Department of

OCEANOGRAPHY

SCHOOL OF SCIENCE

OREGON STATE UNIVERSITY

A Compilation of Observations from Moored Current Meters, Thermographs, and Wind Instrument

Volume IV: Peru Continental Shelf
March-April 1969

by

D. B. Enfield, R. L. Smith
J. G. Pattullo, R. D. Pillsbury
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National Science Foundation
Grant GA 1435
Office of Naval Research
Contract N00014-67-A-0369-0007
Project NR 083-102

Data Report 44 **Reference 70-26**
September 1970

DEPARTMENT OF OCEANOGRAPHY
SCHOOL OF SCIENCE
OREGON STATE UNIVERSITY
Corvallis, Oregon 97331

A COMPILATION OF OBSERVATION FROM MOORED CURRENT METERS, THERMOGRAPHS, AND WIND INSTRUMENT

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John V. Byrne
Chairman

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ABSTRACT

A summary of moored instrument measurements over the continental shelf of Peru is presented. Measurements of variables were made in an upwelling zone between Pisco and San Juan, from 28 March to 9 April, 1969. Time series of temperature and horizontal current and wind velocities were obtained at several depths and locations by an array of moored, recording instruments. Supplementary hydrographic and drogue measurements were also made.

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INTRODUCTION

The measurements summarized in this data report were taken during the 1969 cruise of the R/V THOMAS G. THOMPSON to South America, called the PISCO Cruise. The moored instrument activity was conducted by the Coastal Currents Project as part of the International Biological Program. The study, like similar ones previously conducted off the Oregon coast, was designed to investigate the physical processes in a coastal upwelling regime.

The data from this study were collected from 28 March to 9 April, over the continental shelf of Peru between Pisco and San Juan (Figure 1).

Various first-order statistics and plots of error-corrected and hourly-averaged data are presented for time series of current velocity, wind velocity, and temperature. A tabulated summary of drogue displacements and supplemental drogue information is presented. Hydrographic data are not presented, but are available from the University of Washington (University of Washington Special Report #42).

This is the fourth in a series of data reports summarizing successive phases of activity conducted by the Coastal Currents Project. The data reports of the first phase (Collins, Creech, and Pattullo, 1966), second phase (Mooers, Bogert, Smith, and Pattullo, 1968), and third phase (Pillsbury, Smith, and Pattullo, 1970) have been compiled in similar formats. A more complete description of the mooring system used is given in a paper by Pillsbury, Smith and Tipper (1969). An analysis of the relationships between temperature and winds has been given in a M.S. thesis by Fisher (1970). A comprehensive summary of the results from the first phase of this program has been given in a Ph. D. thesis by Collins (1968), while an excellent theoretical discussion of much of our work is given in a Ph. D. thesis by Mooers (1970). Ph. D. theses in preparation by R. D. Pillsbury and D. Cutchin will contain analyses of data from the third phase of the program. A discussion of the data in this report is presented in an M. S. thesis by Enfield (1970).

Rather than tabulate our "data bank", we think it is of greater interest to display our data records in graphical and tabular forms of first-order statistics. By pursuing this approach, we can provide feedback for subsequent measurements and calculations rather rapidly--months to years in advance of formal publication of only the principal results. A secondary objective is to indicate the need for "auxiliary data" of good quality by showing the utility of that which has actually been available. Since we think it is important to develop the descriptive art of time series and vertical profile presentation at an intermediate stage, i.e., preliminary to correlation and spectral analyses, we expect to continue to experiment with various graphical and tabular presentations in the future, rather than to adhere to a rigid format. In a data report of this nature, it will be necessary to record some items only once, others on all occasions. By exposing ourselves to internal and external review, we hope to stimulate constructive criticism. We believe it is also true that our work is most useful to a broad audience of oceanographers in this intermediate form; the subsequent, more sophisticated analyses are likely to be chiefly of interest to dynamical or theoretical physical oceanographers.

OBSERVATIONAL PROGRAM

Recording current meters and thermographs, and a wind recorder were moored at the locations and depths shown in Figures (1) and (2). During an intensive two week study, continuous data records from these instruments were supplemented by bottle casts, shallow drogues, and surveys of surface properties. Except for the two hydrographic sections shown in Figure (1), almost all work was conducted within an area above the continental shelf and extending about 120 km along the coast (the shelf is relatively narrow, extending only 30 km or less offshore).

Of the three thermographs shown in Figure (2), only the one at 25 meters, inshore (CM-1) yielded usable data. The wind recorder and the five current meters shown all yielded data. The extent of data retrieval for the moored instruments and the times and durations of hydrographic and drogue activities are shown in the bar graph of Figure (3).

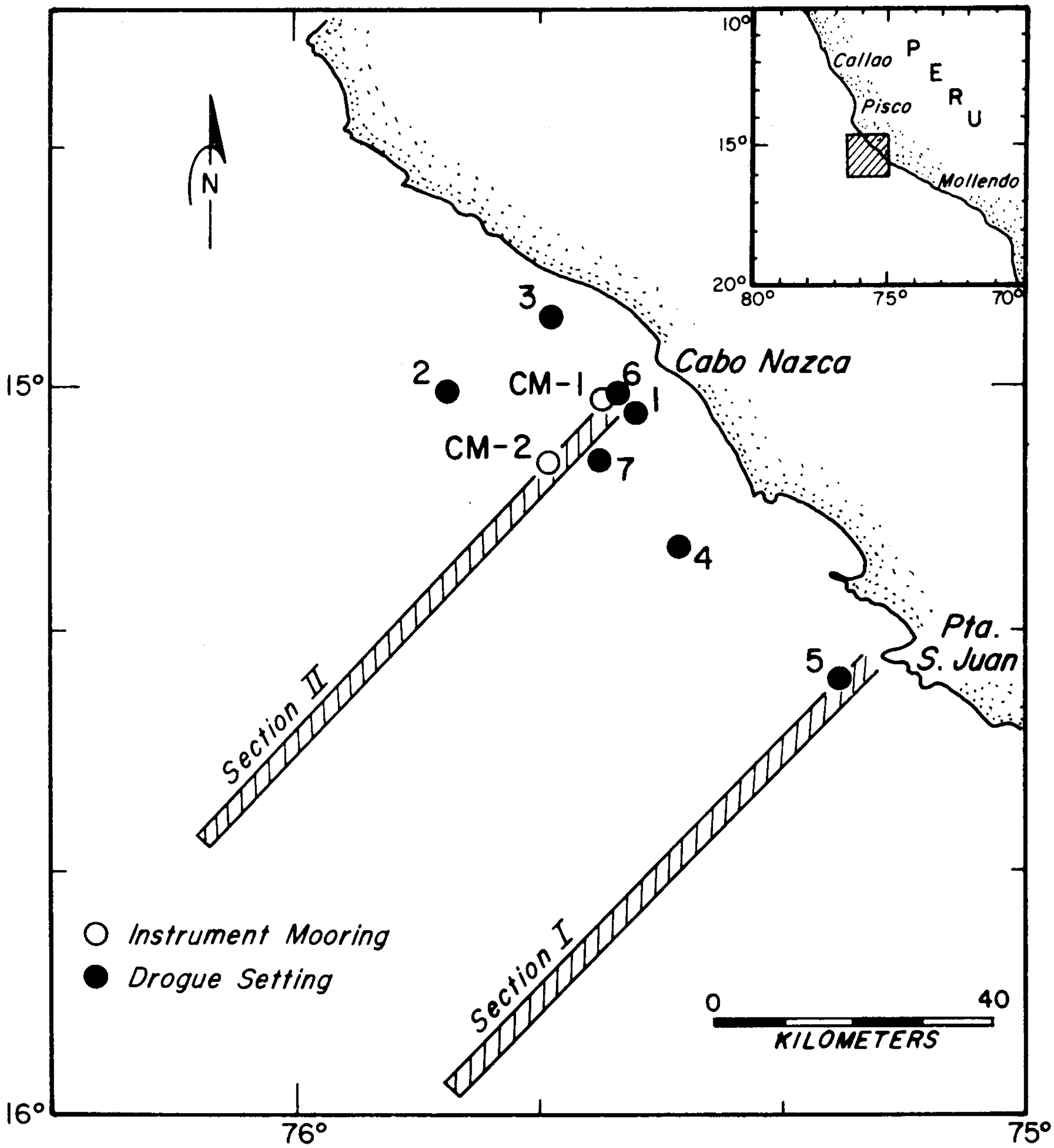


Figure 1. Location of the PISCO study and positions of moored instruments, drogues, and hydrographic sections.

