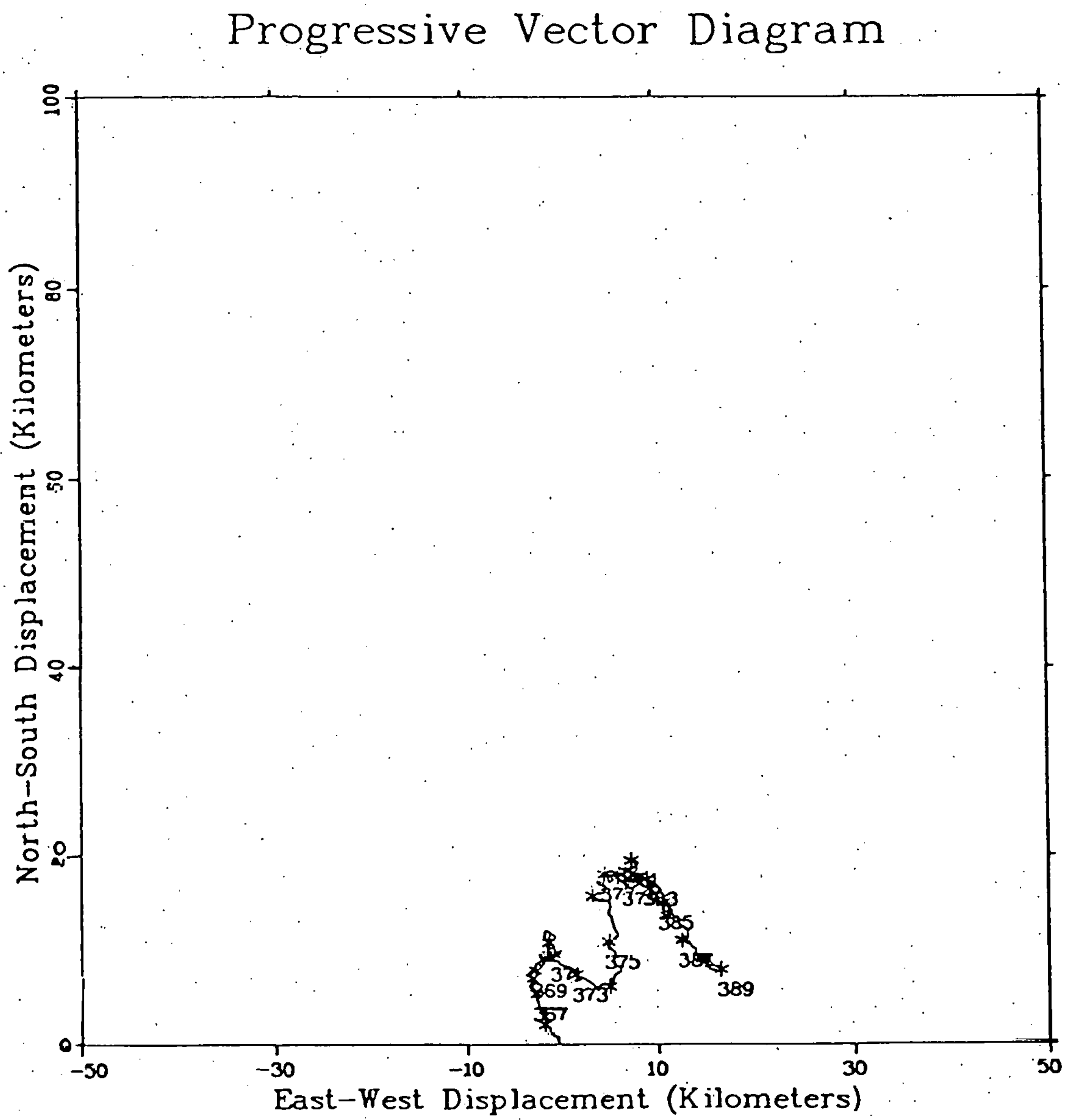
File:	AA1278	Array :	1
Meter:	A-2731	Depth :	61 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979

Progressive Vector Diagram



* Every 24 Hours Starting AT 0000, Julian Day 366

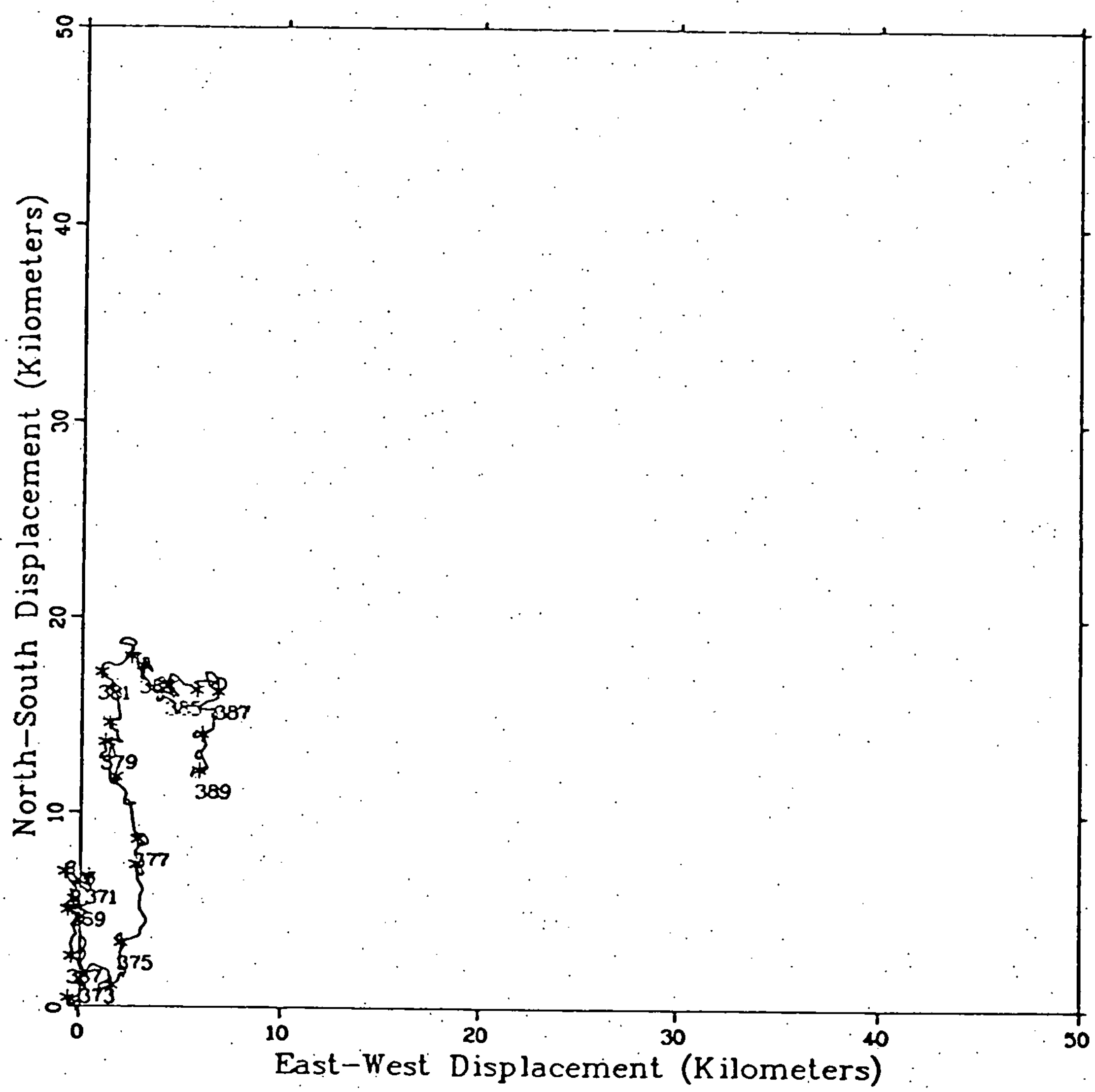
File:	AA1278	Array :	1
Meter:	A-2821	Depth :	92 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979



* Every 24 Hours Starting AT 0000, Julian Day 366

File:	AA1278	Array :	1
Meter:	A-2715	Depth :	153 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979

