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Data from THEMIS Moored Instrumented Ocean Array I

by

K. Gilbert, A. Robinson, R. Still and T. Sakou

Office of Naval Research
Contract NR083-230
Project THEMIS

Data Report No. 43 **Reference 70-25**

September 1970

Department of Oceanography
School of Science
Oregon State University
Corvallis, Oregon 97331

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Chairman

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ABSTRACT

A summary of the first year of the THEMIS observation program is presented. The observations were made from November, 1968 to November, 1969. The primary measurements were time series of current velocity with supplementary data of wind velocity.

The emphasis is on the methods of observation and the procedures used in data reduction and analysis. Discussion and interpretation of the initial analysis is also presented.

List of Illustrations

1. Introduction

From November, 1968, to November, 1969, Project THEMIS at Oregon State University carried out a large-scale effort to obtain continuous current and temperature measurements off the Oregon Coast. Both current meter and thermistor chain were supported by the taut line subsurface mooring device. The installation sites ranged in depth from 500 to 1000 meters of water. Figure 1 shows the sites occupied during this time frame.

2. Background

Project THEMIS, "Use of on-line computers for environmental research," is primarily concerned with air-sea interaction in the easternmost boundary of the North Pacific.

The observational program for 1969 was designed primarily to establish an efficient and scientifically meaningful plan of observation. It requires the capability of remaining operation for an extended period of time in the intermediate depth of water (intermediate between the continental shelf and deep ocean), and supporting instrumentation whose data quality is compatible with the requirements of the scientific program for which it is designed.

The scale of oceanic variable processes should be selected on the basis that our interest is local rather than global, that a year's duration should be considered sufficiently long and that our present technological resources do not currently permit our occupancy beyond the foot of the continental slope. The scale in the order of one hundred kilometers with the corresponding time scale of a few days to a week is probably the most realistic range in which our program may evolve.

In this scale range the most conspicuous features are the tides and the inertial period motion. Both are suspected of supplying energy to higher frequency turbulence. Inertial period motion may be the most immediate and substantial response to the variation in wind stresses. It would then represent the important link between the high frequency micro-scale air-sea interaction and the low-frequency macro-scale atmosphere-ocean interaction.

The data acquisition program was designed to respond to the frequency range between half-an-hour to a week with the main focus on the inertial and quasi-inertial period motions. The horizontal configuration

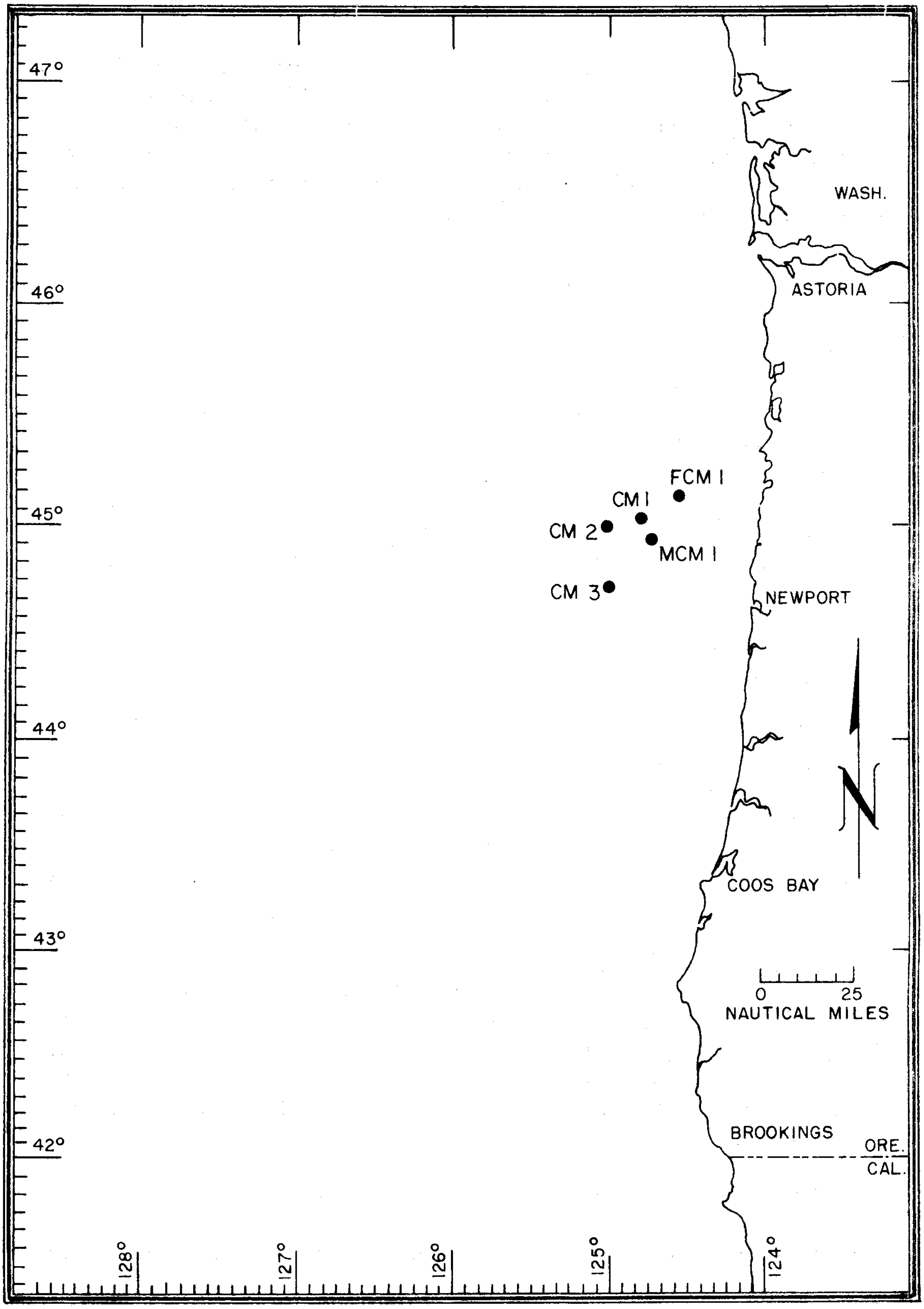


Figure 1 Current meter station locations

of the array, according to this design principle, should be L-shaped, with the onshore-offshore component separated by 15~30 kilometers and the alongshore component separated by 30~50 kilometers. The shore end of the array should be close to the margin of the continental shelf and the off-shore end should be extended, as technology permits, to the edge of the deep ocean.

The vertical configuration of the array is selected essentially on the same principle. The inertial period response decreases rapidly with depth so it is necessary to keep the first sensor as close as possible to the surface. However, high frequency noise due to surface wave action increases sharply toward the surface. The depth of 40 meters was a compromise between these two limitations. The second factor in selecting the vertical configuration is the complex vertical structure of the ocean in this region. The existence of temperature inversion is illustrated by the CTD profile given in Figure 2. The CTD profile also shows that the most probable cut-off frequency for internal waves lies in the nieghborhood of 0.1 cpm, the basis of sampling scheme selection for the thermistor array. The thermistor array is designed primarily to resolve the verticle mode of motion and the focus is on the high frequency end of the spectrum. By closer spacing of sensors and higher density sampling the thermistor data, when combined with the simultaneous current meter record, is expected to aid our search into the structure of high frequency motion (turbulence vs. internal waves, etc.).

3. Moored Array Configuration - design consideration and performance record

The two major design considerations of the mooring were (1) ease in servicing and reinstallation of instruments carried by the mooring and (2) a minimum vertical movement of the upper element of the taut line mooring so that current records would require no tilt correction and temperature records could be treated as being from a constant depth. Accordingly, the design limit of ten meters vertical excursion was found compatible with the equipment available.

The mooring configuration used was of the type shown in Figure 3, and is a deviation of a mooring configuration used previously at Oregon State University (1, 2).

In order to limit the vertical movement of the sub-surface float to less than ten meters, if installed in 1,000 meters of water, the positive buoyance of the float should be 2,000 pounds. The shape of the sub-surface