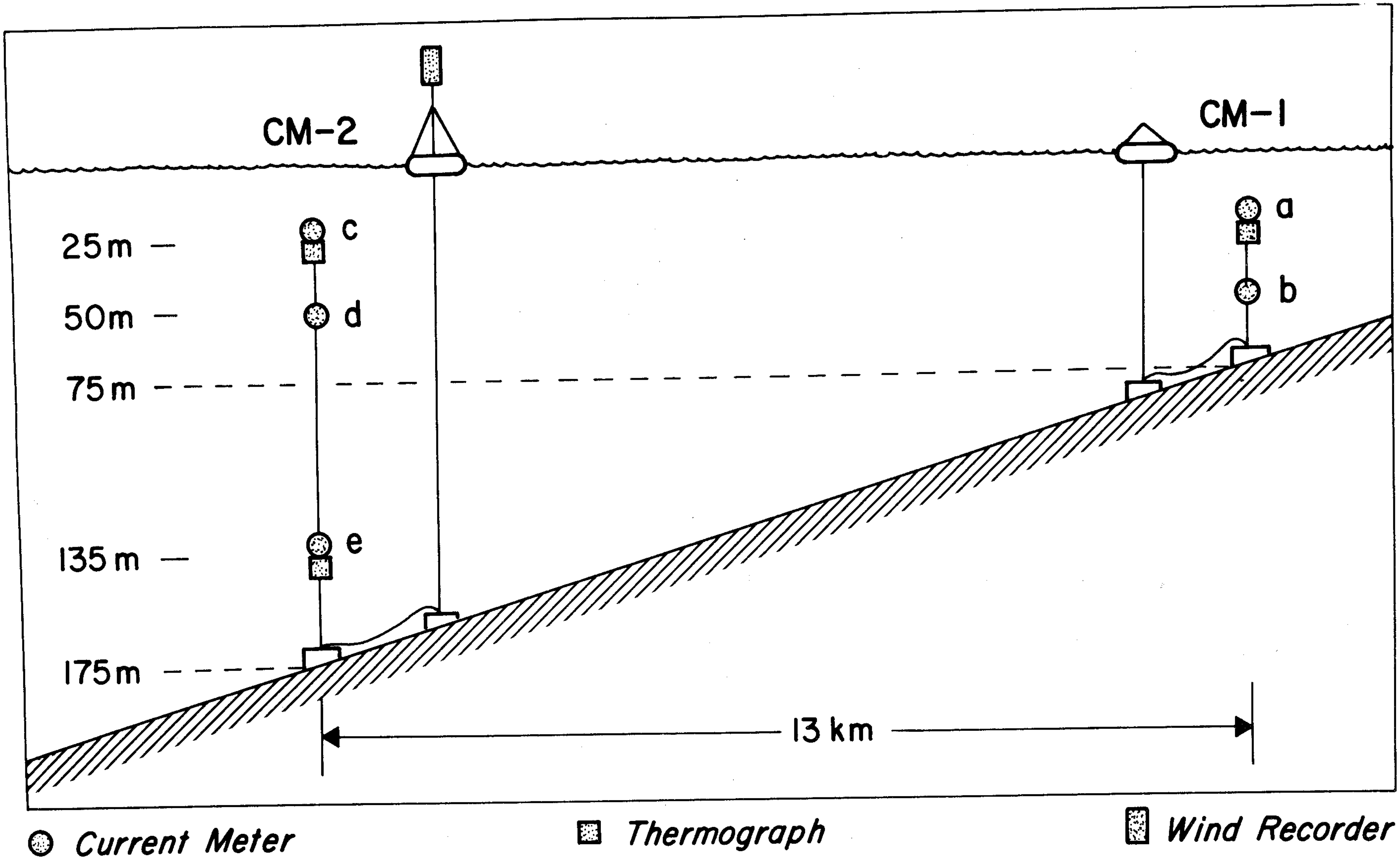


Figure 2. Configuration of the moored instrument array.

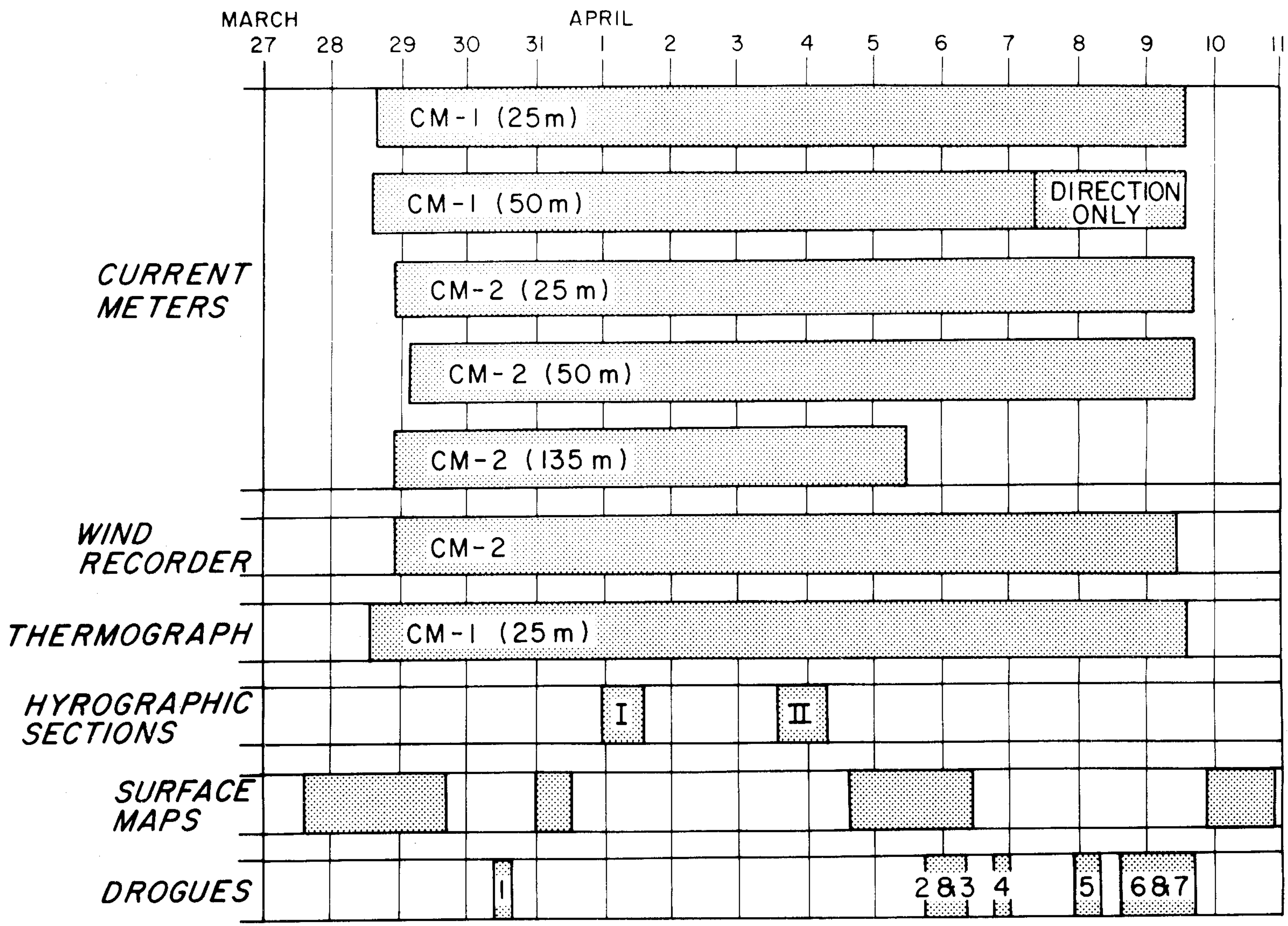


Figure 3. Summary of data retrieved. Vertical lines refer to 00 hours (GMT) on the indicated date.