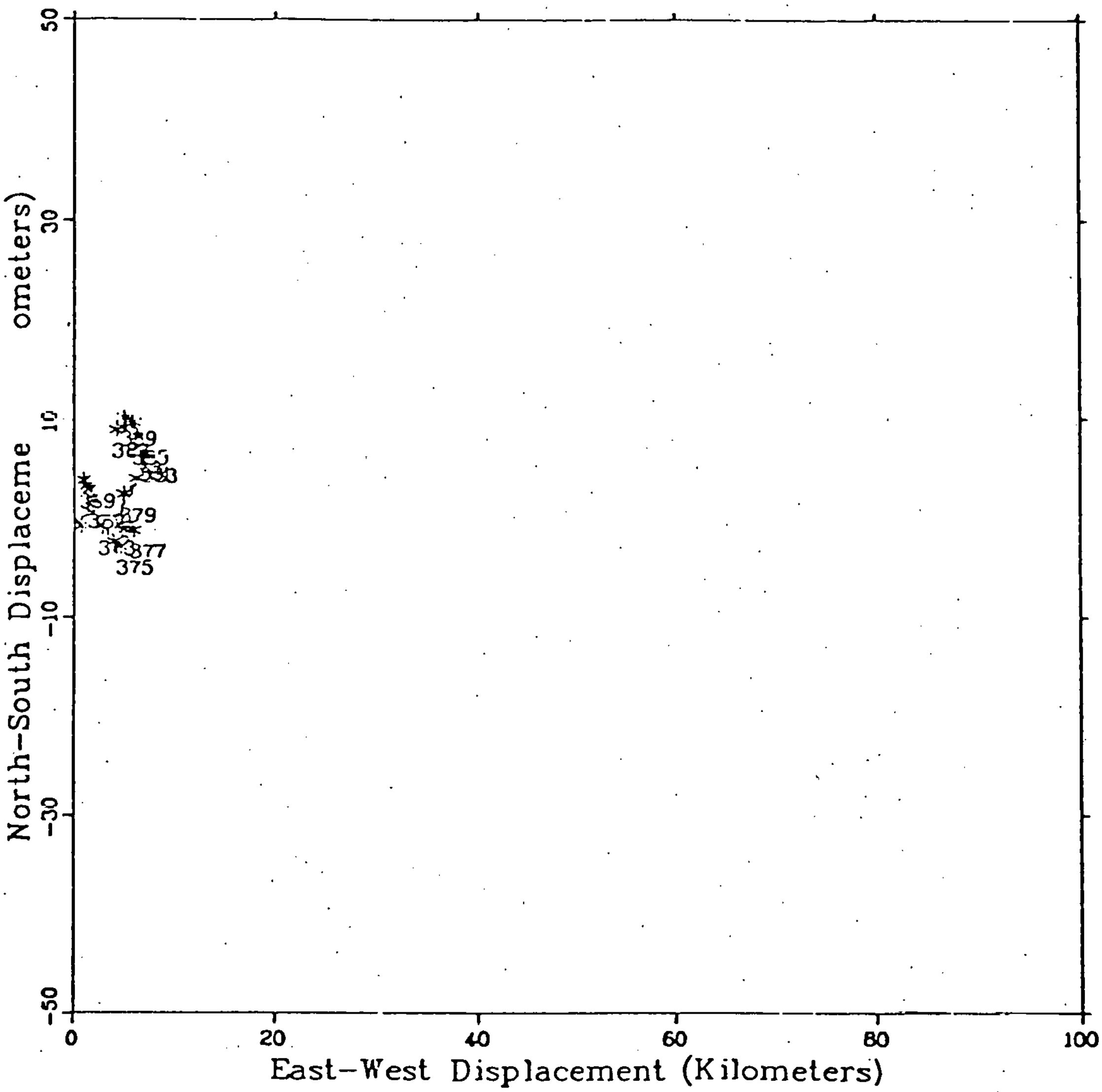
Progressive Vector Diagram



* Every 24 Hours Starting AT 0000, Julian Day 366

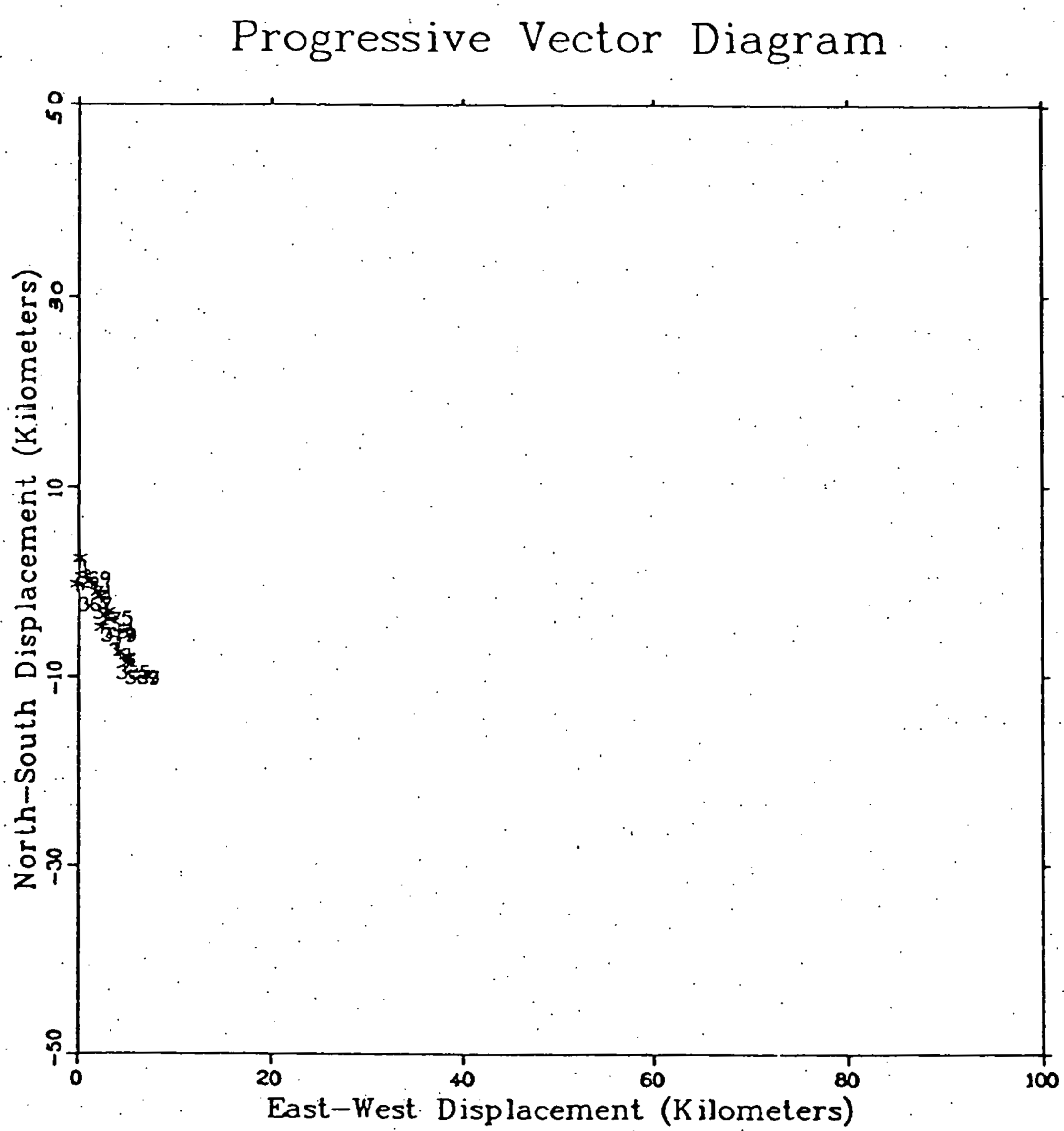
File:	AA1278	Array :	1
Meter:	A-2939	Depth :	183 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979

Progressive Vector Diagram



* Every 24 Hours Starting AT 0000, Julian Day 366

File:	AA1278	Array :	1
Meter:	A-2822	Depth :	214 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979



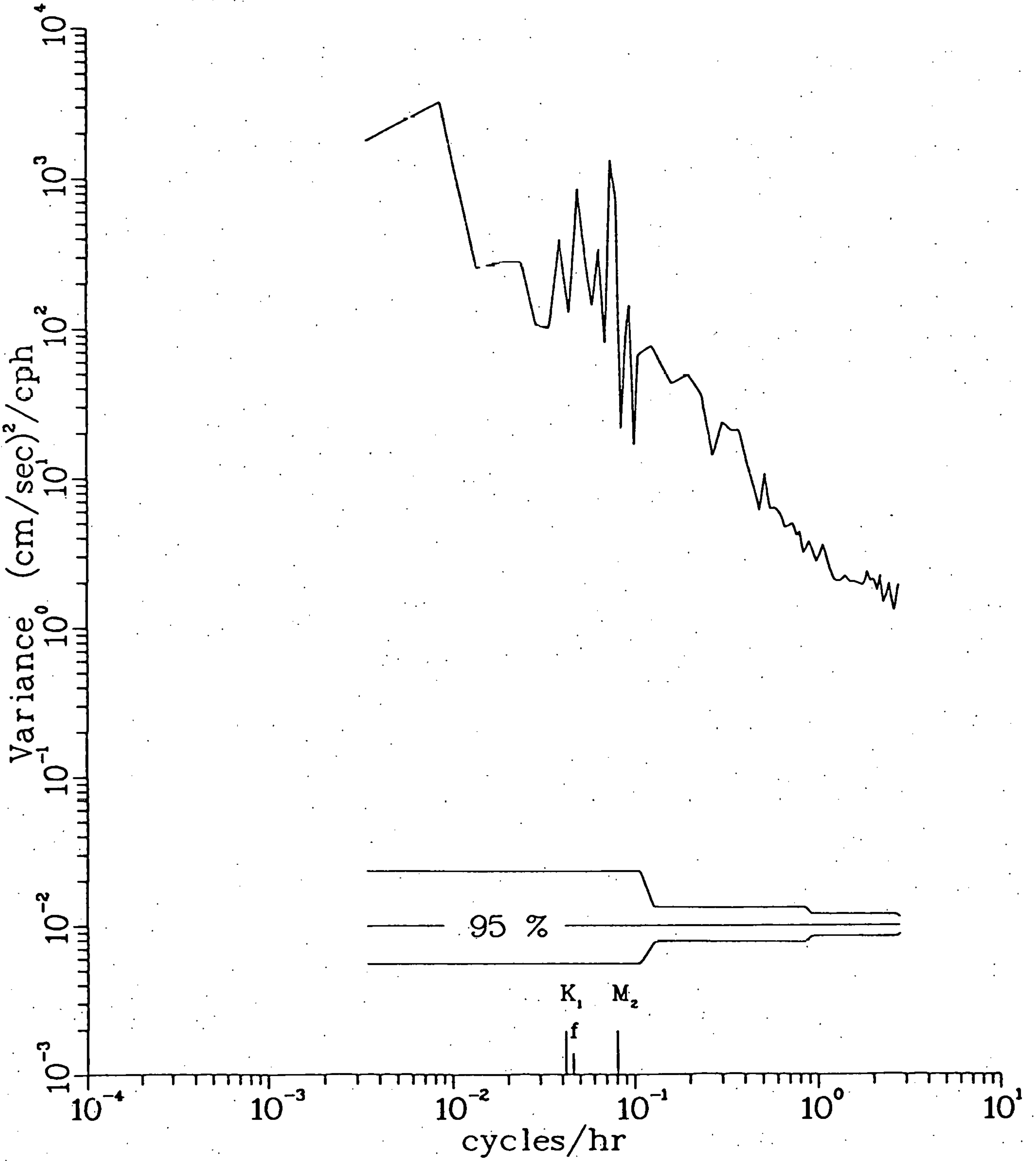
* Every 24 Hours Starting AT 0000, Julian Day 366

File:	AA1278	Array :	1
Meter:	A-2617	Depth :	244 M
Latitude :	33-24-10 N	Deployed :	30 DEC 1978
Longitude:	118-32-10 W	Recovered:	24 JAN 1979