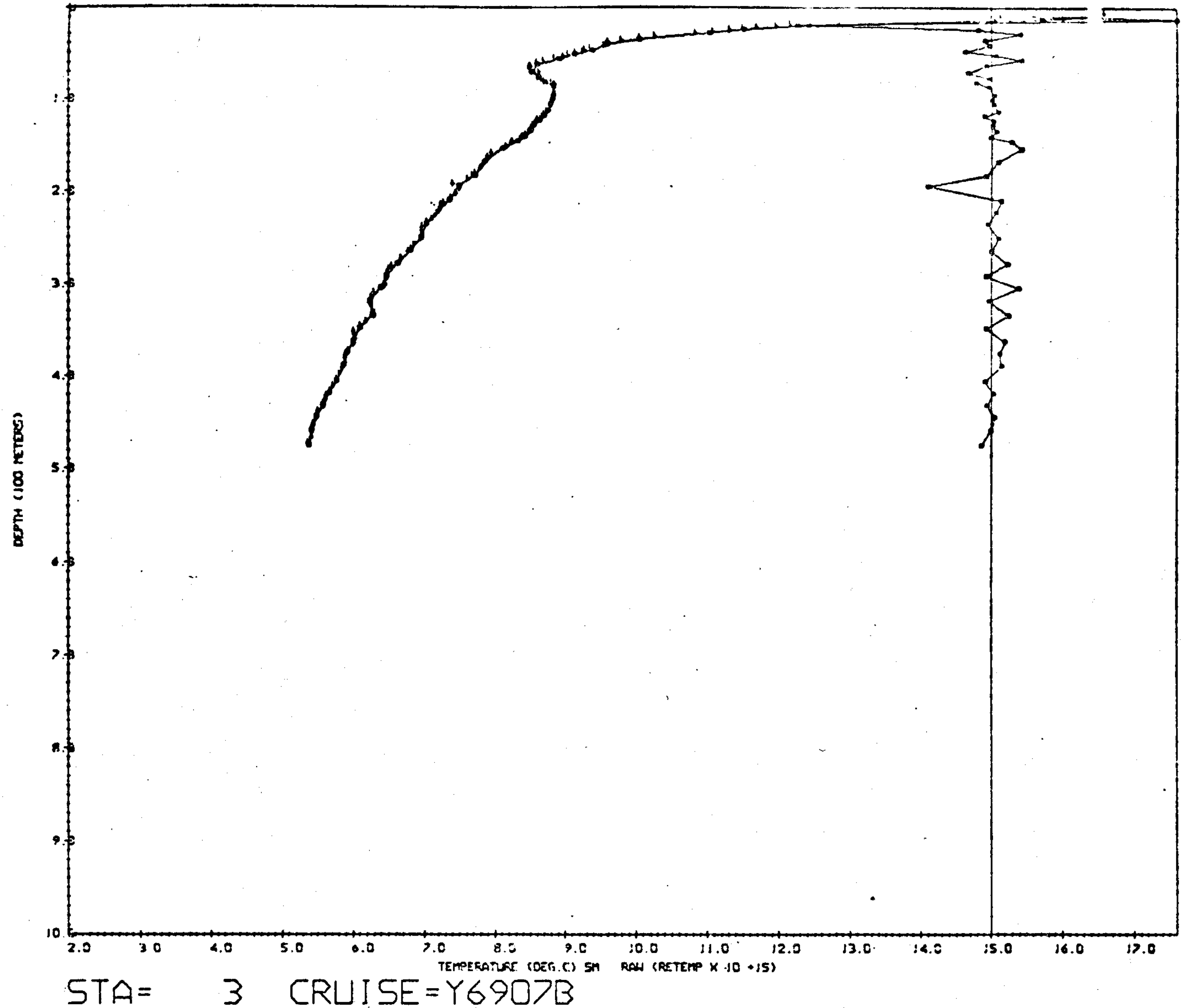


Figure 2 CTD profile

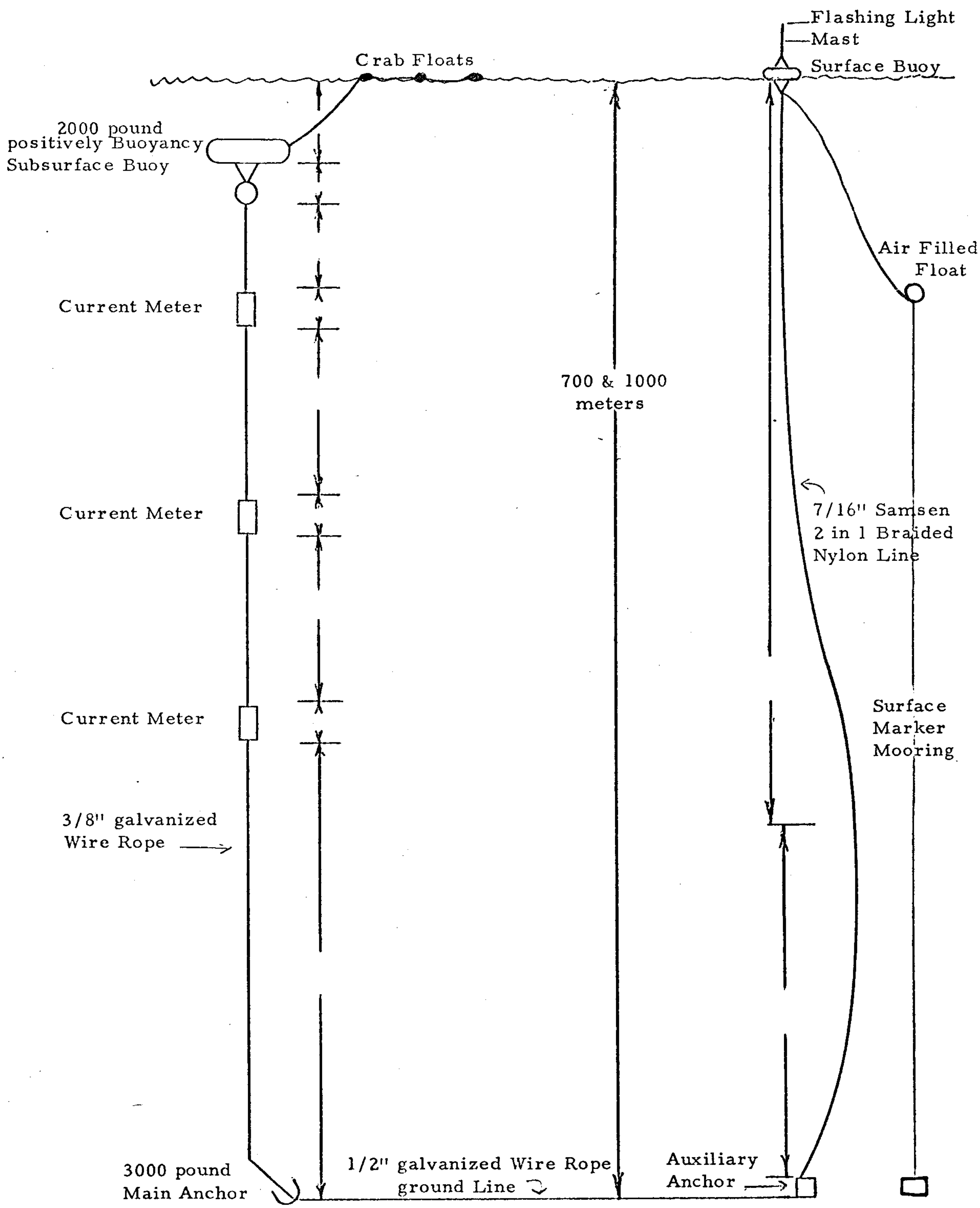


Figure 3. Mooring configuration

float was dictated by materials on hand and the desire to minimize the horizontal current drag. Cross sections of the shape used are illustrated in Figure 4.

Attached to the sub-surface float were three brightly painted crab pot floats and polypropylene line long enough to reach the sea surface.

The initial choice for the instrument string wire, 1/4 inch stainless steel wire rope, was made on a 4.5 to one safety factor. However, upon retrieval of the first installation the wire was badly unlaid and kinked. One-quarter inch wire rope was used on the second installation unsuccessfully. Three-eighths inch galvanized wire rope was used on the third and subsequent installations with no serious problems of unlaying.

The first main anchors used were 3,000 pound Navy surplus anchors. As more installations were deployed and more anchors were needed, they were made from surplus anchor chains lashed together and contained in a 42 inch diameter section of pipe.

The ground line was 1/2 inch galvanized wire rope, this size was chosen to facilitate grappling operations when necessary.

The auxiliary anchor was a 2' x 2' x 8'' clump of concrete to anchor the nylon retrieval line and to act as a dead weight on the downstream side of the ground line in the event of grappling.

A nylon retrieval line, 9/16 inch in diameter, manufactured by Samsen Cordage Works, Boston, Massachusetts, was used between the auxiliary anchor and the surface float. It was described by the manufacturer as 2 in 1 braided nylon rope with an approximate breaking strength of 9,500 pounds. The mooring design called for the retrieval line to have a 1.5 to 1 scope. For shallower depths this ratio worked well, however, in depths of 700 to 1,000 meters it became apparent that the scope was too large. Retrievals became difficult because the length of the retrieval line permitted the lower portion to lay on the sea floor and chafe. When tension increased, as the auxiliary anchor and ground line were retrieved, the retrieval line on occasion parted forcing a grappnel retrieval. For later installations, the length of the retrieval line was reduced to water depth plus 200 meters. During the launching procedure an in-line float was used to buoy the retrieval line and keep it off the sea floor. When in place, this buoyancy package was between 50 and 100 meters below the surface. This procedure solved the retrieval line chaffing problem.

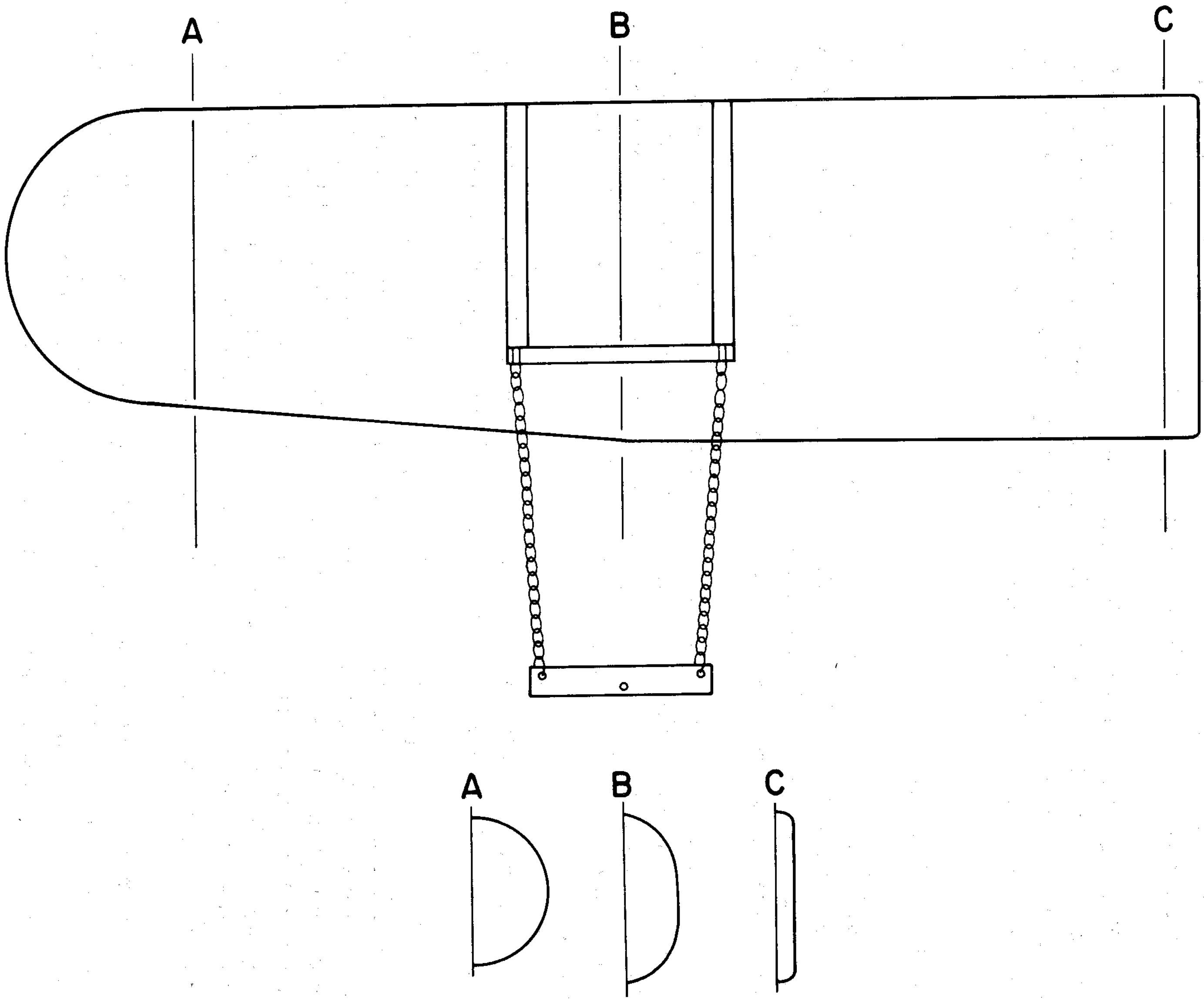


Figure 4 Cross-sections of the sub-surface float

The surface float employed was a toroidal shaped buoyancy package with appropriate attaching bridle, developed at OSU (2). A six-foot tubular mast guyed to the float carried a white flashing light.