INSTRUMENTS

Current velocity in the sensor array was measured by Braincon Type 316 Histogram Current Meters (Braincon Corporation, 1965; Sunblad, 1965). Current observations were made continuously over 20-minute periods and recorded on photographic film; actually, one minute of the sampling period was used for film advance so only 19 minutes of data were recorded at the the 20-minute sampling rate. Current speed was integrated by the meter over this period and current direction was sampled by the meter as a quasi-frequency curve such as to serve as a low quality histogram which is usually sufficient to identify the extremes and the mode of direction. The mode of direction is taken to be the "mean direction." The "mean direction" and the speed are then combined in a polar coordinate format to give the mean velocity in an observational interval, since a true vector mean is impossible to achieve with the present recording procedure.

The Braincon Type 146 Thermograph recorded temperature at 10-minute intervals (1 minute for film advance and nine minutes of film exposure).

The operational characteristics of the Type 316 Histogram Current Meters and the Type 146 Thermographs are discussed in Mooers (et al., 1968).

The Braincon Histogram Wind Recorder, whose operation is similar to that of the current meters, sampled wind speed and direction at intervals of 20 minutes. A discussion of the operation and calibration of this instrument and the errors involved is given in the APPENDIX.

DATA FROM MOORED INSTRUMENTS

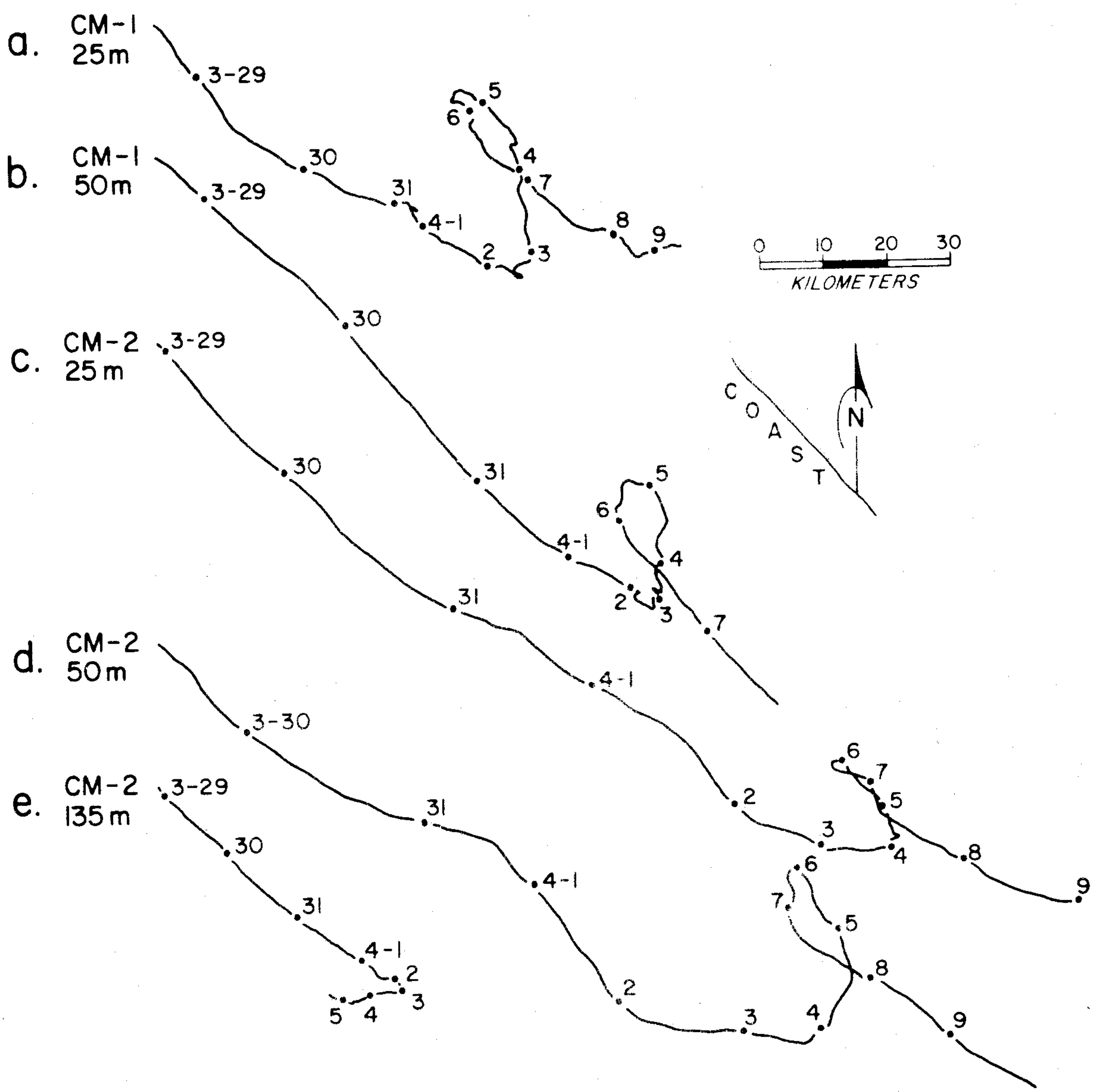
The time series of current, temperature and wind were processed for error detection and first order statistics. These statistics are summarized in Table 1. Details of the data processing techniques are described by Mooers (et al., 1968).

Hourly averaged time series of current and wind were obtained by block-averaging consecutive groups of three twenty-minute values. The figures which follow were constructed from the time series of hourly averages, and include:

(a) Progressive vector diagrams;
(b) Histograms of speed, direction, and the onshore and offshore velocity components;
(c) Plots of speed and velocity components versus time.

Table 1. Statistics from moored instruments.

Mooring location	Depth (m)	Number of observations	Variable	Mean	Standard deviation	Maximum	Minimum	Principal Mode	r.f. (%)	Secondary Mode	r.f. (%)
Current statistics											
CM-1	25	859	Speed, cm/sec	17.6	6.7	39	6	12	18.5	--	--
			Onshore, cm/sec	3.2	6.7	20	-15	0	27.9	--	--
			Longshore, cm/sec	-8.6	15.0	30	-40	-10	23.1	10	9.2
			Direction, °True	169	138	--	--	120	12.8	330	4.1
	50	702	Speed, cm/sec	22.5	10.7	48	9	12	14.0	35	4.4
			Onshore, cm/sec	0.7	6.4	15	-15	0	31.3	--	--
			Longshore, cm/sec	-15.4	18.5	20	-50	-10	16.7	-35	14.1
			Direction, °True	162	83	--	--	130	27.1	335	3.4
CM-2	25	845	Speed, cm/sec	23.7	10.6	53	9	12	7.2	31	3.6
			Onshore, cm/sec	4.2	6.8	25	-30	5	28.2	--	--
			Longshore, cm/sec	-17.9	16.6	25	-55	-10	14.9	-30	13.3
			Direction, °True	148	73	--	--	120	17.6	320	3.3
	50	831	Speed, cm/sec	22.5	8.9	48	6	28	5.8	16	4.3
			Onshore, cm/sec	4.6	8.5	30	-15	0	22.0	--	--
			Longshore, cm/sec	-15.2	16.1	35	-50	-25	21.7	--	--
			Direction, °True	146	77	--	--	130	17.0	330	3.0
	135	542	Speed, cm/sec	10.4	5.8	25	2	7	10.5	16	7.2
			Onshore, cm/sec	-0.7	3.4	20	-10	0	53.9	--	--
			Longshore, cm/sec	-6.6	9.2	10	-25	-15	22.7	5	22.7
			Direction, °True	179	72	--	--	130	20.9	250	6.1
Wind statistics											
CM-2		827	Speed, knots	8.9	3.0	14	1	10.5	10.7	--	--
			Onshore, knots	4.2	2.3	8	-1	5.0	20.3	7.0	12.6
			Longshore, knots	7.5	2.9	13	0	8.5	23.0	5.0	13.4
			Direction, °True	163	16	190	100	170	22.2	--	--
Temperature statistics											
CM-1	25	1718	Temperature °C	16.2	0.3						



Progressive vector diagrams of the recorded currents. Symbols refer to 00 hours (GMT) on the indicated date.