APPENDIX E

NORTH-SOUTH CURRENT SPECTRA
U-COMPONENTS

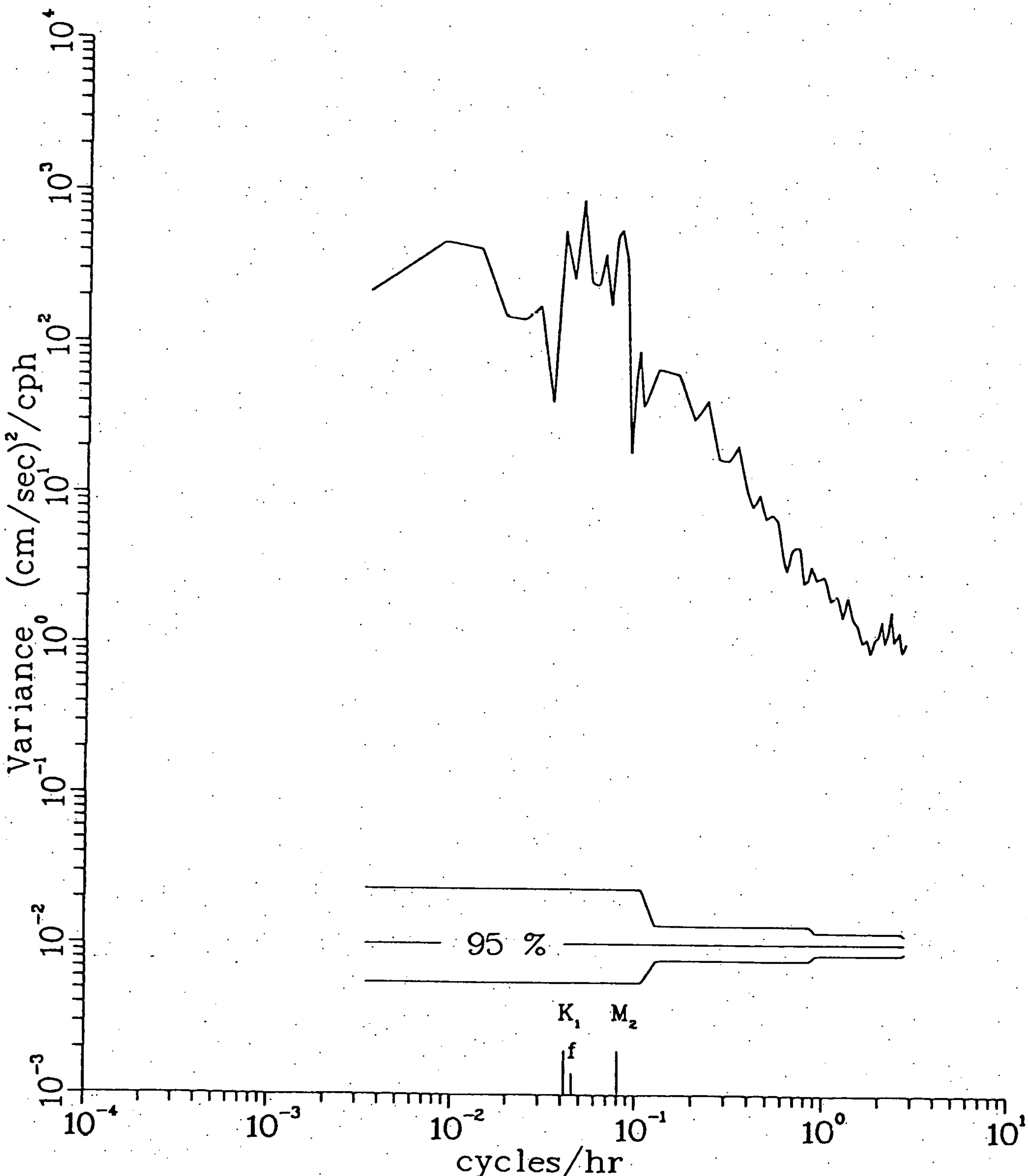
CURRENT SPECTRUM



Variable : U
File : AA1278
Meter : A-2731
Lat. : 33-24-10 N
Long. : 118-32-10 W

Array : 1
Depth : 61 M
Deployed : 30 DEC 1978
Recovered : 24 JAN 1979

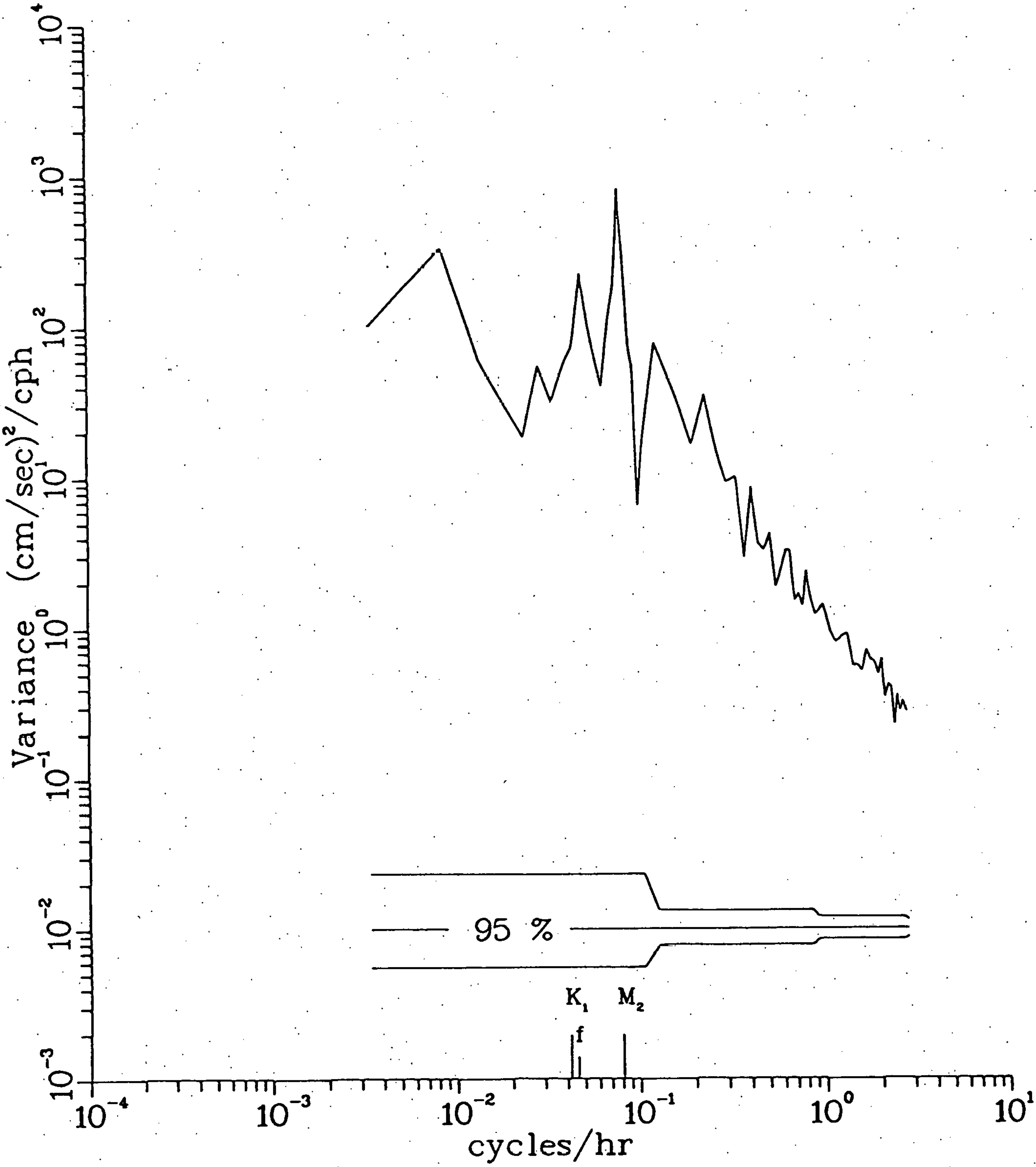
CURRENT SPECTRUM



Variable : U
File : AA1278
Meter : A-2821
Lat. : 33-24-10 N
Long. : 118-32-10 W

Array : 1
Depth : 92 M
Deployed : 30 DEC 1978
Recovered : 24 JAN 1979

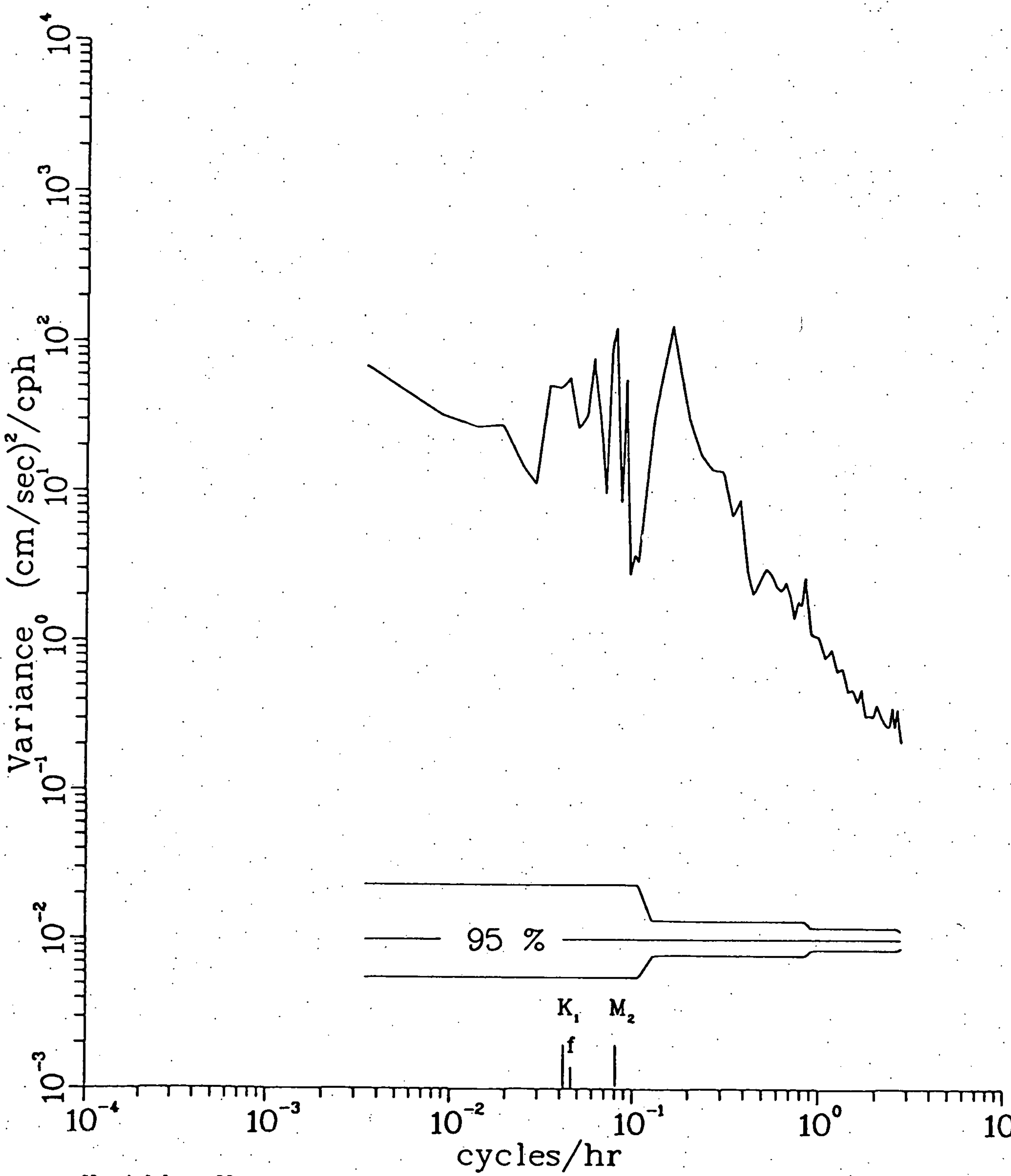
CURRENT SPECTRUM



Variable : U
File : AA1278
Meter : A-2715
Lat. : 33-24-10 N
Long. : 118-32-10 W

Array : 1