A description of the method of installation and manufacture of the mooring hardware can be found in Appendix B.

Through the course of the year a number of changes were made in equipment used in the mooring, the method of installation or recovery to increase the degree of confidence of data acquisition. Table 1 is a description of the installations made and the methods of recovery.

4. Data Collection

Summaries of the current data recovered from the current meters for the period of November, 1968, to November, 1969, by station and exposure period are found in Tables 2 and 3. Two Geodyne current meter records are being processed but the results have not yet been obtained.

Thermistor installations were carried out from June through October, 1969, but, no usable data has been recovered from the installations (Table 2). This lack of success is due to instrument failures, incompatibility problems with computers available, or a combination of these and other factors.

Figure 5 illustrates five days' averages of the wind vectors for winds recorded at Newport, Oregon from April, 1969 to October, 1969.

Data collected by the Braincon Type 381 Histogram current meters are recorded on photographic film for a nine minute and thirty second interval. Between data frames, thirty seconds are allowed for film advance. A continuous ten minute record of current speed is obtained by taking the difference between the arc value of the beginning of successive frames. The mean current direction is taken to be the mode of the current direction on the interval. The mean velocity on the interval is obtained by combining the current speed and direction in polar coordinate form.

On numerous occasions, camera failures occurred with the Braincon current meters. Several different causes have been found for these failures, however, no one solution has been found. The most common failure occurred with the gear train on the film advance motor.

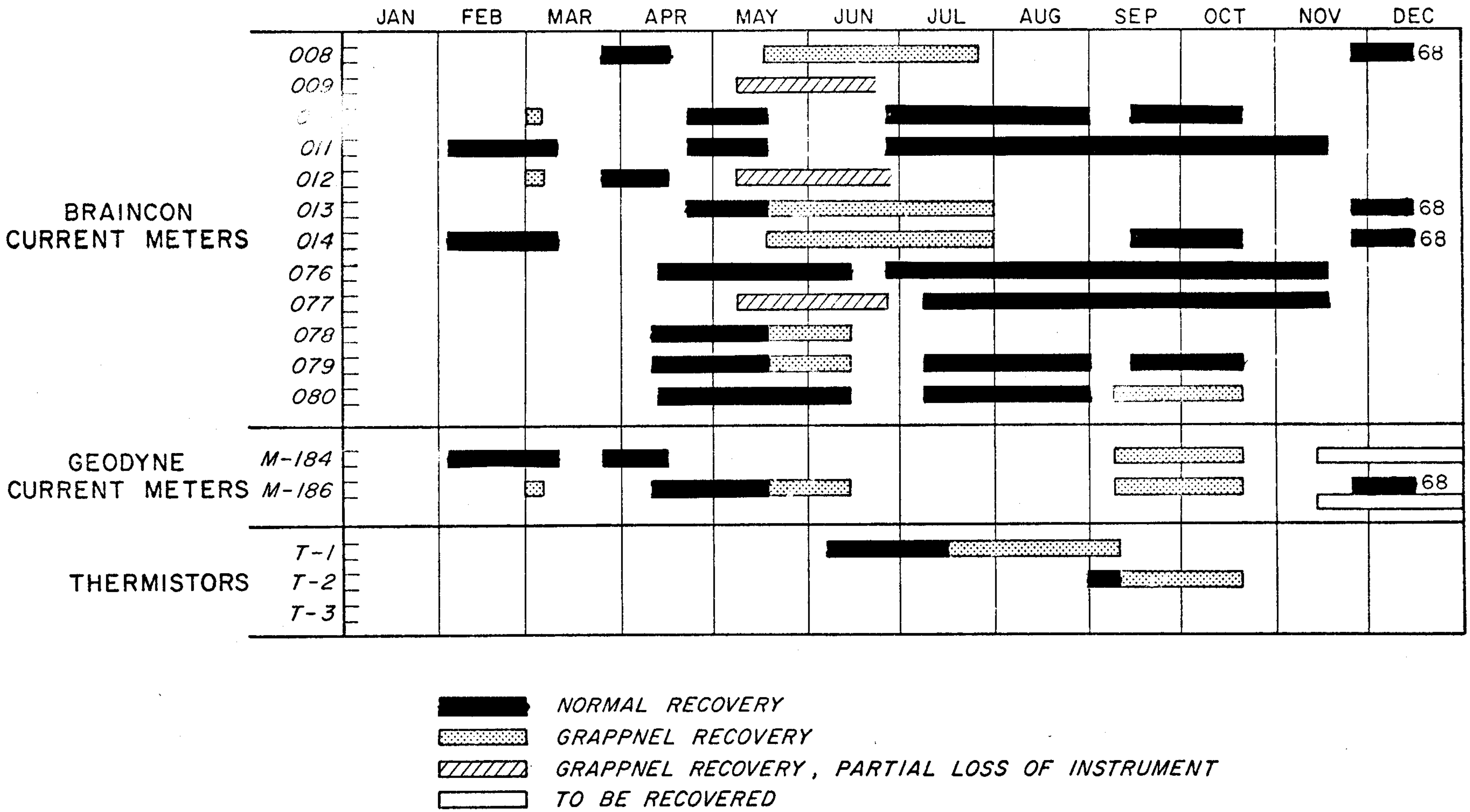


Table 1 Mooring Summary

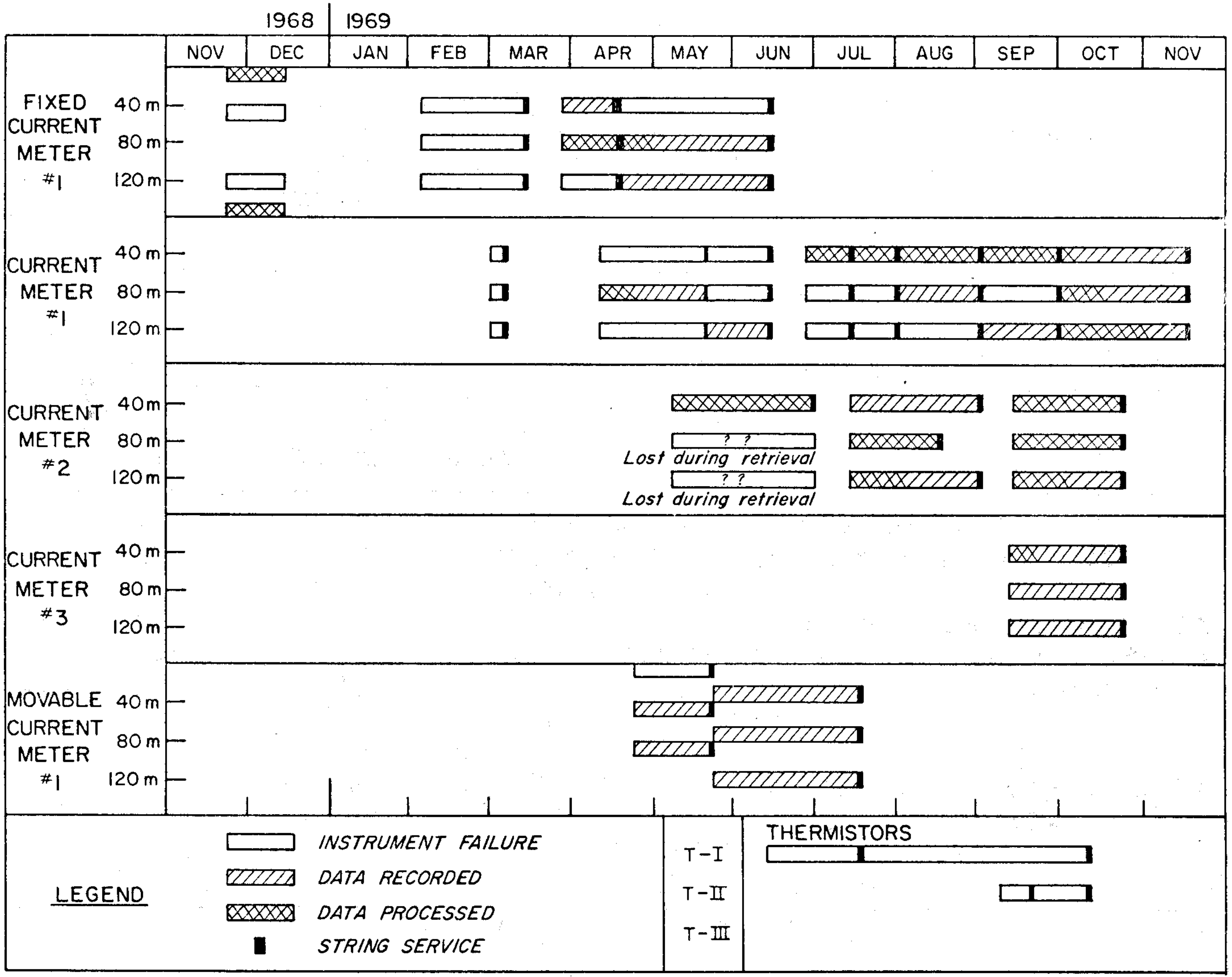


Table II Exposure periods of current meter data for 1968-1969

Table III

DATA SUMMARY OF CURRENT METER DATA, 1968-1969

BRAINCON

Station	Exposure Period	Depth (m)	Total # of Frames Exposed	Total # of Usable Date Frames
FCM 1				
45° 00. 1'N	11/26/68 - 12/ 5/68	320	1751	1751
124° 39. 0'W	3/26/69 - 4/11/69	80	2750	2210
in 500 m	4/11/69 - 6/14/69	80	4100	830
CM 1				
45° 00. 2'N	4/10/69 - 5/17/69	80	1150	963
124° 46. 8'W	6/25/69 - 7/17/69	40	3170	3140
in 700 m	7/17/69 - 7/31/69	40	1980	1978
	7/31/69 - 8/30/69	40	4276	4275
	8/30/69 - 9/29/69	40	4320	4315
	9/29/69 - 11/17/69	80	7072	1025
	9/29/69 - 11/17/69	120	7073	3135
CM 2				
44° 59. 8'N	5/ 7/69 - 6/26/69	40	7220	7214
125° 00. 8'W	7/ 8/69 - 8/29/69	80	2350	2344
in 1, 000 m	7/ 8/69 - 8/29/69	120	1680	1587
	9/12/69 - 10/20/69	40	5067	5064
	9/12/69 - 10/20/69	80	5058	5055
	9/12/69 - 10/20/69	120	1970	1626
CM 3				
44° 32. 6'N	9/ 9/69 - 10/20/69	40	2700	728
124° 58. 2'W				
in 1, 000 m				
		TOTAL	63, 687	47, 240
GEODYNE FCM 1	11/25/68 - 12/13/68	25	53, 072	53, 072