INSTALLATION DETAILS

PISCO STATION CM-1

Position: 15°01.9'S, 75°32.8'W
Depth of Water: 76 meters
Set at 1500 GMT, 28 March, 1969, by R/V THOMPSON
Retrieved at 1430 GMT, 9 April, 1969, by R/V THOMPSON
Data Interval: 1520 GMT, 28 March-1340 GMT, 9 April, 1969

Instrumentation

Current meters and a thermograph were placed at depths of 25 and 50 meters as follows:

Depth	Histogram Current Meter Serial No.	Thermograph Serial No.
25m	3160054	1460087
50m	3160049	

Current meters cycled every 20 minutes; thermograph cycled every 10 minutes.

PISCO STATION CM-2

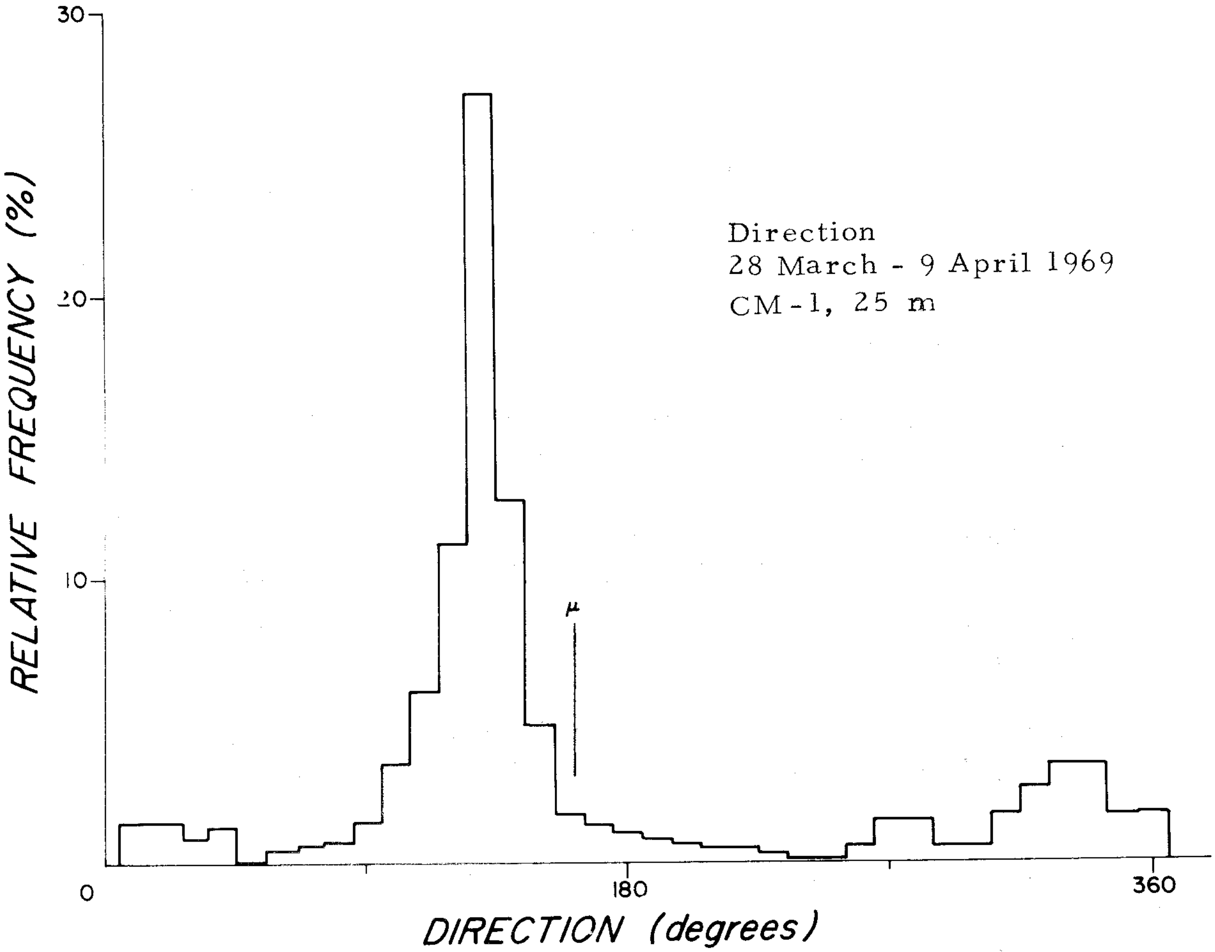
Position: 15°06.3'S, 75°36.5'W
Depth of Water: 178 meters
Set at 2200 GMT, 28 March, 1969, by R/V THOMPSON
Retrieved at 1630 GMT, 9 April, 1969, by R/V THOMPSON
Data Interval: 2220 GMT, 28 March-1600 GMT, 9 April, 1969

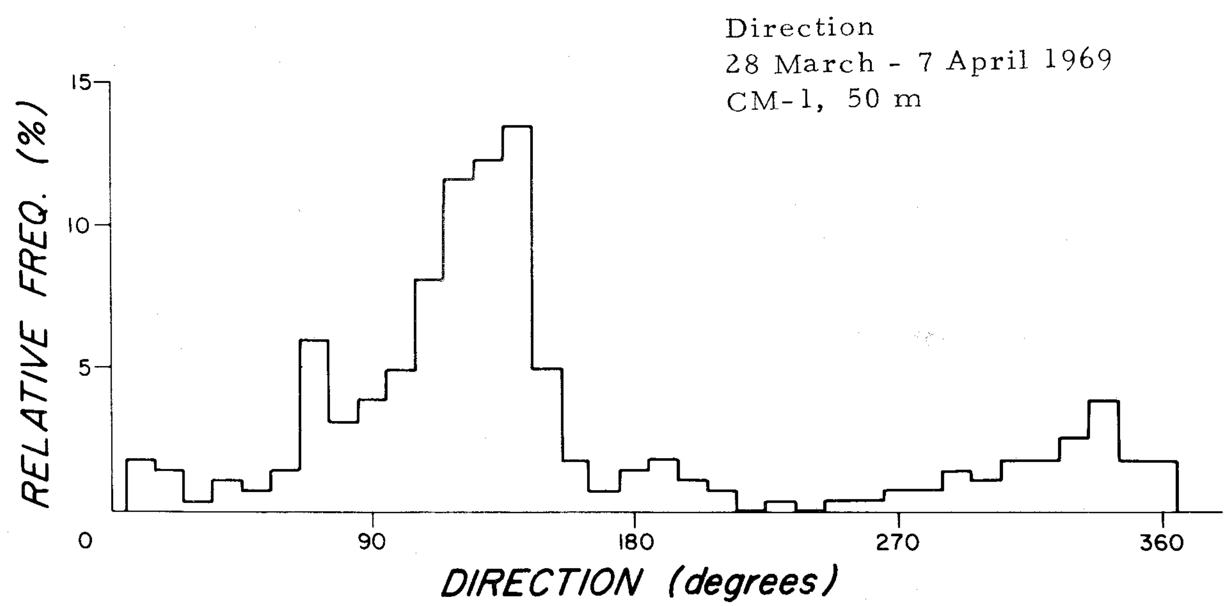
Instrumentation

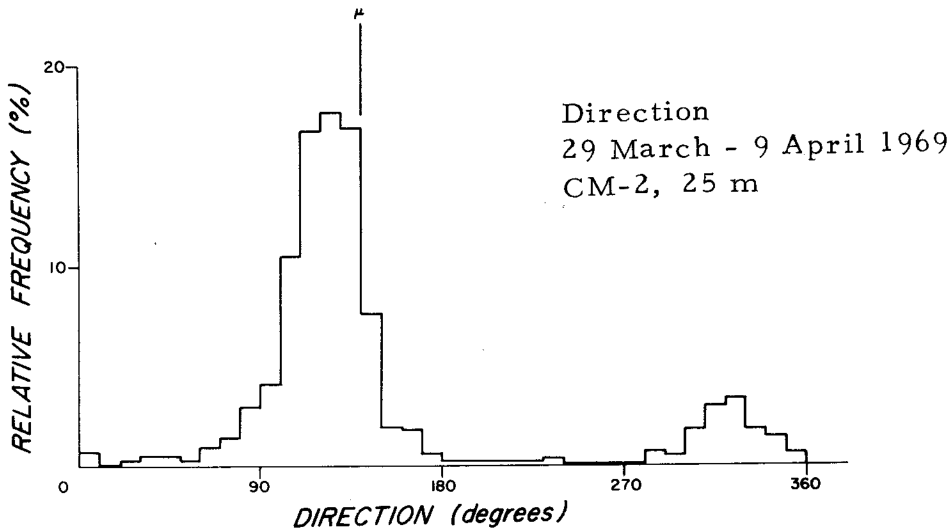
Current meters and thermographs were placed at depths of 25, 50, and 135 meters as follows:

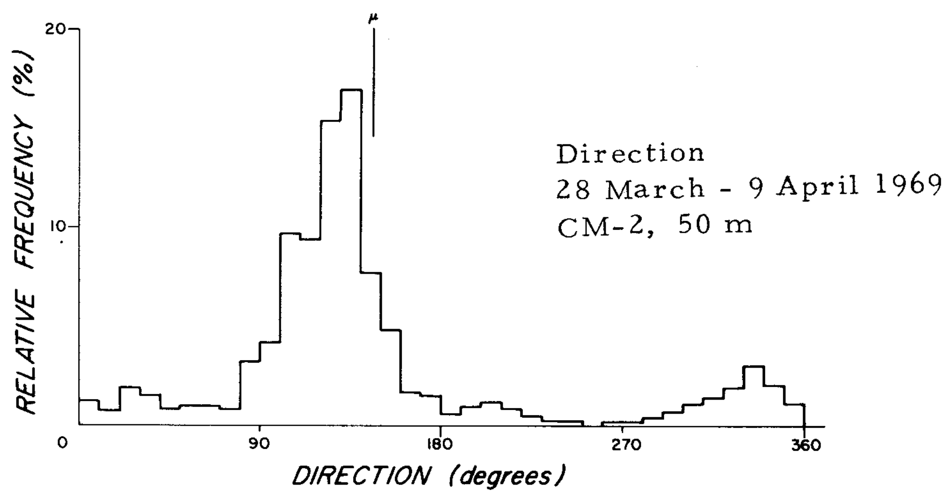
Depth	Histogram Current Meter Serial No.	Thermograph Serial No.
25m	3160088	14600089
50m	3160089	
135m	3160055	14600088

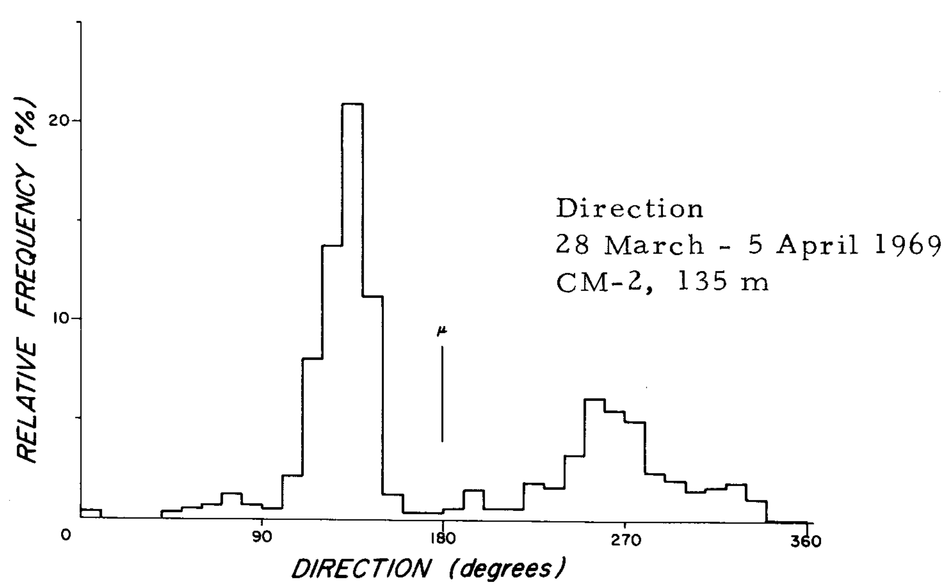
Current meters cycled every 20 minutes; thermographs cycled every 10 minutes.

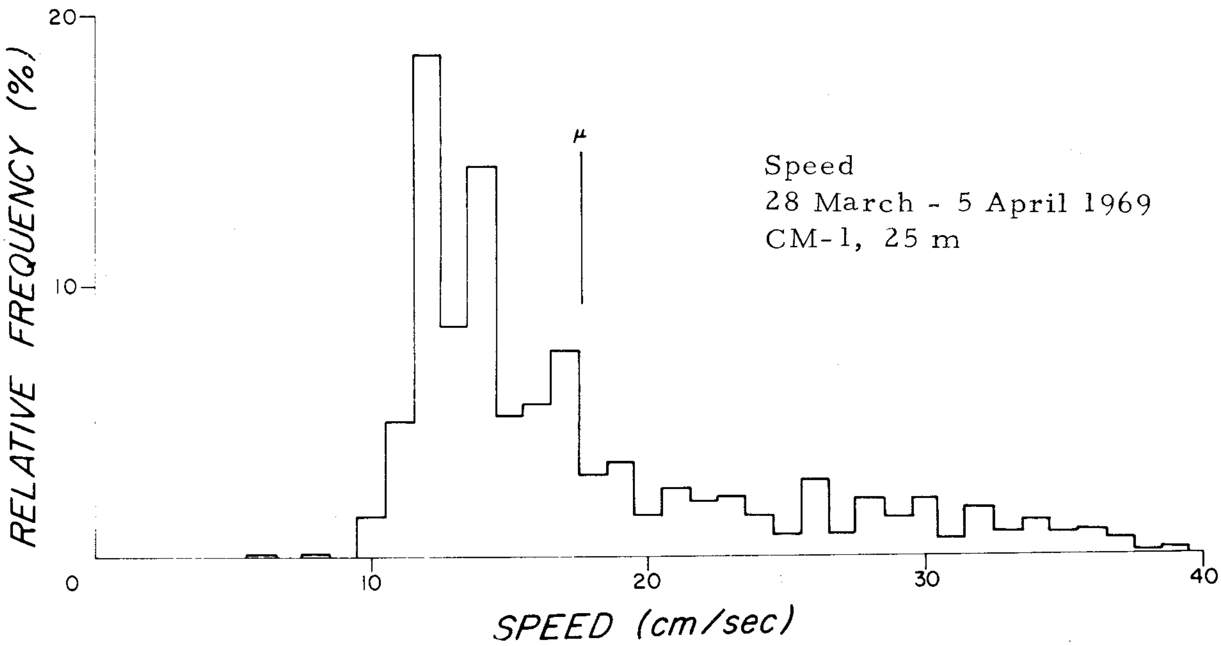

Direction
28 March - 9 April 1969
CM-1, 25 m
RELATIVE FREQUENCY (%)
30
20
10
0
μ
180
360
DIRECTION (degrees)