Depth : 153 M
Deployed : 30 DEC 1978
Recovered : 24 JAN 1979

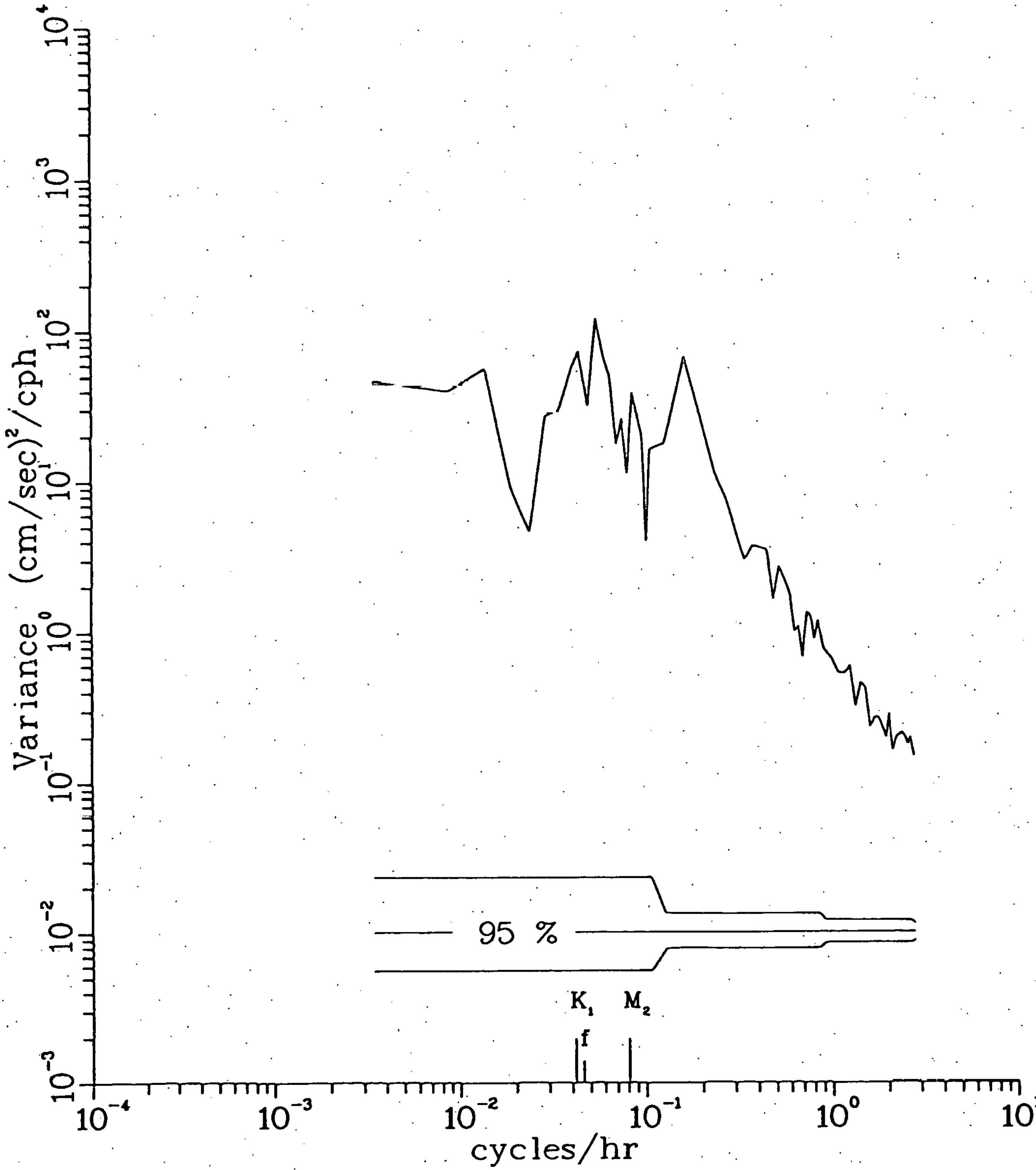
CURRENT SPECTRUM



Variable : U
File : AA1278
Meter : A-2939
Lat. : 33-24-10 N
Long. : 118-32-10 W

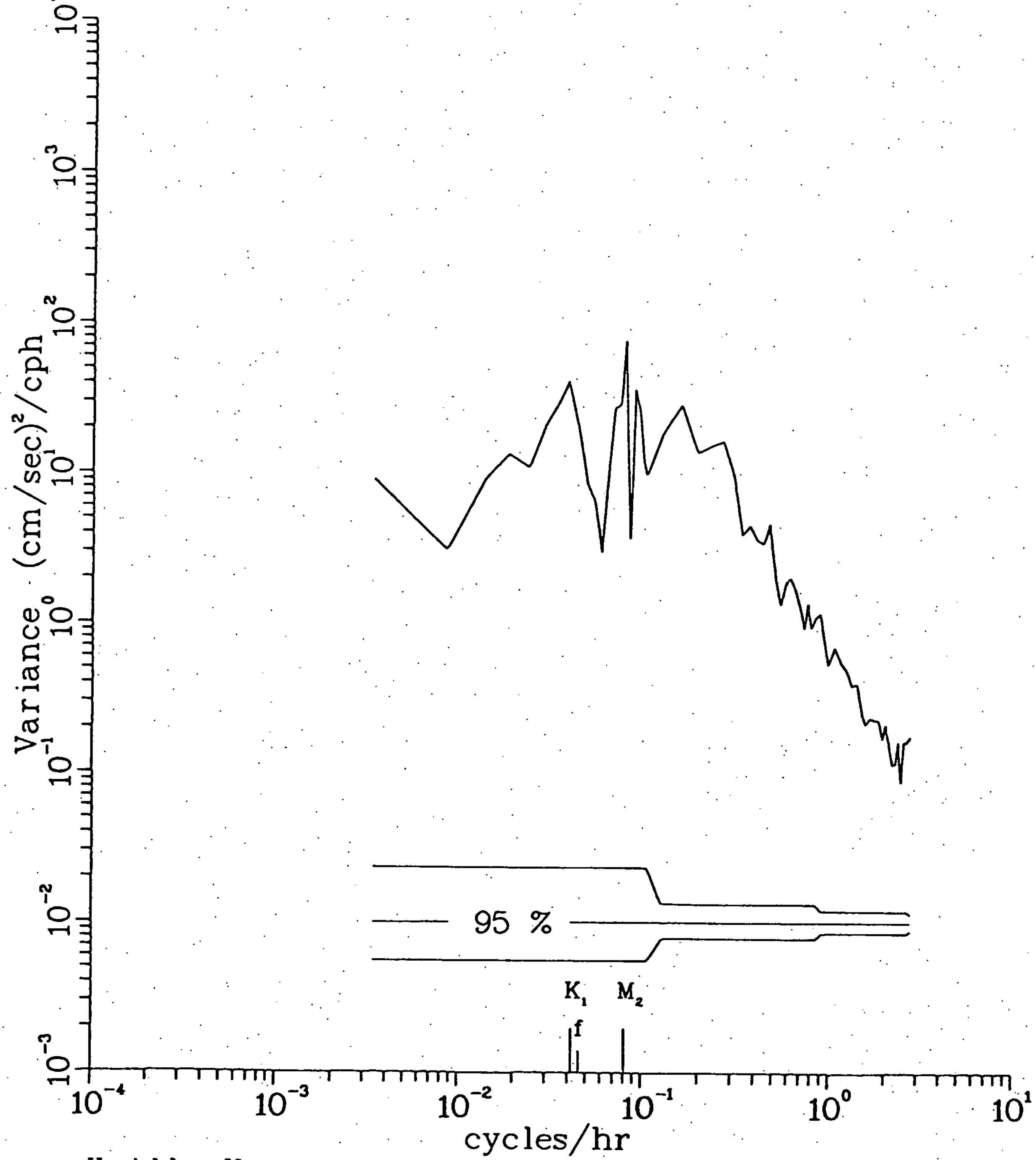
Array : 1
Depth : 183 M
Deployed : 30 DEC 1978
Recovered : 24 JAN 1979

CURRENT SPECTRUM



Variable :	U	Array :	1
File :	AA1278	Depth :	214 M
Meter :	A-2822	Deployed :	30 DEC 1978
Lat. :	33-24-10 N	Recovered :	24 JAN 1979
Long. :	118-32-10 W		

CURRENT SPECTRUM



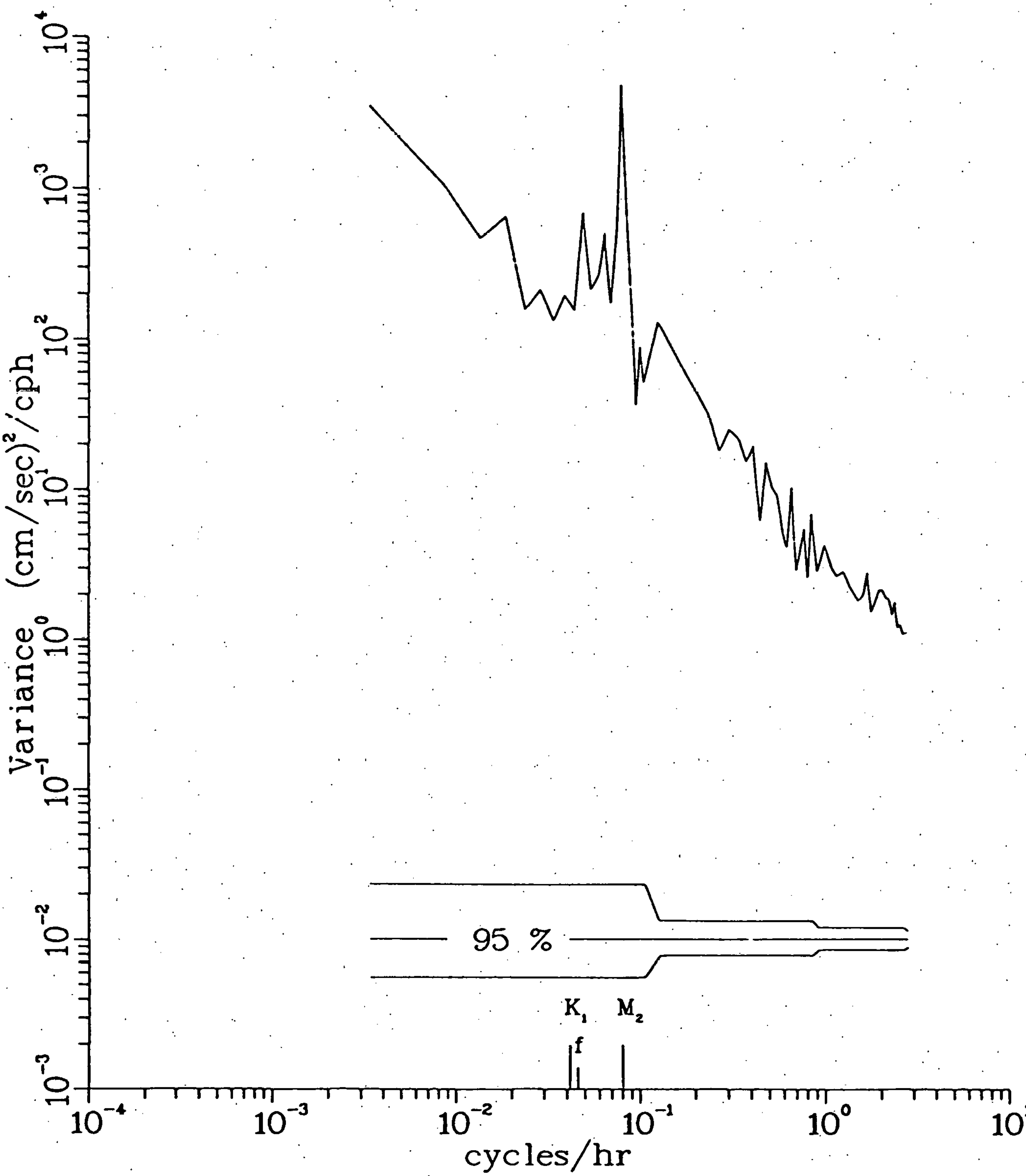
Variable : U
File : AA1278
Meter : A-2617
Lat. : 33-24-10 N
Long. : 118-32-10 W