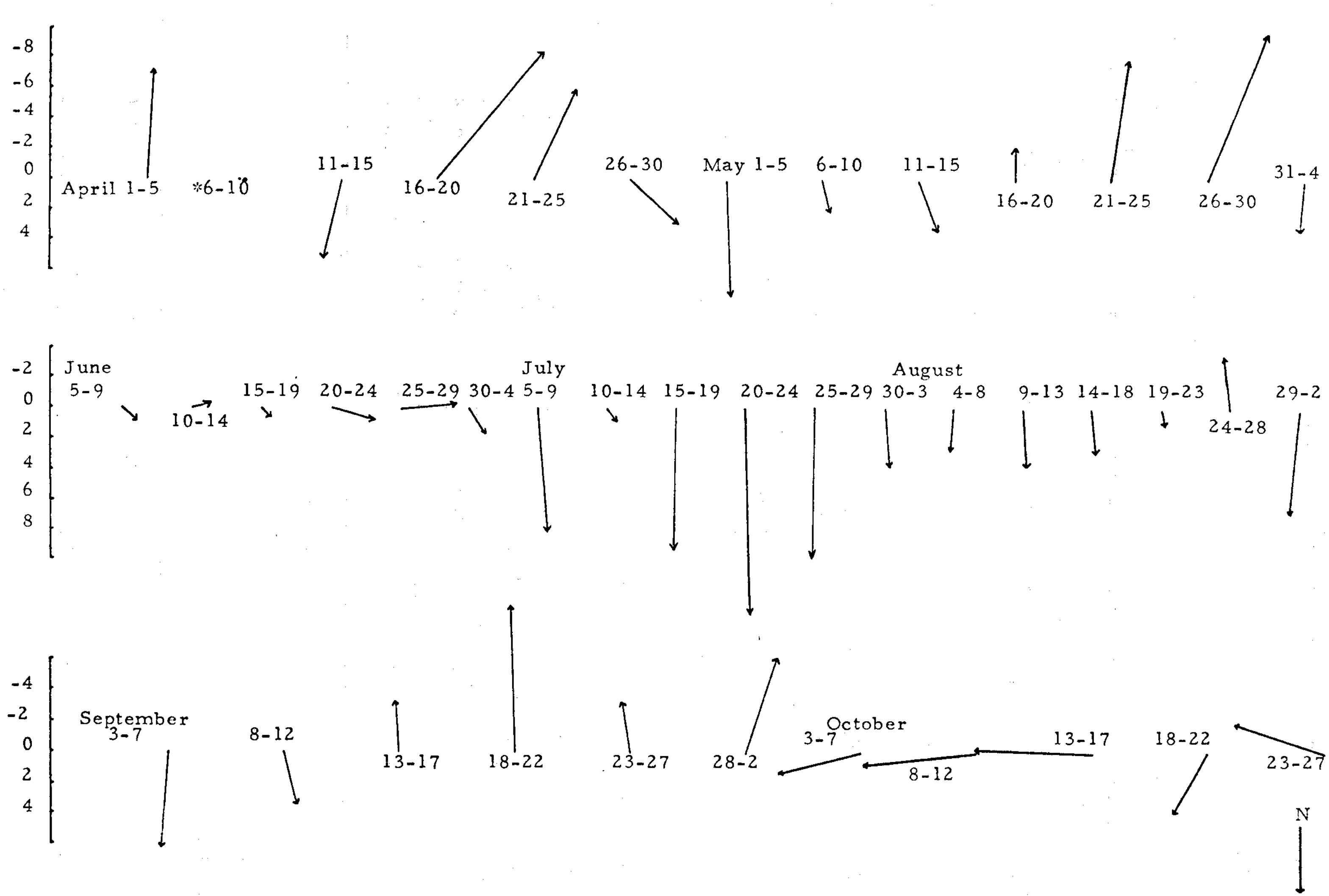


Figure 5 Five day averages of wind vector from Newport, Oregon

Data collected by the Geodyne Model 850-D magnetic tape recording current meters are recorded on magnetic tape in cartridges in the following way: thirty-one readings of current speed and direction are taken in a two minute interval at the beginning of every fifteen minute period. Mean velocity is calculated for each reading and averages are calculated for each fifteen minute period.

The wind data available was recorded at Newport, Oregon by the Weather Bureau Office of the OSU Marine Science Center. Hourly averages were obtained from the strip chart of wind direction and speed.

5. Data Reduction

The procedures used in data reduction differ according to the form in which it was collected. The data reduction process for Braincon current meter data was completed entirely at OSU, whereas only a portion of the data reduction procedure for Geodyne current meter data was completed here.

The data reduction procedure for Braincon current meter data consists of a series of manual operations and computer programs. A brief description of these programs is given in Appendix C. The process is composed of the following steps:

i) commercial development of the photographic film
ii) examination of the film for indications of instrument malfunction. In the event of malfunction, the film was deemed partially or completely useless, depending on when the malfunction occurred.
iii) reading of the usable film using equipment designed at OSU for this purpose.
iv) transfer of the raw data from paper tape generated during film reading to magnetic tape using the NCR 735 Magnetic Tape Encoder System of the OSU Computer Center.
v) transfer of the raw data from the magnetic tape to disc file and initial calculation and error detection. The types of errors detected are an incorrect number of frames for one day's record, negative speed readings, numbers greater than 360°, and characters other than numerals.
vi) correction of the data frames found to be in error. This is a manual procedure accomplished by examining the frames in question.
vii) calculation of the North-South and East-West components of velocity.
viii) recording of the data on magnetic tapes for storage.

The data reduction procedure for the Geodyne current meter data consisted of the following steps:

i) transfer of the raw data from the magnetic tape cartridge to magnetic tape compatible with IBM computer systems. This step was completed by Geodyne Division, Woods Hole, Massachusetts.

ii) decoding of the raw data into speed, direction, and components of velocity for each reading and averaging for each fifteen minute period.

6. Discussion

i) Data Quality

Before the analysis of the data is complete, the question of data quality arises. There are several possible sources of error in the collection and reduction of data. The errors can be human or mechanical or a combination.

In the Braincon current meter data collection and reduction process, the sources of mechanical errors could be the current meters themselves or the film reading machine. According to manufacturer's specifications, (3) the current meters are accurate to within ± 3% of the full scale of current speed and ± 1% of current direction. Speeds less than 0.05 knots are below the threshold of the instruments. The Bulova Accutron watches used to time the film advance mechanisms are accurate to within two seconds per day under normal operating conditions. These errors are out of the control of humans, however.

Film reading machine errors due to maladjustment of the equipment were minimized by constant scrutiny of the equipment. Any inconsistent machine error is extremely difficult to find, but quite rare.

One problem over which there has been little control is obtaining all of the film that was exposed from the film processor. On numerous occasions, the processor clipped off the end of the film so that the end exposure dot and perhaps data were not present. Only after changing film processors and demanding individual service was the film processed as requested.

Human errors could be introduced at every stage of the procedure. Precautions were taken to minimize these errors. They can occur during the film reading by a frame being skipped, reading one twice, or general carelessness. These errors have been anticipated in the error detection programs, and reduced by restricting the time one person can read to two hours at one sitting.

The data is examined six times during the reduction process by at least two persons. Extreme care in each examination aids in minimizing the errors introduced by people.

The errors that might occur in the Geodyne current meter data are primarily mechanical. According to the manufacturer's specification (4), the Geodyne current meters have a threshold of 0.05 knots and are accurate to within 0.05 knots at speeds less than one knot and to within 0.1 knot at speeds greater than 1.0 knots. The current direction vane is accurate to within 10° at 0.05 knots and 2° at 0.25 knots and above. There are no stages at which the data is handled manually. This eliminates the subjectivity to which the Braincon current meter data has been subjected.

ii) Synopsis

To summarize the data, the integral velocity diagrams (or progressive vector diagram) are presented in Figures 6-9. The general temporal trend is consistent with the description given to the oceanic flow in this part of the north Pacific (e.g. reference to 5, 6). The mean currents were toward the south during the spring and the early summer months and they were toward the north during the fall and the winter months. The transition for 1969 came in August. The transition was a fairly lengthy one. The southward current is associated with offshore transport and the northward current is associated with the onshore transport, respectively, in the upper part of the ocean. This may also be interpreted as the indirect manifestation of the upwelling during the summer months and the start of the downwelling during the fall months. Comparing vect 14 and 15 with vect 16 (Figure 8), one may conclude that the onshore transport during the month of September is limited to the upper one hundred meters at Station #2.

iii) Statistical Analysis

To see more details of the frequency structure, the data was subjected to a set of statistical time-series analysis subroutines (7). The outputs of such operations may be the simple statistical parameters such as the mean, the variance and the correlation coefficient, or a set of auto and cross correlation functions, spectral density functions, cross-spectral function and the associated coherence and phase information or the auxiliaries of complex demodulates.