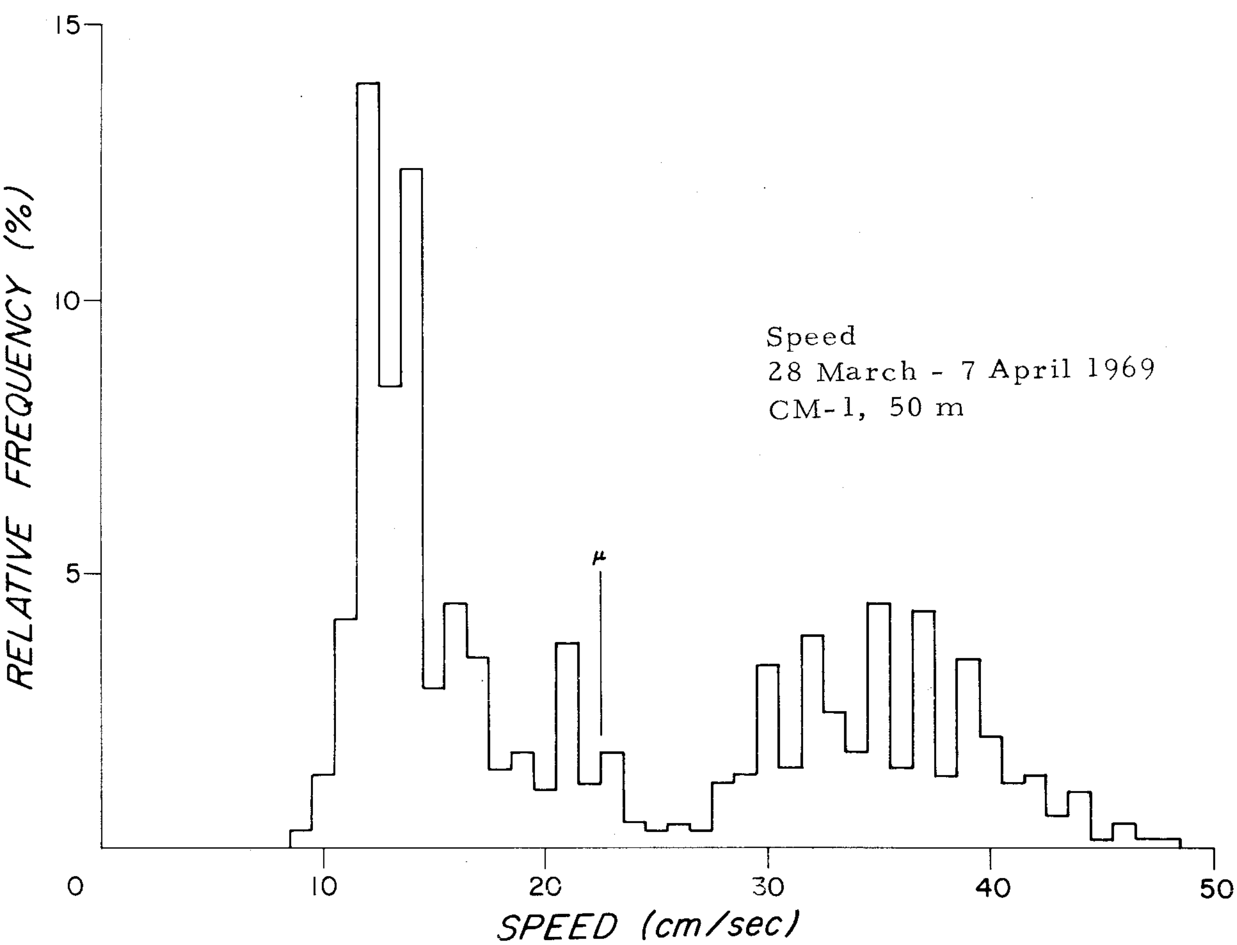

Direction
28 March - 7 April 1969
CM-1, 50 m
RELATIVE FREQ. (%)
15
10
5
0
90
180
270
360
DIRECTION (degrees)

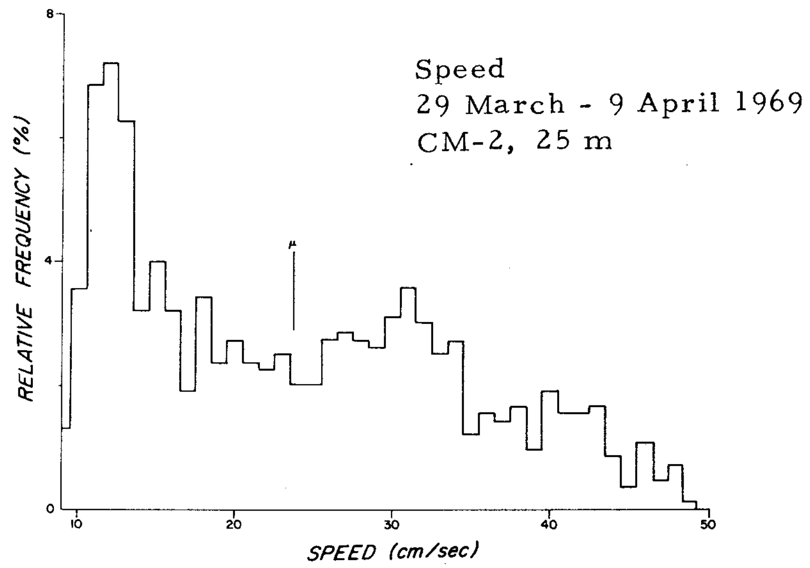

μ
20
10
0
RELATIVE FREQUENCY (%)
90
180
270
360
DIRECTION (degrees)
Direction
29 March - 9 April 1969
CM-2, 25 m

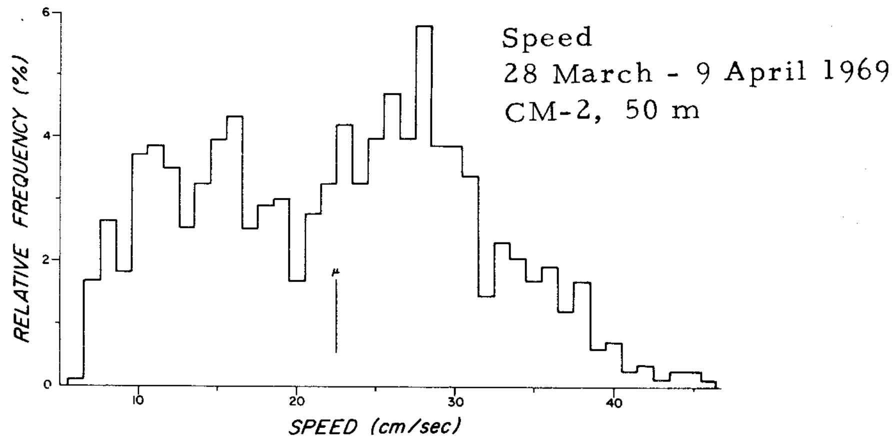

μ
20
10
0
RELATIVE FREQUENCY (%)
90
180
270
360
DIRECTION (degrees)
Direction
28 March - 9 April 1969
CM-2, 50 m

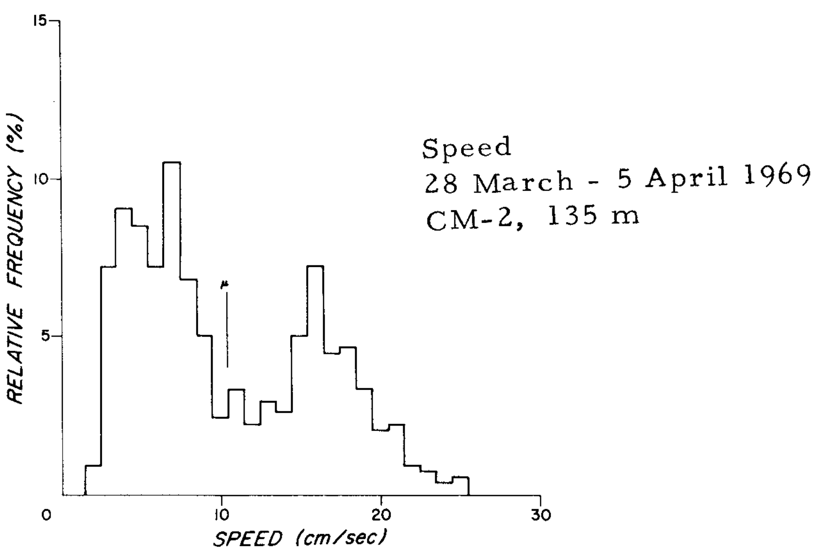

20
10
0
RELATIVE FREQUENCY (%)
μ
90
180
270
360
DIRECTION (degrees)
Direction
28 March - 5 April 1969
CM-2, 135 m


20
10
0
RELATIVE FREQUENCY (%)
μ
Speed
28 March - 5 April 1969
CM-1, 25 m
10
20
30
40
SPEED (cm/sec)


15
10
5
0
RELATIVE FREQUENCY (%)
μ
Speed
28 March - 7 April 1969
CM-1, 50 m
10
20
30
40
50
SPEED (cm/sec)