Array : 1
Depth : 244 M
Deployed : 30 DEC 1978
Recovered : 24 JAN 1979

APPENDIX F

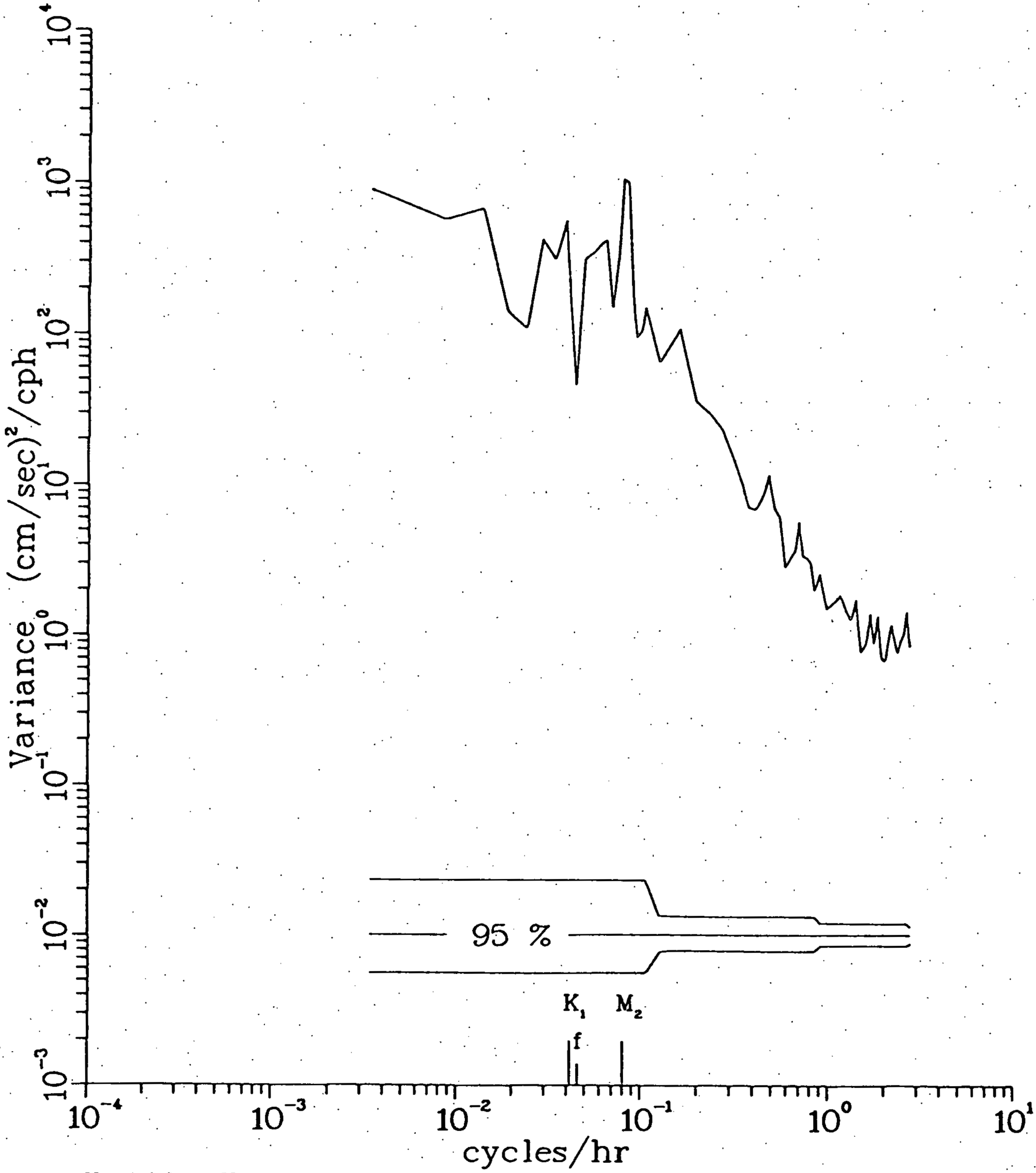
EAST-WEST CURRENT SPECTRA
V-COMPONENTS

CURRENT SPECTRUM



Variable :	V	Array :	1
File :	AA1278	Depth :	61 M
Meter :	A-2731	Deployed :	30 DEC 1978
Lat. :	33-24-10 N	Recovered :	24 JAN 1979
Long. :	118-32-10 W		

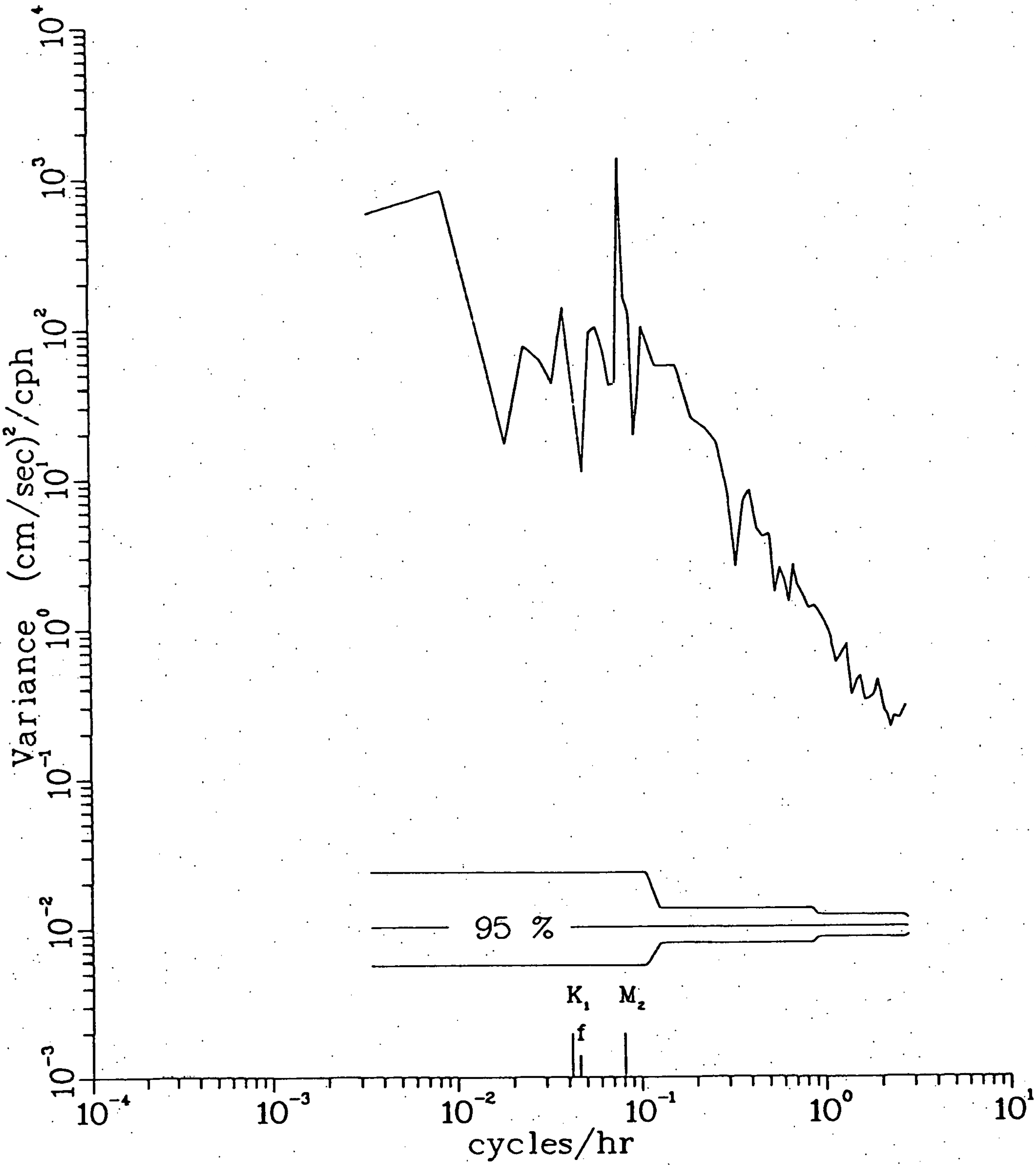
CURRENT SPECTRUM



Variable : V
File : AA1278
Meter : A-2821
Lat. : 33-24-10 N
Long. : 118-32-10 W

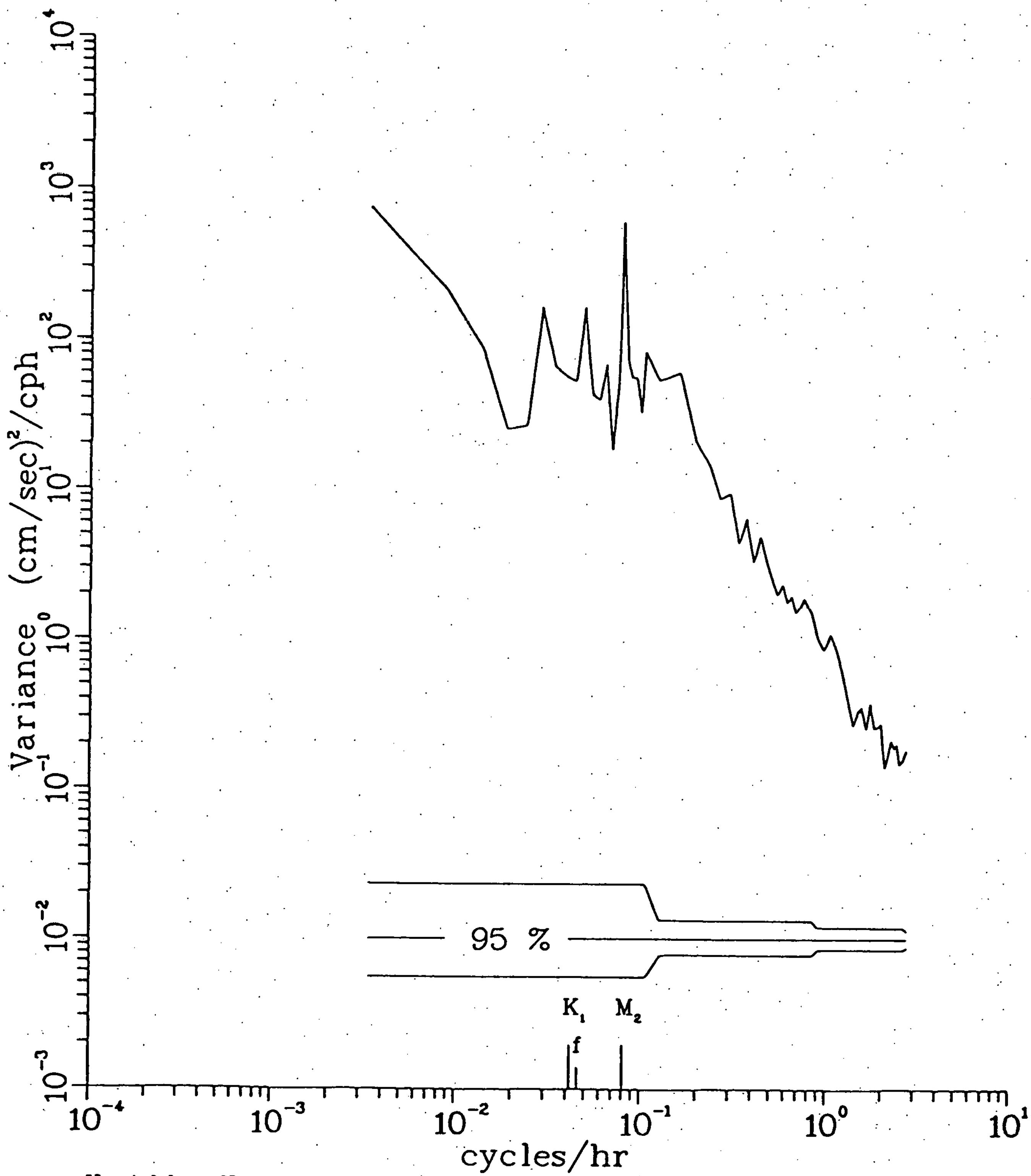
Array : 1
Depth : 92 M
Deployed : 30 DEC 1978
Recovered : 24 JAN 1979