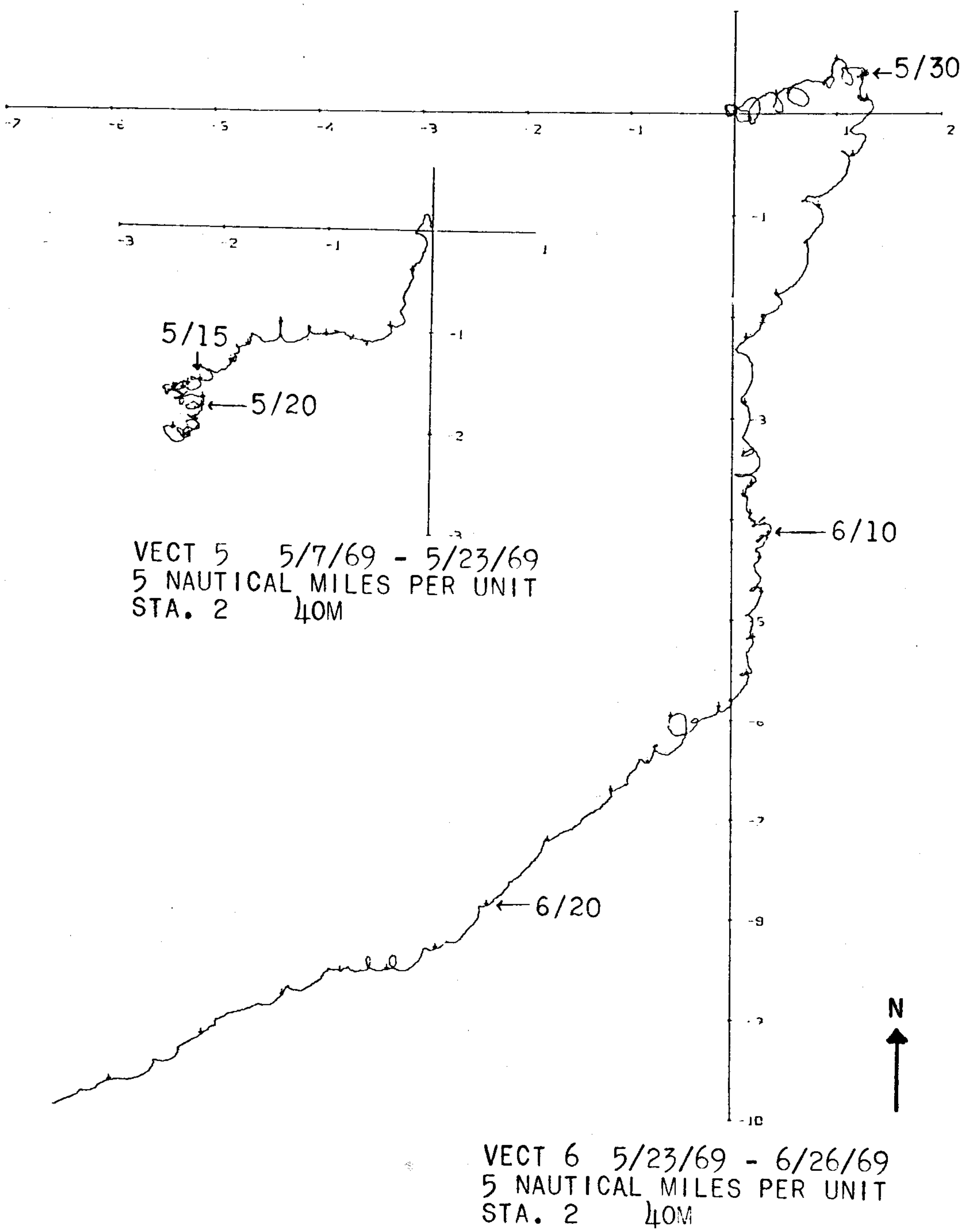


Figure 6 Progressive vector diagrams of vect 5 - vect 6

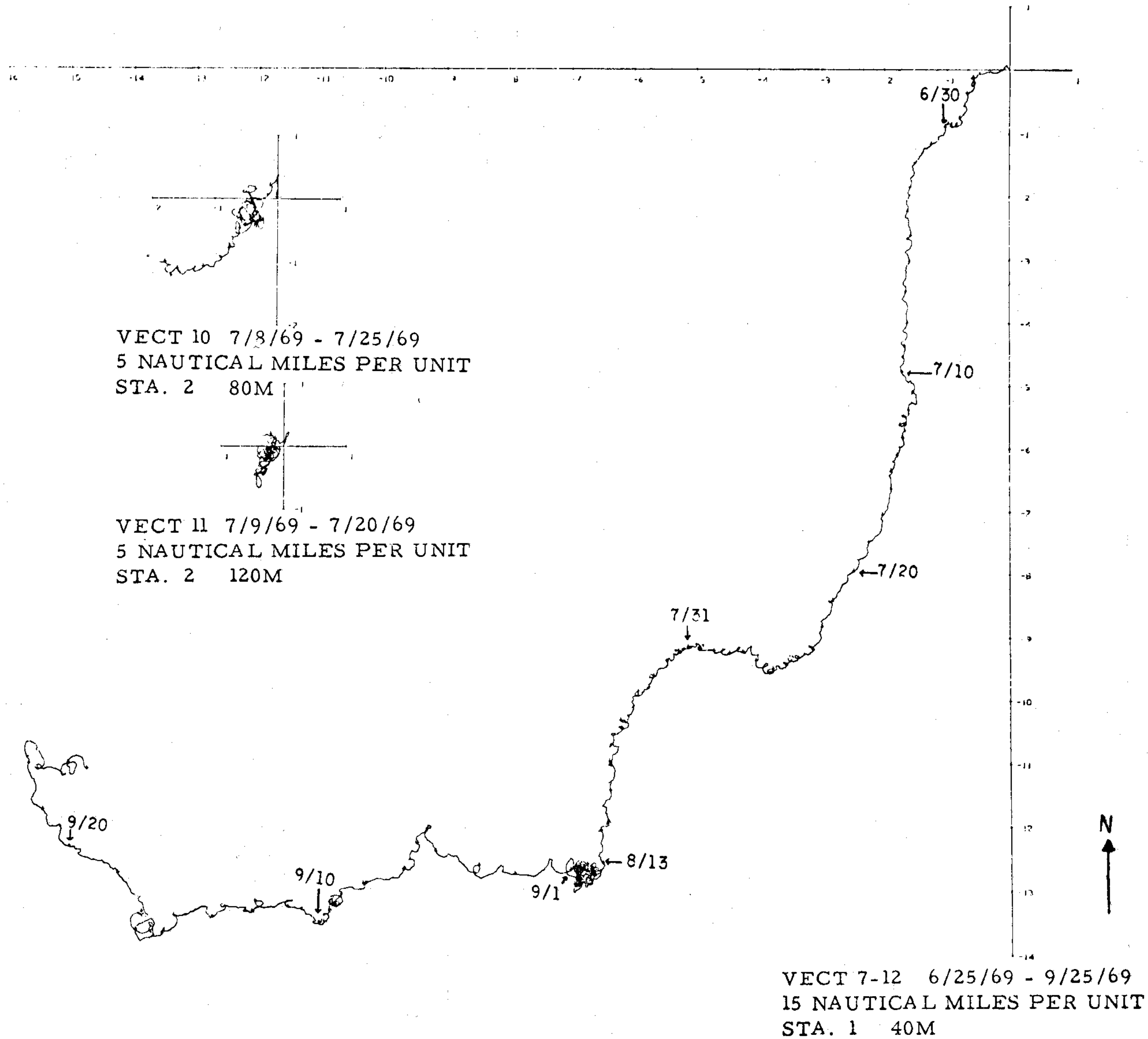
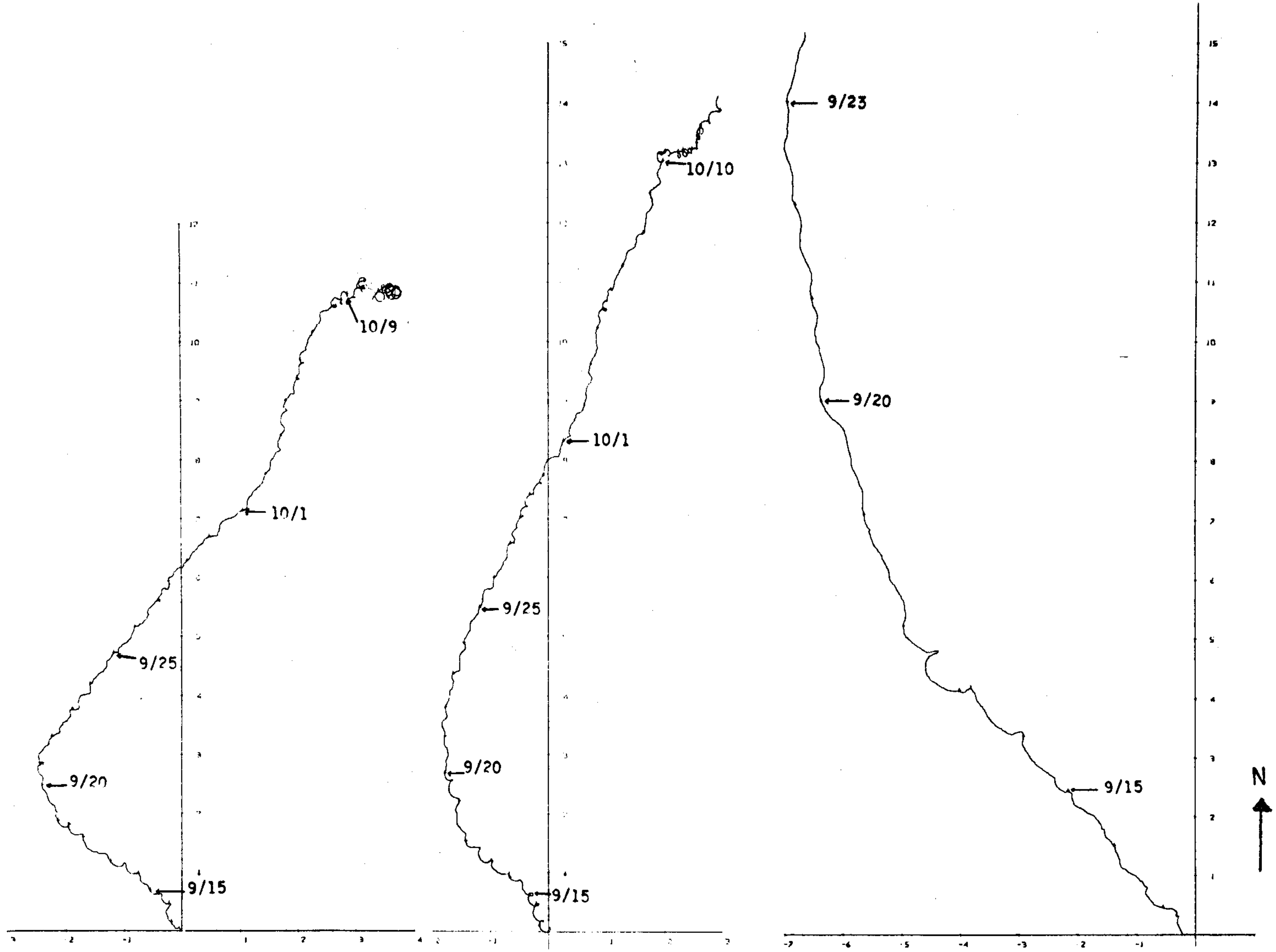