Speed
29 March - 9 April 1969
CM-2, 25 m
RELATIVE FREQUENCY (%)
SPEED (cm/sec)
μ


Speed
28 March - 9 April 1969
CM-2, 50 m
RELATIVE FREQUENCY (%)
SPEED (cm/sec)
μ


Speed
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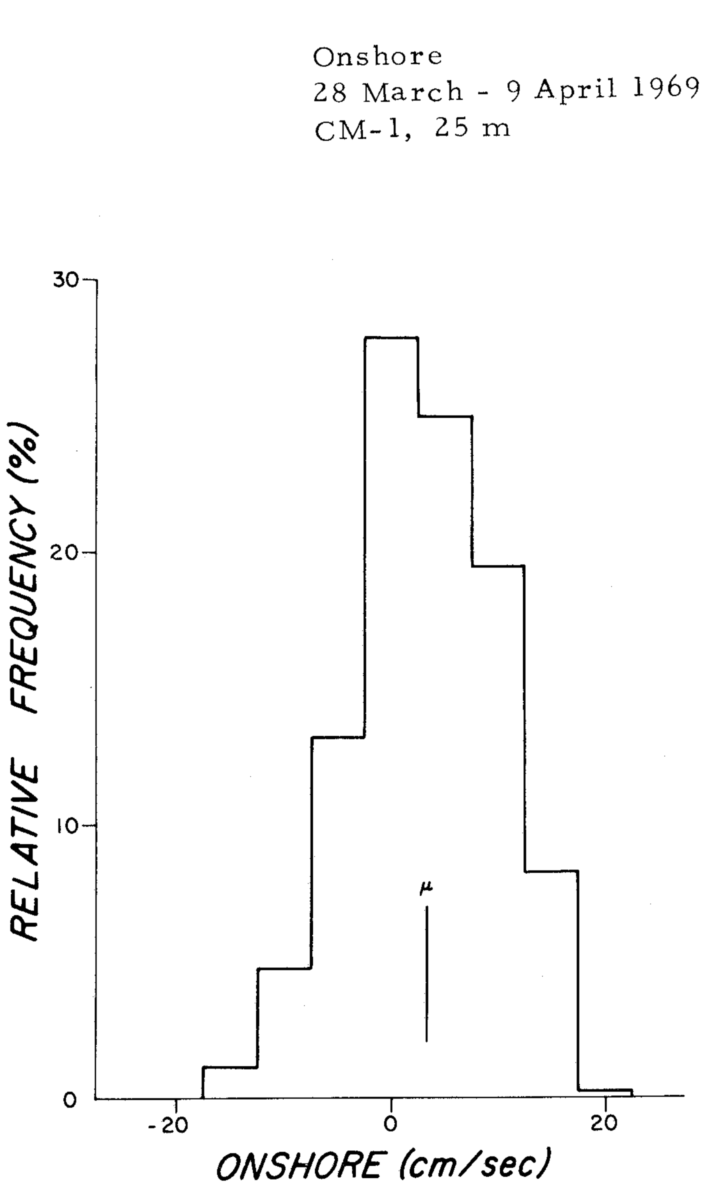
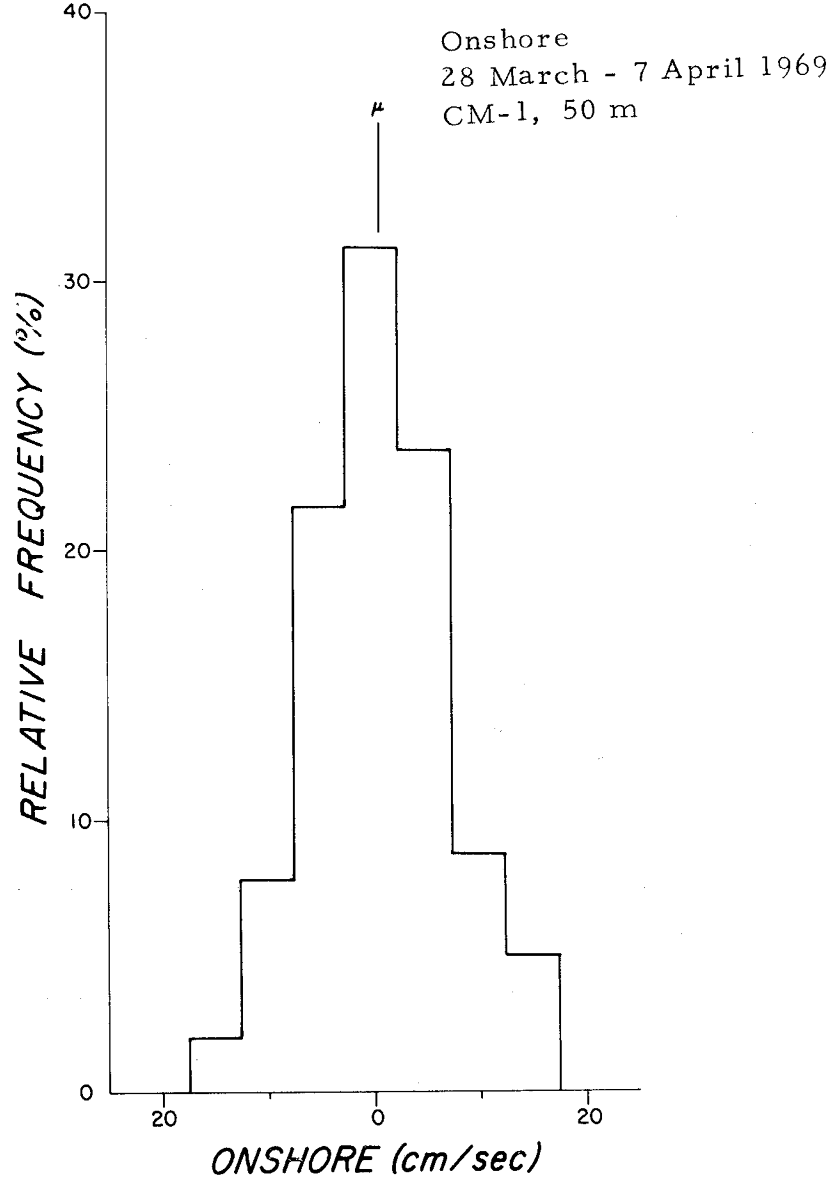
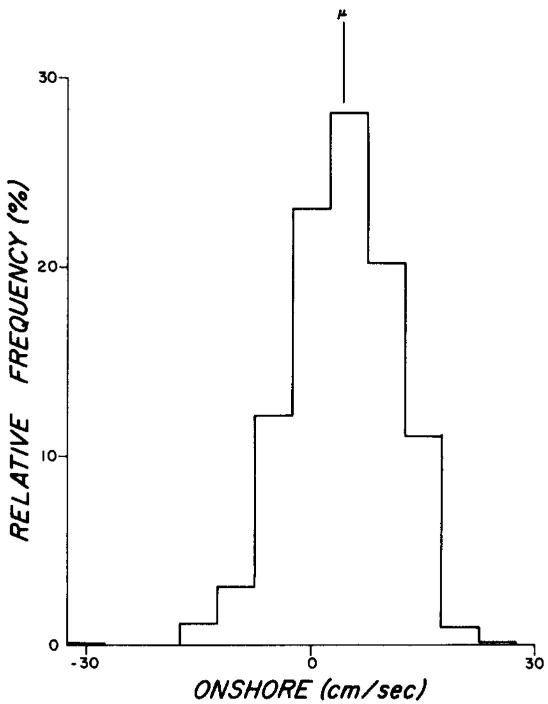
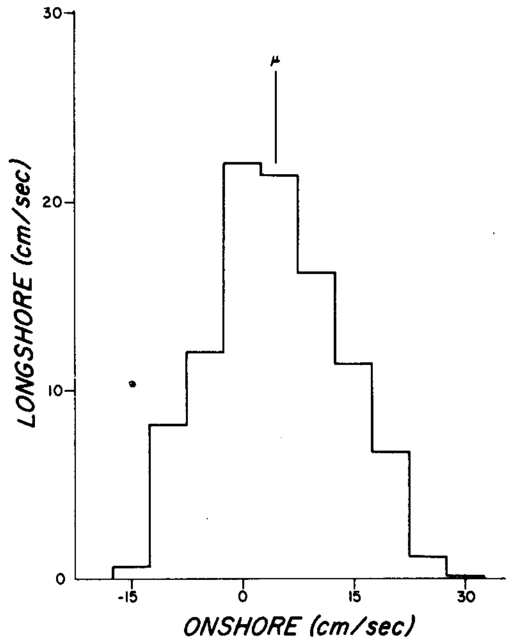
CM-2, 135 m
RELATIVE FREQUENCY (%)
SPEED (cm/sec)
μ


Onshore
28 March - 9 April 1969
CM-1, 25 m
μ
RELATIVE FREQUENCY (%)
30
20
10
0
-20
0
20
ONSHORE (cm/sec)