CURRENT SPECTRUM



Variable :	V	Array :	1
File :	AA1278	Depth :	153 M
Meter :	A-2715	Deployed :	30 DEC 1978
Lat. :	33-24-10 N	Recovered :	24 JAN 1979
Long. :	118-32-10 W		

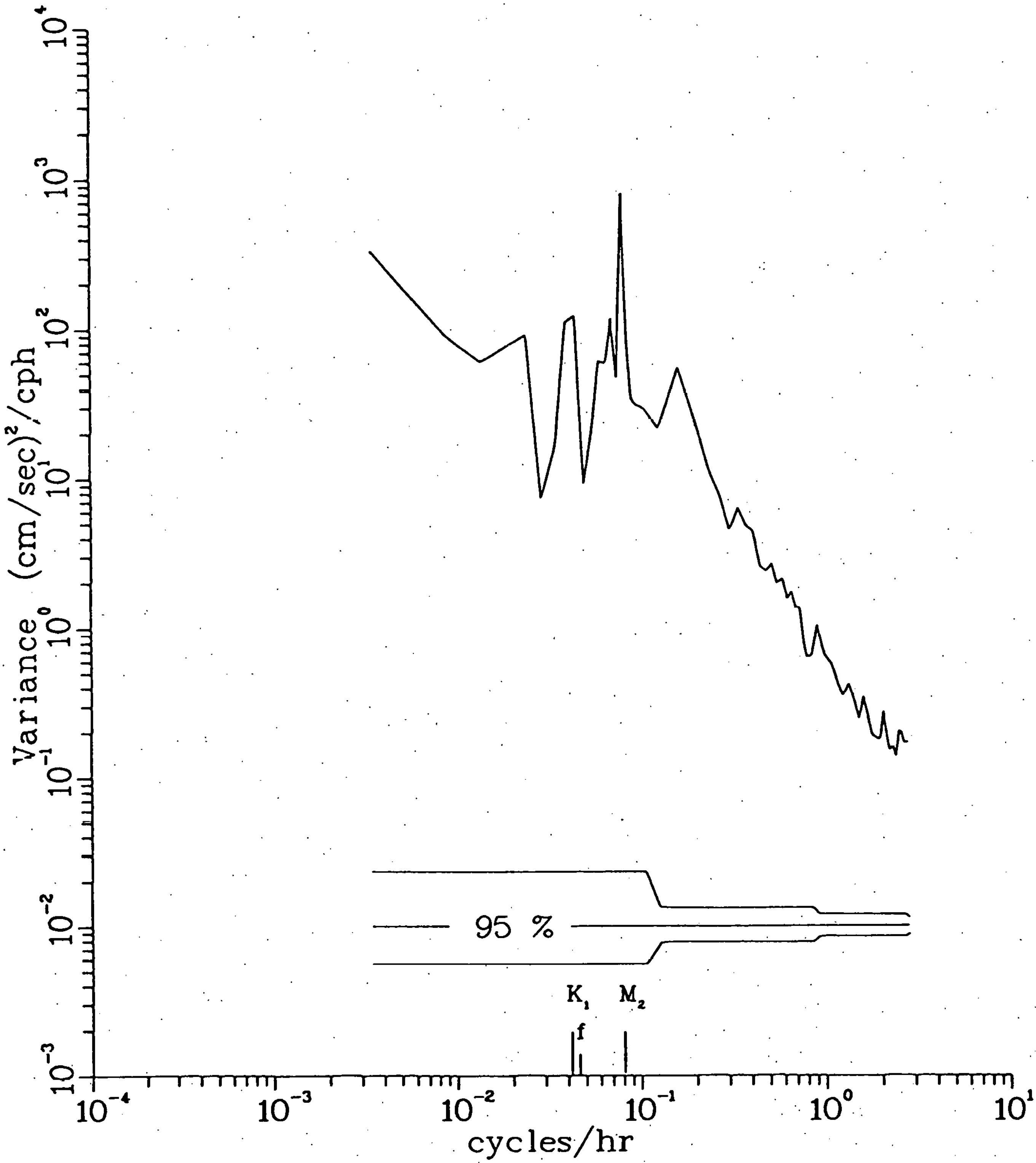
CURRENT SPECTRUM



Variable : V
File : AA1278
Meter : A-2939
Lat. : 33-24-10 N
Long. : 118-32-10 W

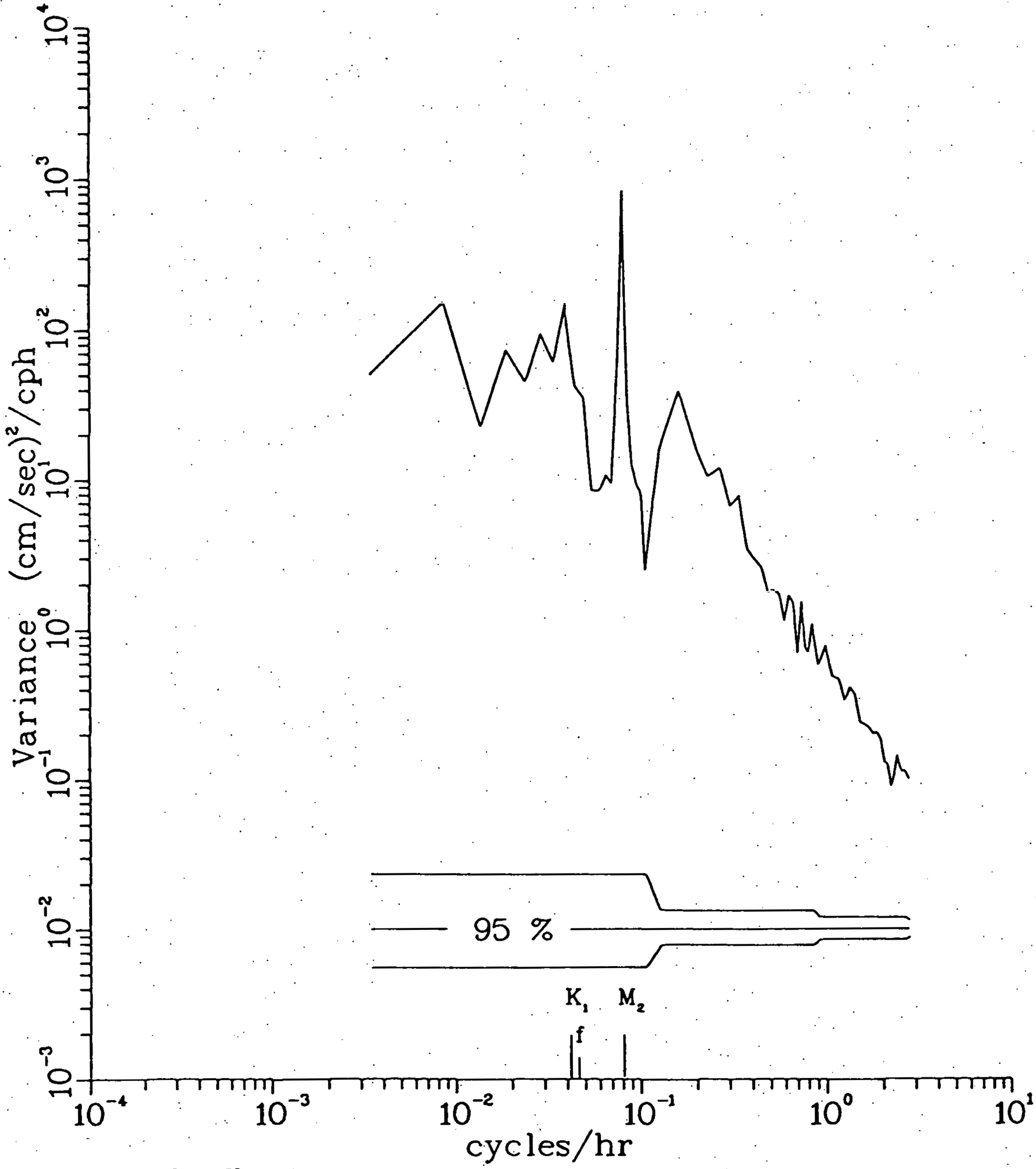
Array : 1
Depth : 183 M
Deployed : 30 DEC 1978
Recovered : 24 JAN 1979

CURRENT SPECTRUM



Variable :	V	Array :	1
File :	AA1278	Depth :	214 M
Meter :	A-2822	Deployed :	30 DEC 1978
Lat. :	33-24-10 N	Recovered :	24 JAN 1979
Long. :	118-32-10 W		

CURRENT SPECTRUM



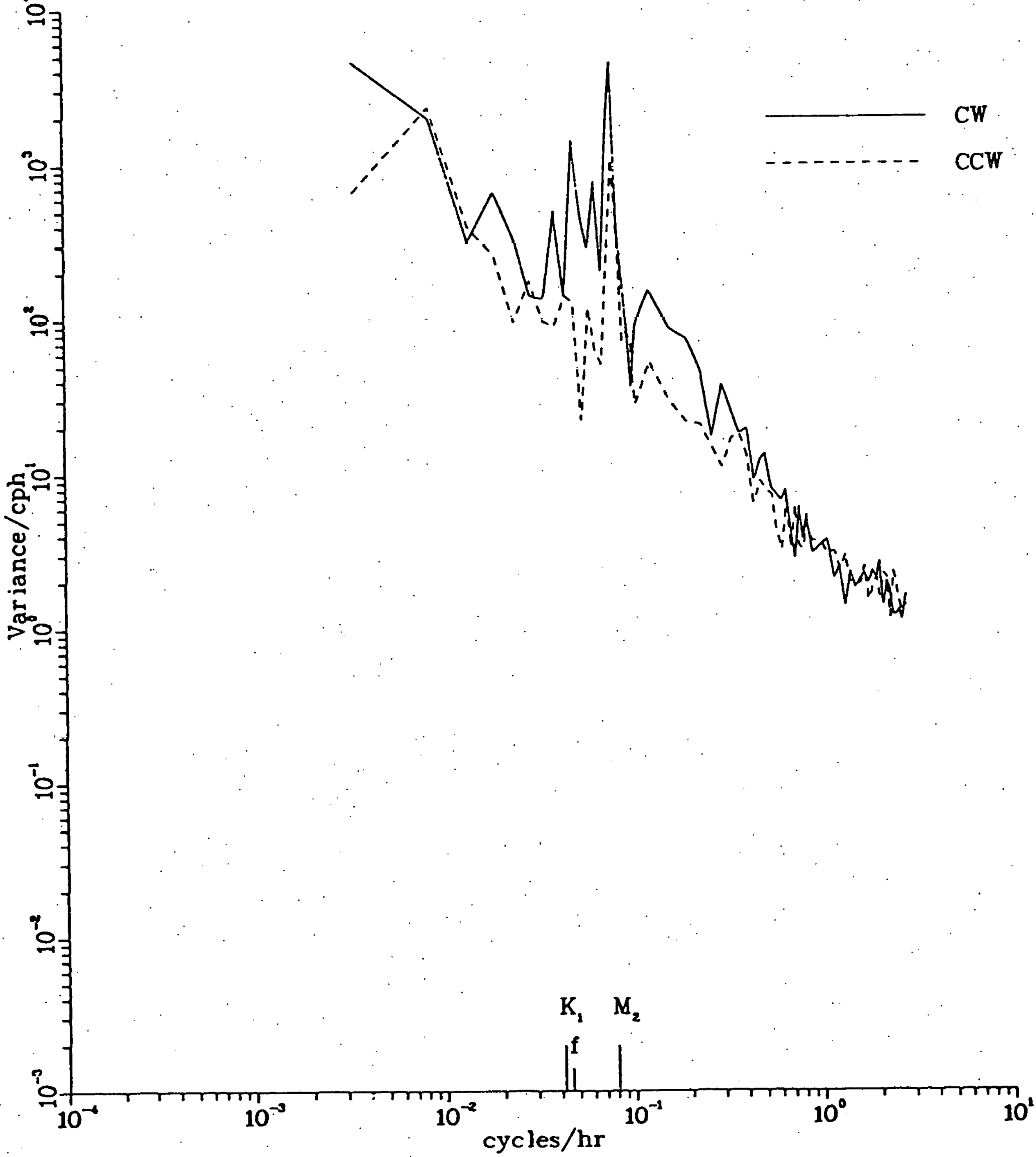
Variable : V
File : AA1278
Meter : A-2617
Lat. : 33-24-10 N
Long. : 118-32-10 W