Figure 7 Progressive vector diagrams of vect 7-9, 10, 11, 12



VECT 14 9/12/69 - 10/17/69
15 NAUTICAL MILES PER UNIT
STA. 2 40 M

VECT 15 9/12/69 - 10/17/69
15 NAUTICAL MILES PER UNIT
STA. 2 80M

VECT 16 9/12/69 - 9/23/69
5 NAUTICAL MILES PER UNIT
STA. 2 120M

Figure 8 Progressive vector diagrams of vect 14, 15, 16

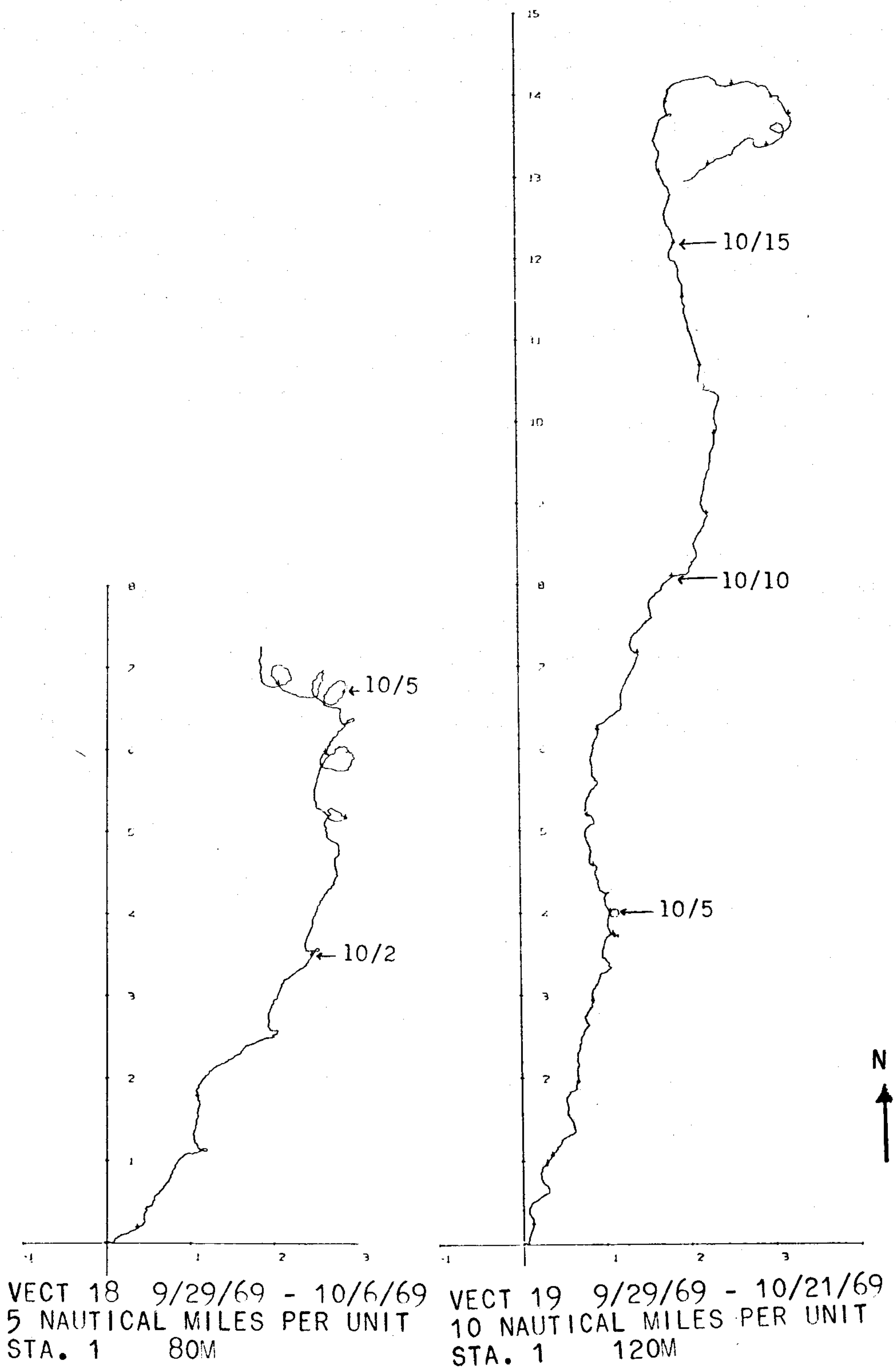


Figure 9 Progressive vector diagrams of vect 18, 19

Figures 10-12 show one example of cross spectral computation for a set of u(east-west) and v(north-south) components of velocity at 120 meters from the surface at Station #1, during the months of September - November, 1969. The calculation is carried out by time averaging over short modified periodograms.

In general, the spectrum of oceanic current in the region may be divided into three characteristic subranges. The high frequency range with the period shorter than that of the semi-diurnal tide, show linear decrease on the log-log plot as the frequency increases. The coherence is low in this range. The intermediate frequency range consists of a few notable peaks: semi-diurnal tide, inertial period motion and diurnal tide. In many cases the inertial period motion is the dominant feature in this frequency range. The coherence between the u and v components very often becomes significant, but the coherence between the different stations usually is not.

The lowest frequency range, with a period of days, is again represented by a rise in spectral density toward the lower frequency end. The coherence between the u and v components normally is small but the coherence over the horizontal distance of many kilometers very often rises to a significant level. The comprehensive discussions on the spectral structure of the observed currents are given elsewhere (8, 9).

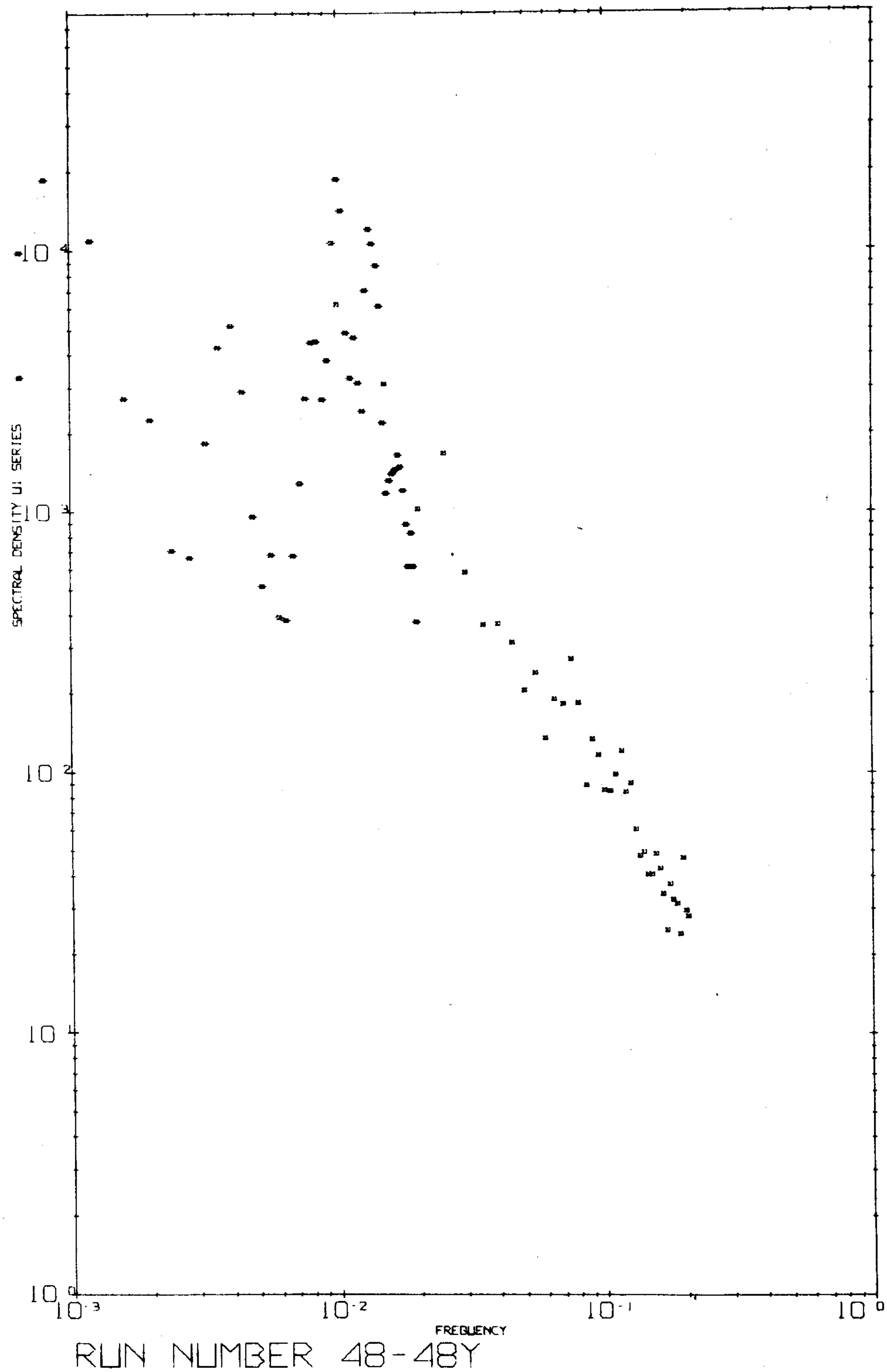


Figure 10 Spectral density function of u (east-west) component of velocity at 120 meters, Station #1, September - November, 1969