Array : 1
Depth : 244 M
Deployed : 30 DEC 1978
Recovered : 24 JAN 1979

APPENDIX G

ROTARY CURRENT SPECTRA
RESULTANT VELOCITIES

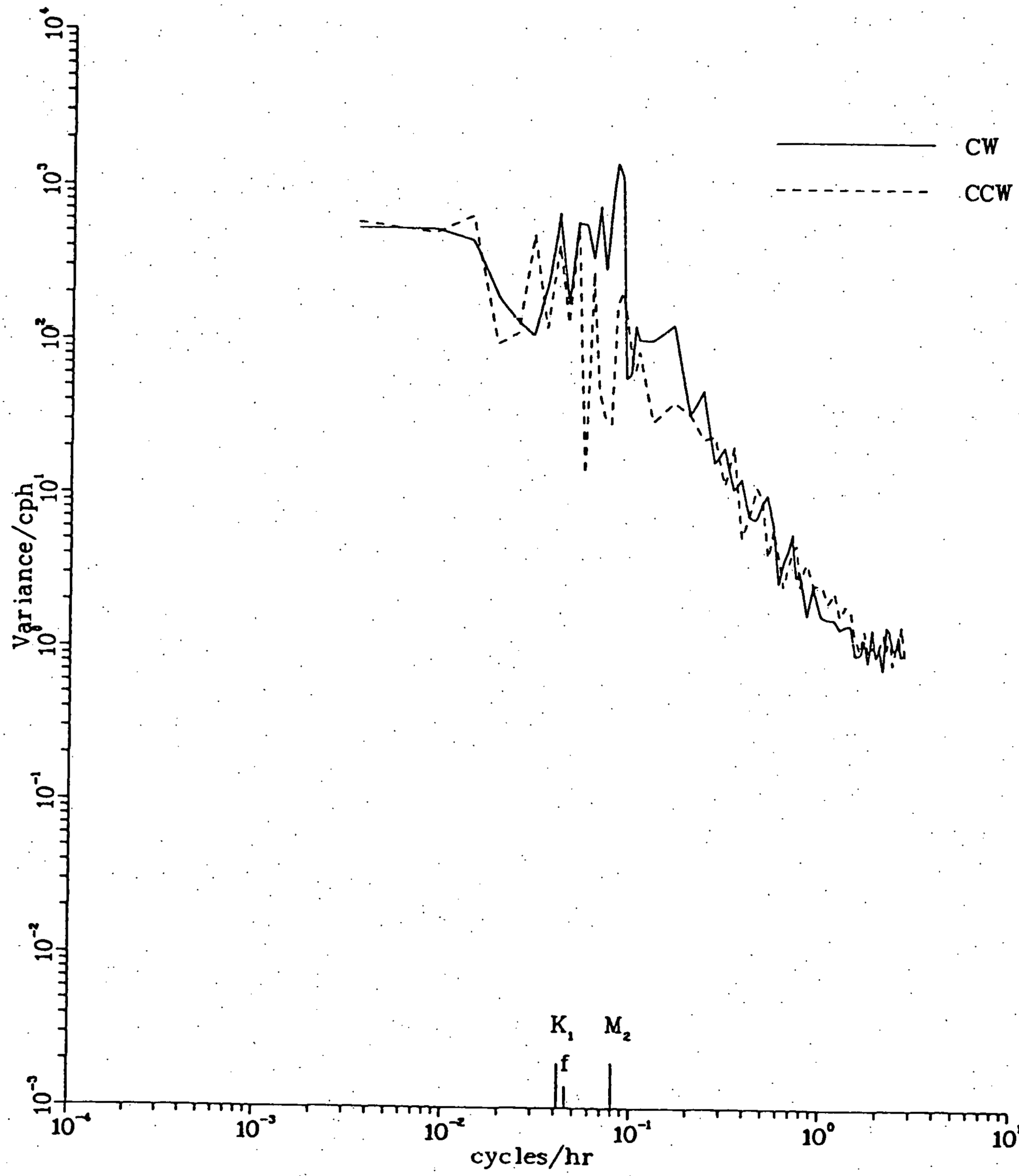
ROTARY SPECTRUM



Variable : U
Depth : 61 M
Meter : A-2731
Lat. : 33-24-10 N
Long. : 118-32-10 W

Variable : V
Depth : 61 M
Meter : A-2731
Lat. : 33-24-10 N
Long. : 118-32-10 W

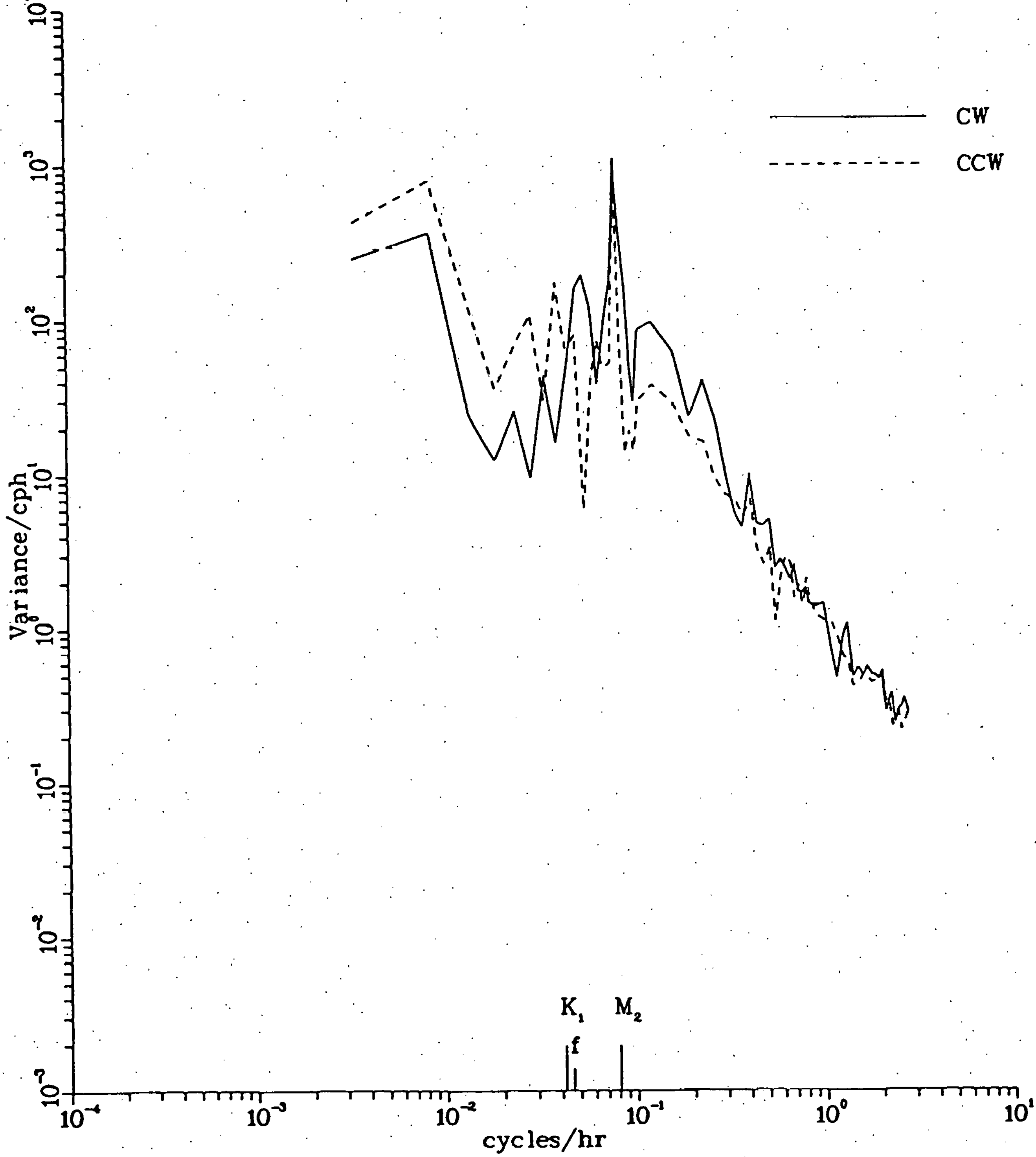
ROTARY SPECTRUM



Variable : U
Depth : 92 M
Meter : A-2821
Lat. : 33-24-10 N
Long. : 118-32-10 W

Variable : V
Depth : 92 M
Meter : A-2821
Lat. : 33-24-10 N
Long. : 118-32-10 W

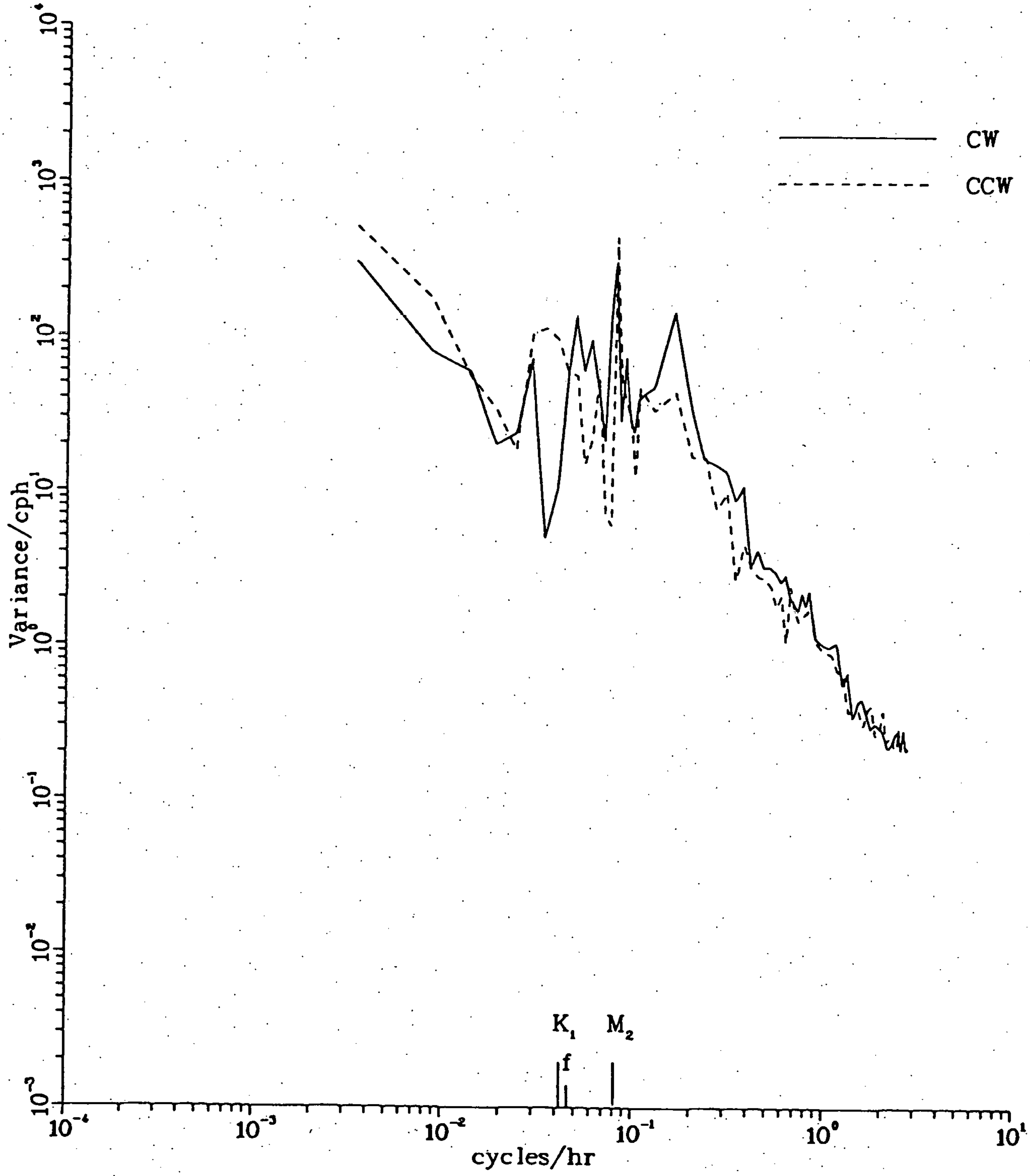
ROTARY SPECTRUM



Variable : U
Depth : 153 M
Meter : A-2715
Lat. : 33-24-10 N
Long. : 118-32-10 W

Variable : V
Depth : 153 M
Meter : A-2715
Lat. : 33-24-10 N
Long. : 118-32-10 W

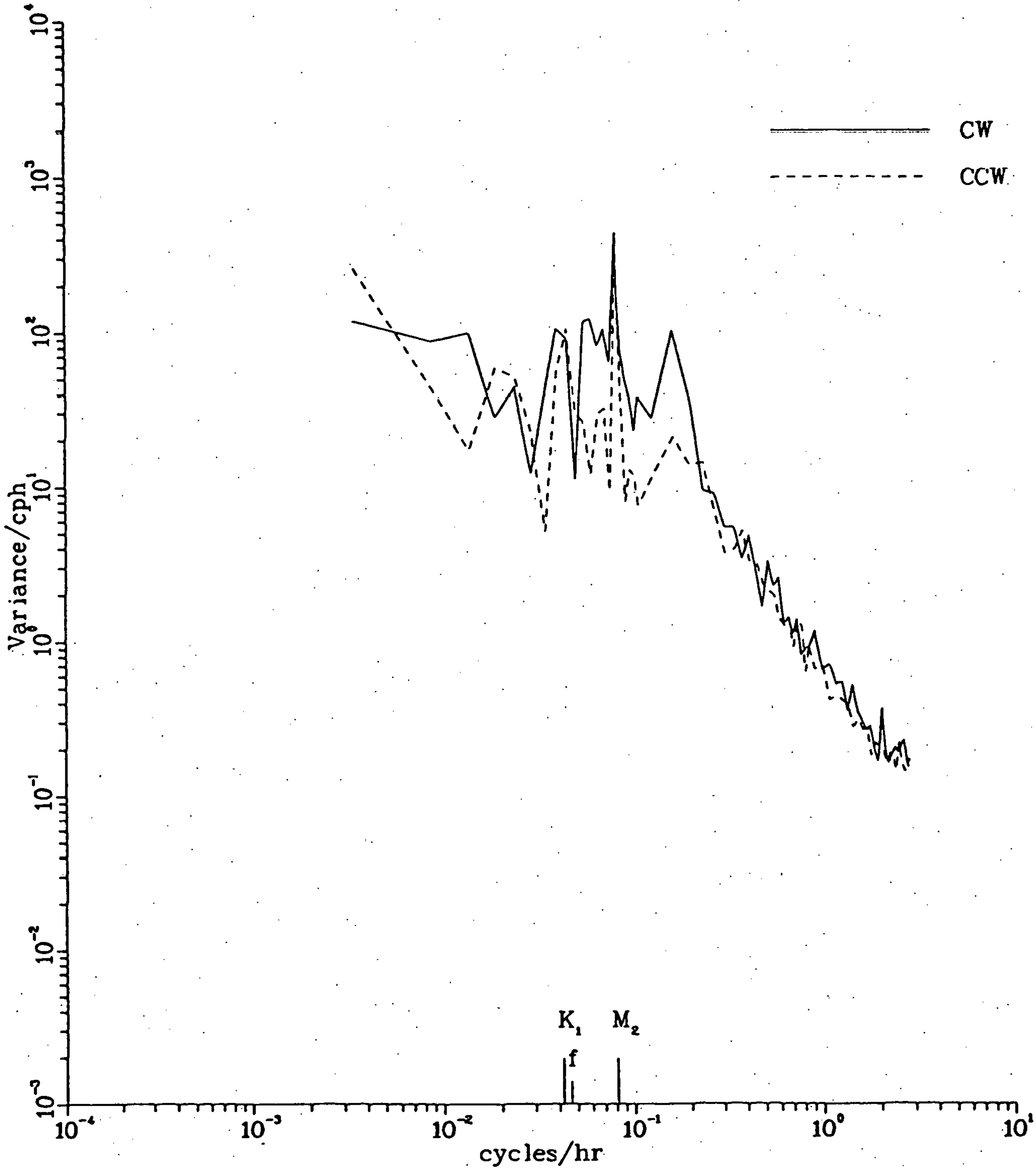
ROTARY SPECTRUM



Variable : U
Depth : 183 M
Meter : A-2939
Lat. : 33-24-10 N
Long. : 118-32-10 W

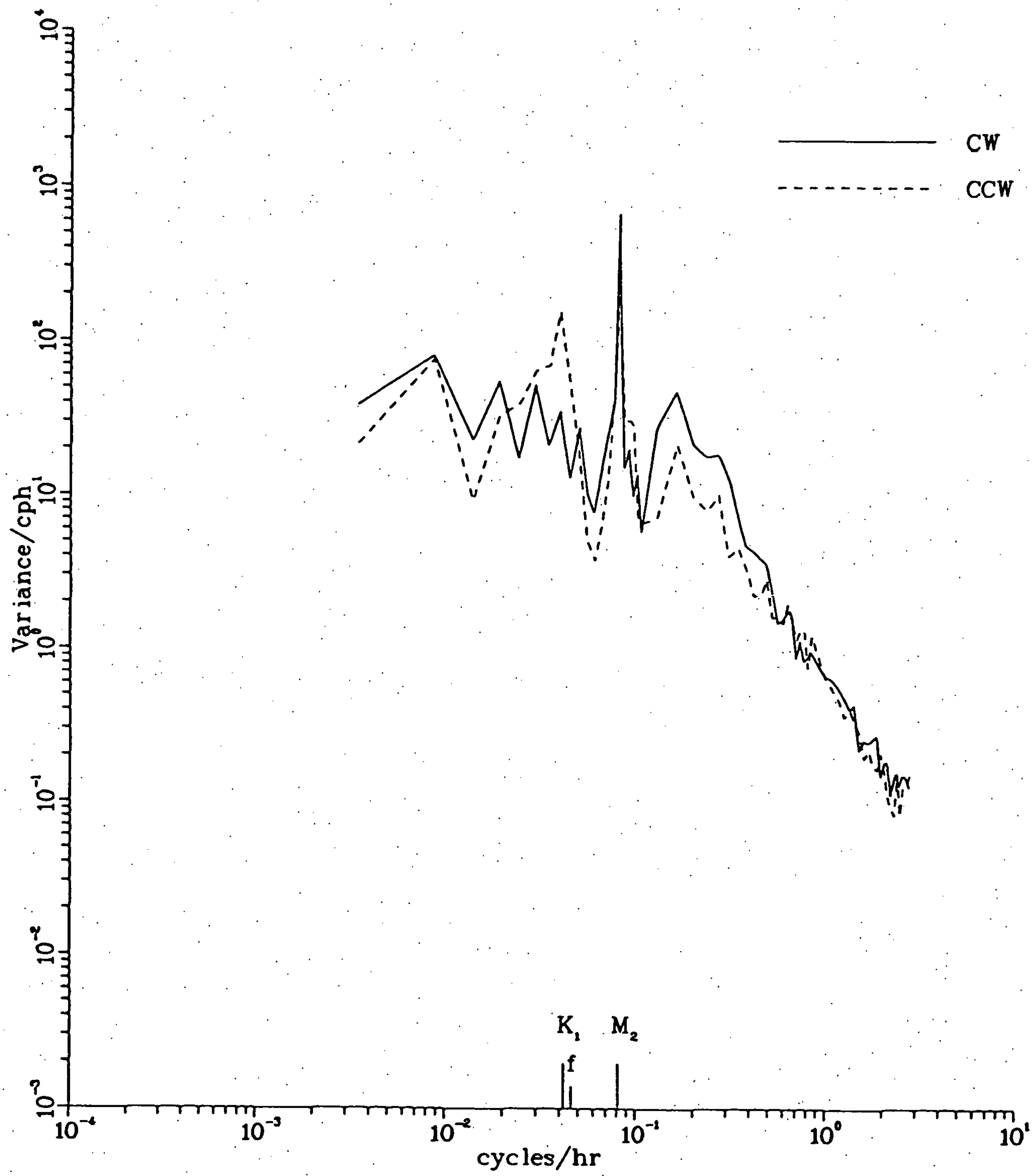
Variable : V
Depth : 183 M
Meter : A-2939
Lat. : 33-24-10 N
Long. : 118-32-10 W

ROTARY SPECTRUM



Variable : U		Variable : V	
Depth :	214 M	Depth :	214 M
Meter :	A-2822	Meter :	A-2822
Lat. :	33-24-10 N	Lat. :	33-24-10 N
Long. :	118-32-10 W	Long. :	118-32-10 W

ROTARY SPECTRUM



Variable : U
Depth : 244 M
Meter : A-2617
Lat. : 33-24-10 N
Long. : 118-32-10 W

Variable : V
Depth : 244 M
Meter : A-2617
Lat. : 33-24-10 N
Long. : 118-32-10 W

☆U.S. GOVERNMENT PRINTING OFFICE: 1980-640-258/403