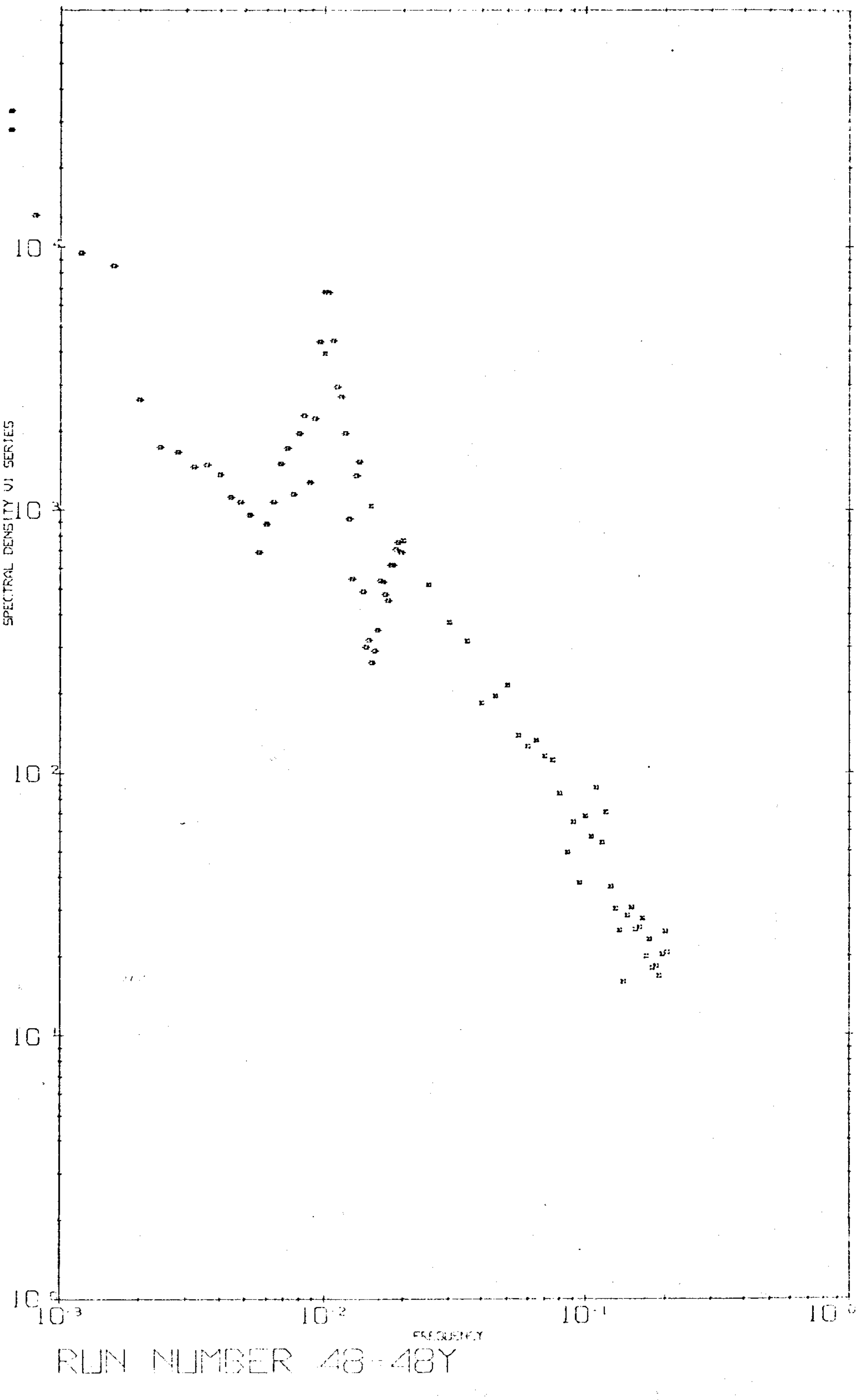


Figure 11 Spectral density function of v (north-south) component of velocity at 120 meters, Station #1, September - November, 1969

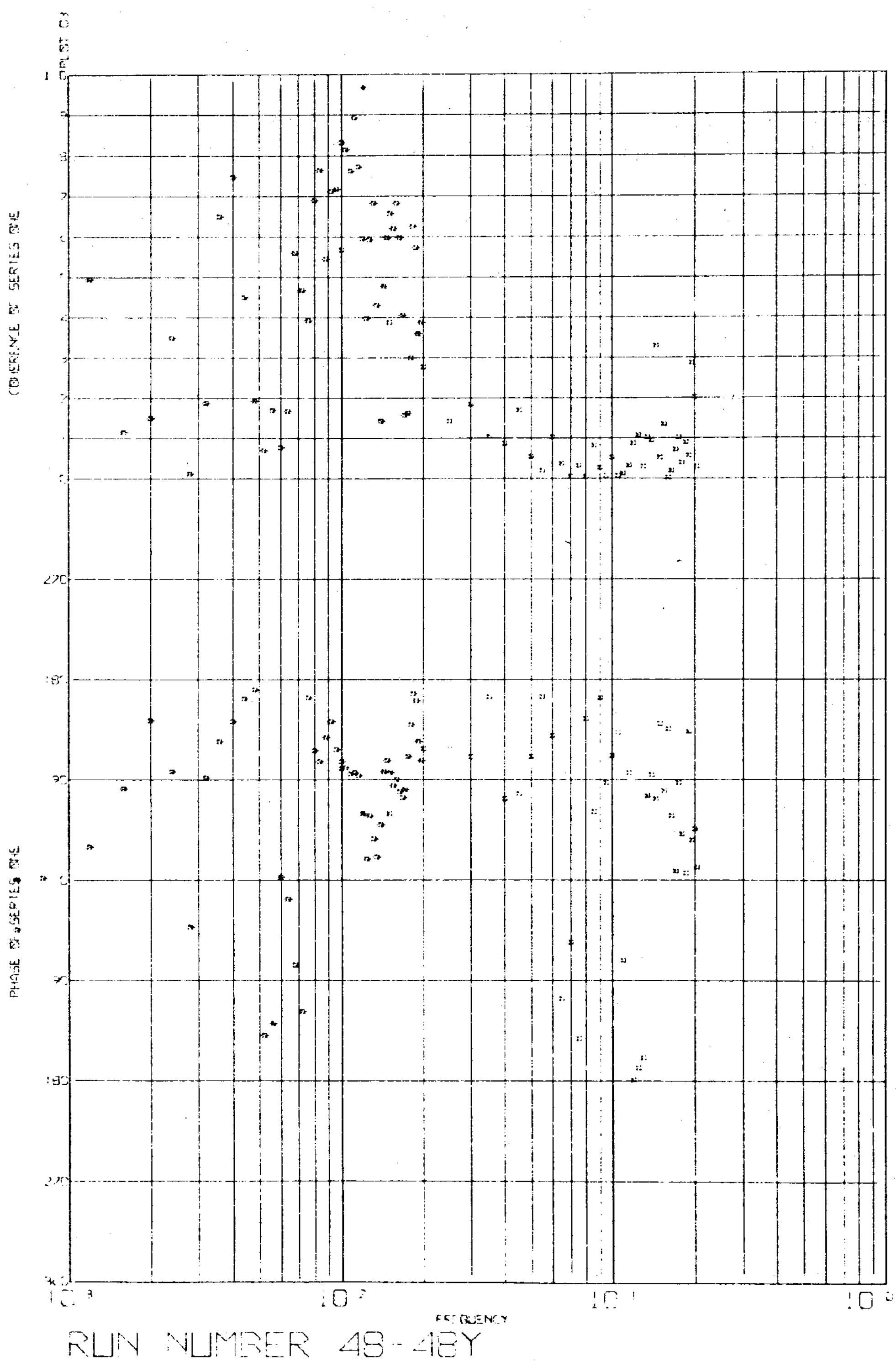


Figure 12 Phases and squared coherence between u and v components of velocity at 120 meters, Station #1, September - November, 1969

Acknowledgements

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APPENDIX A METHOD OF INSTALLATION

Installation began with the launching of the subsurface float. With the subsurface float in the water, the instrument string wire was payed out to the pre-selected and prepared cable terminals. All instruments used in this sampling period were in line and were connected into the string wire. Each instrument was connected to the string wire employing 1/2 inch galvanized safety shackles. Three stainless steel swivels were used in the instrument string: one above the top current meter, one below the bottom current meter, one below the bottom current meter, and one at the anchor. Nominal depths of the current meters were 40, 80, and 120 meters.

After the last meter was attached to the cable, the remaining string wire was payed out via a snatch block on the cargo boom forward of the main block. At 75 to 100 meter intervals, air-filled floats manufactured by Polyform, Allesund, Norway, were attached to sustain the string wire along the water surface. The string wire was payed out as the ship drifted downwind.

String wire installation and retrieval on the first eight installations was made using the gypsy winch mounted on the cargo boom with the wire being payed out from a reel and stand on deck. At this point it was determined that adequate winch capacity existed to spool and store the string wire over the ground wire already stored on the trawl winch drum -- a tremendous time and work saving scheme.

A strain transfer pennant (Fig. A.1) was attached to the anchor end of the string wire prior to spooling the wire onto the winch drum. This pennant consisted of an 8 to 9 foot section of 3/8" wire rope with an eye Nicopressed in one end. The other end of the section of wire was Nicopressed to the string wire 7 to 9 feet from the thimbled anchor end. When the string wire was spooled onto the winch drum, the eye of the pennant was shackled to the working end of the ground line leaving free the thimbled anchor end of the string wire.

When the entire length of string wire has been payed out, the pennant section is passed through to the outboard side of the fair leading snatch block. The thimbled anchor end of the string wire is attached to the bridle of the main anchor which is lashed to the deck of the vessel. Strain is transferred from the ground line on the deep sea winch drum to the main anchor on deck. The ground line is cleared from the snatch block and passed through the main cargo boom block and attached to the ground

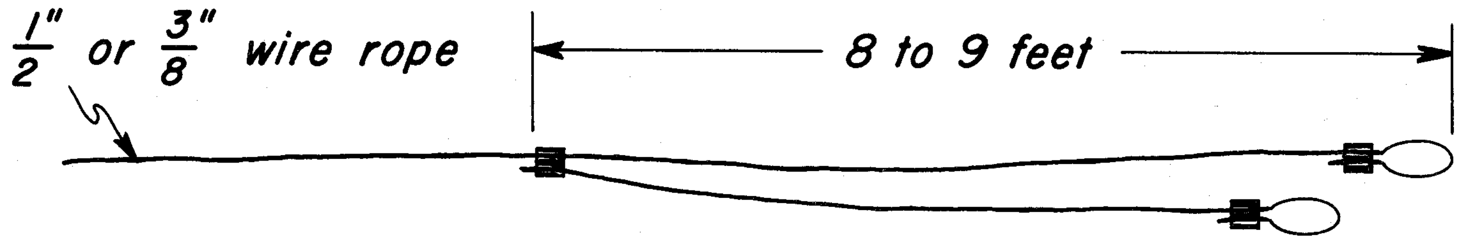

Figure A1 Strain transfer pennant used in current meter installations line anchor bridle. The main anchor is unlashed from the deck and is ready for launch. The vessel is reoriented with the wind and seas if necessary. The main anchor is lowered.

When the main anchor has been lowered to a depth about 100 meters above the sea floor, the precise depth of meter is determined, using the onboard PDR. Calibration of the vessel's PDR was required during our first installations (requirements on PDR depth accuracy in 500 to 1,000 meters have not been stringent prior to the placement of our main anchors). All instruments string wire from the subsurface float to the main anchor is pre-measured and cut before starting the installation. The advantage to this technique over cutting wire to match water depth is that the main anchor can be lowered to very near the sea floor before the precise depth is located. The main anchor is then lowered to the sea floor. Depth and Loran readings are obtained and main anchor location recorded in the ship's log.

Once the ground line is substantially payed out, a check is made of the number of crab floats visible at the surface above the location of the subsurface float. This number reveals the actual depth of the subsurface float. In the event that initial installation was incorrect, the ship master would strain the ground line either up-slope or down-slope to position the system correctly.

Transfer of strain from ground line to nylon retrieving line via the auxiliary anchor is carried out similar to the strain transfer from the instrument string wire to the gound line as described above.

When the strain has been transferred, the auxiliary anchor is lowered to 50 to 75 meters above the sea floor. A subsurface float is attached to the nylon line in an attempt to keep the nylon off the sea floor to prevent chaffing. When the subsurface float was secured, the remainder of the nylon was payed out. The toroidal surface float was attached to the upper end of the nylon retrieval line and launched.

Through Loran fixes the longitude and latitude of the surface marker are determined. The installation is complete when the mooring location is transmitted to the U.S. Coast Guard in Seattle to be published in the Notice to Mariners.

APPENDIX B MANUFACTURE OF MOORING HARDWARE

A. Subsurface Flotation Package

A two-piece fiber glass shell was formed and mounted in a wooden frame. The unit was placed on end, spherical end down. Foam-in-place polyurethan plastic material was mixed in 35 lb. batches and poured into the mold cavity (weather vane end). Batches of foam were mixed and poured at about 30 minute intervals. Upon the completion of the foam pouring process the unit was allowed to stand overnight.

The foam material used was PE-8 Isofoam, manufactured by Isocynate Products, Inc., Wilmington, Delaware. It was to have a density of 8 lbs. per cubic foot when mixed and poured in accordance with the manufacturer's recommendations. Laboratory tests carried out at OSU indicated that the product we poured at OSU had a density of 8.5 to 9 lbs. per cubic foot.

The molded foam core was initially intended to remain in the molding shell. After the first float was poured, it was found that the foam had contracted upon cooling, leaving about 1/4" space between the fiberglass mold shell and the solid foam core. The method of construction was revised to provide for removal and reuse of the fiberglass mold shell for subsequent float molding.

B. Insulating Gromets for stainless steel hardware.

Insulating gromets were constructed to reduce corrosion in the mixed metal situations. Strain members of the current meters, thermistor recorders and stainless steel swivels required an electrical isolation from the galvanized safety shackles, wire rope and other non-stainless items of the mooring.

Mylar gromets were constructed as shown in Figure B-1. No noticeable corrosion was evident due to the mixed metals when employing the above described insulators.

C. Inverted grappnels

A revision in the mooring line was made to include an inverted grappnel. The inverted grappnel was designed and constructed at OSU. The configuration of the inverted grappnel is shown in Figure B-2.

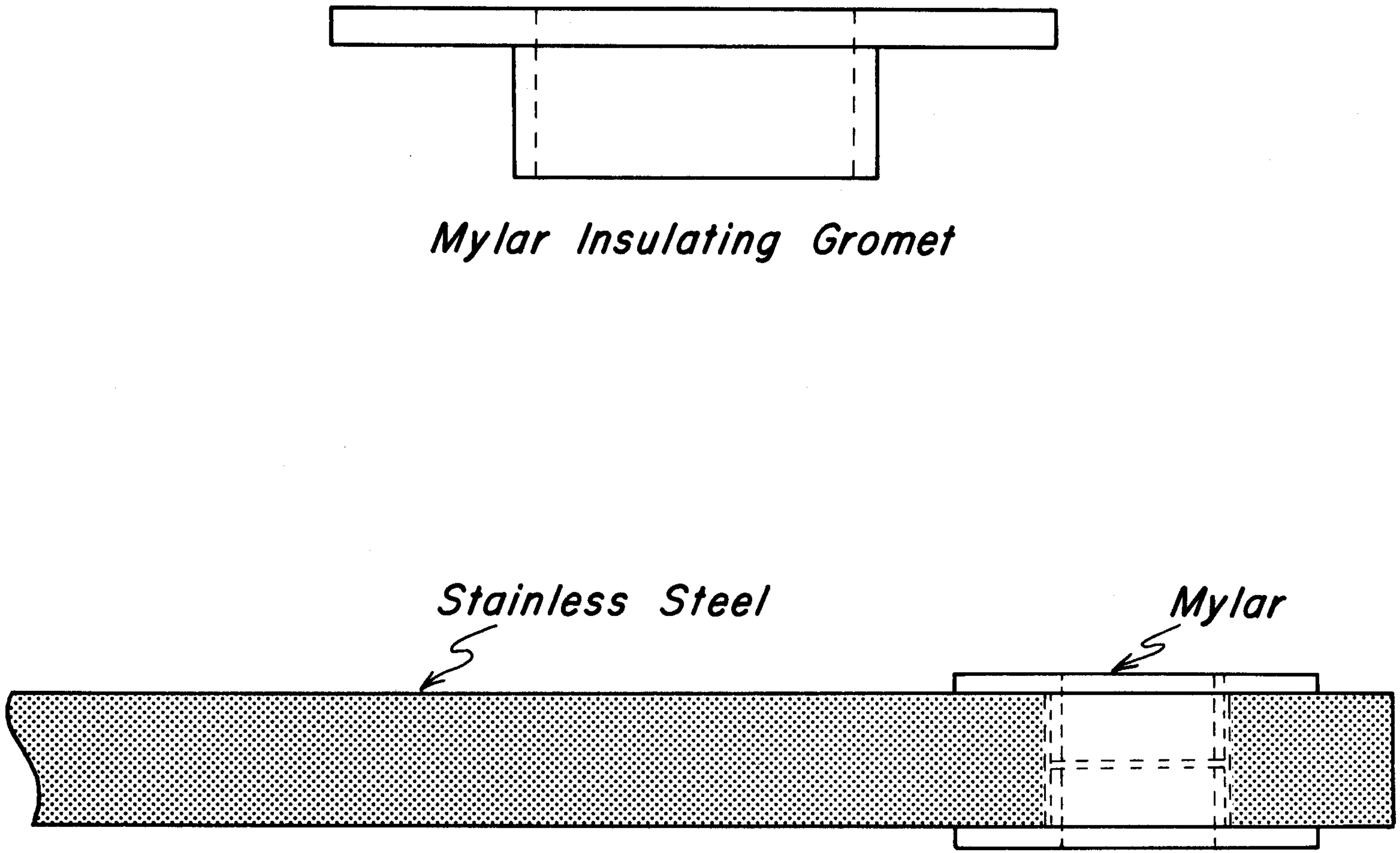

Figure B1 Mylar insulating gromets

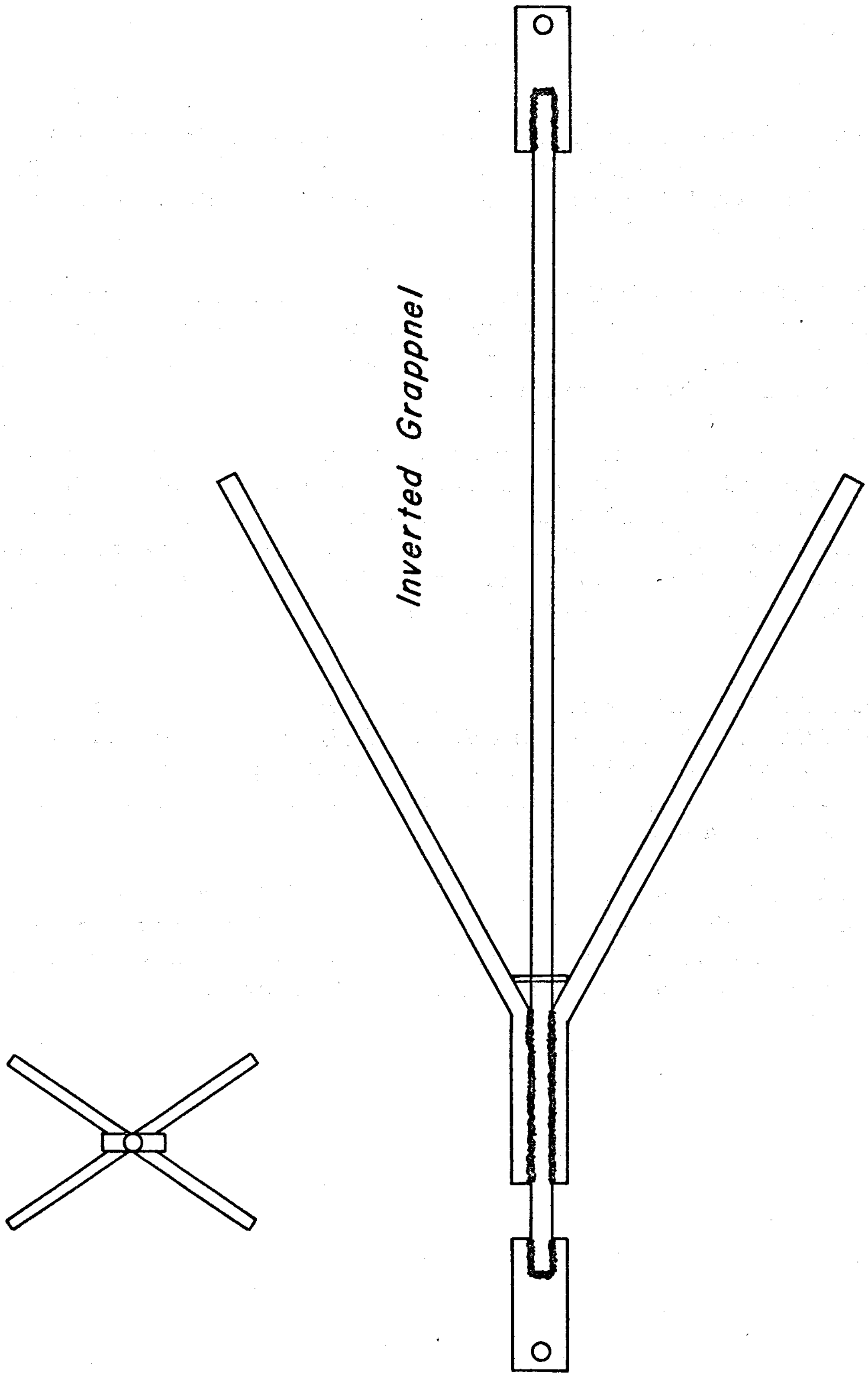

Figure B2 Inverted grappnel

APPENDIX C COMPUTER PROGRAMS

The computer programs written for data reduction of the Braincon current meter data were all written in Fortran IV for use on the CDC 3300 computer of the OSU Computer Center. The major features of each program used are described.

TAPECONV reads the magnetic tape containing raw data and checks for illegal characters. If none occur, the information is buffered out and continues the process, however, if an illegal character does occur, indication of it is given by this program.

DATACON assumes the data to be of the correct form and calculates the first and second differences (using subroutine DIFFS) between each successive speed and direction reading. The readings themselves and the first speed differences are checked for negative speeds, numbers greater than 360°, frame count errors, and delimeter errors. These are listed as are the speed and direction and the first and second differences of each.

CORRECTD allows corrections to be made in the data obtained from DATACON. The corrections are made from a remote terminal. The types of correction which can be made by this program are (1) deleting a frame entirely, (2) inserting data frames, and (3) replacing values of a data frame.

VECTOR reads the corrected data, calculates the u(east-west) and v (north-south) components of velocity for each reading, calculates the time at which the readings were taken, lists the results, and buffers out the speed, direction, u and v values onto a disk file.

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13. ABSTRACT

A summary of the first year of the THEMIS observation program is presented. The observations were made from November, 1968 to November, 1969. The primary measurements were time series of current velocity with supplementary data of wind velocity.

The emphasis is on the methods of observation and the procedures used in data reduction and analysis. Discussion and interpretation of the initial analysis is also presented.

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