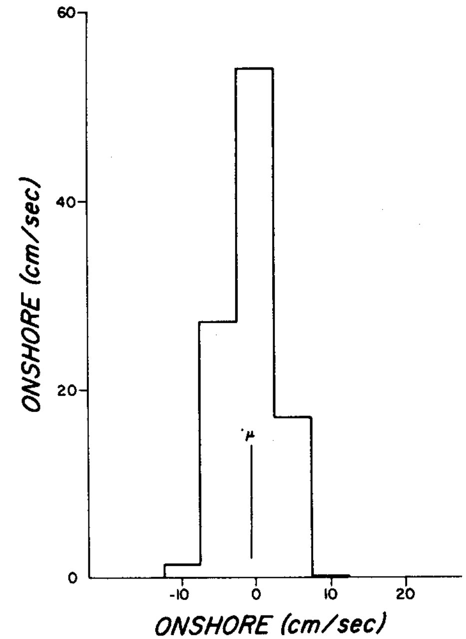

Onshore
28 March - 7 April 1969
CM-1, 50 m
μ
RELATIVE FREQUENCY (%)
40
30
20
10
0
20
0
20
ONSHORE (cm/sec)



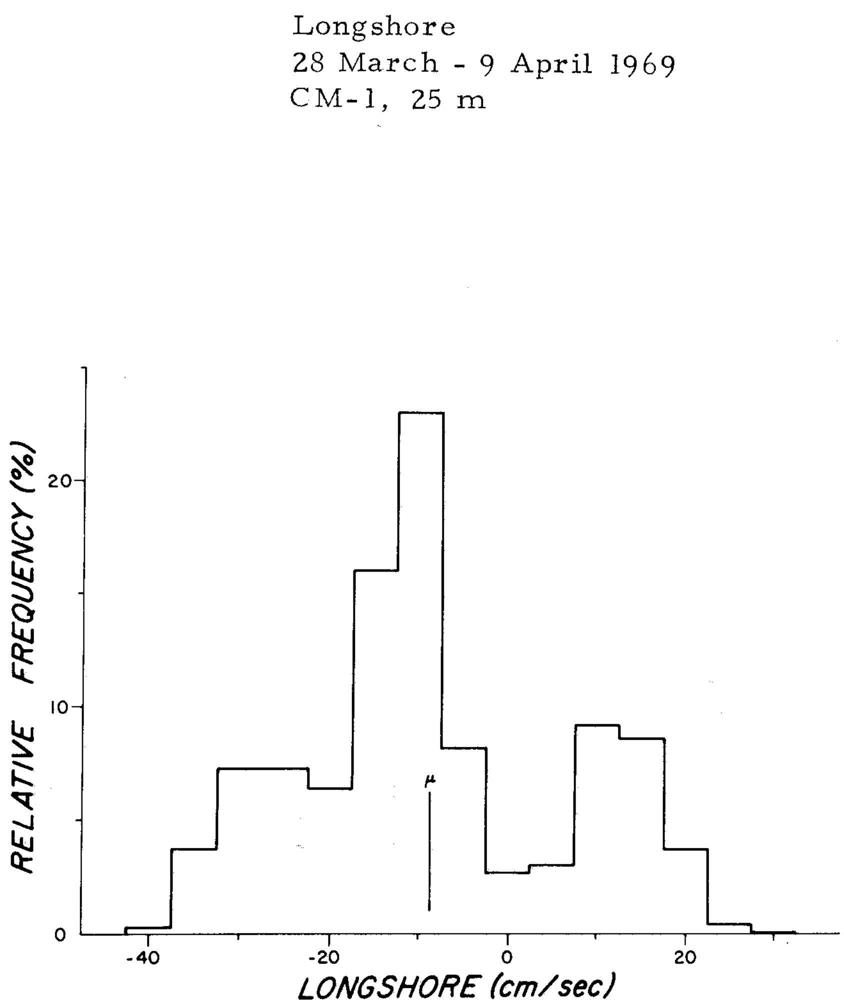
Onshore
29 March - 9 April 1969
CM-2, 25 m

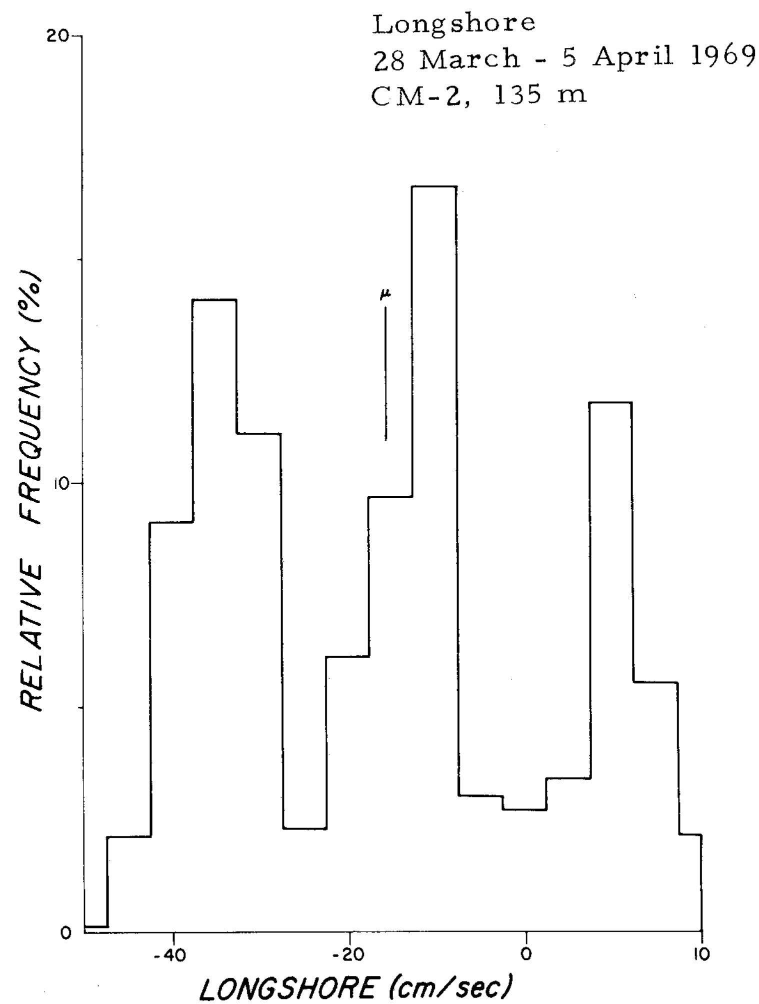


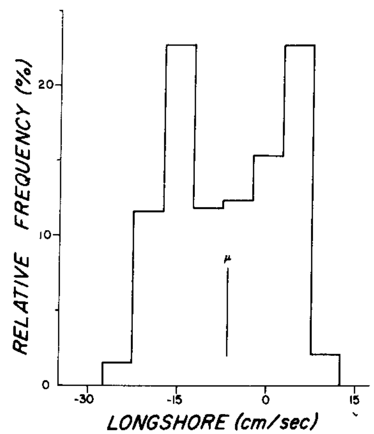
Onshore
28 March - 9 April 1969
CM-2, 50 m



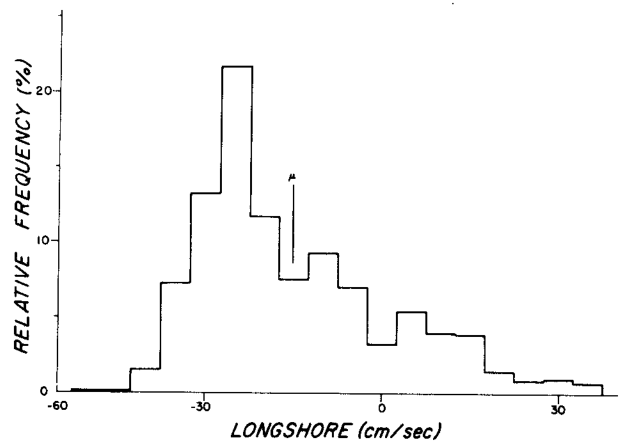
Onshore
28 March - 5 April 1969
CM-2, 135 m


Longshore
28 March - 9 April 1969
CM-1, 25 m
RELATIVE FREQUENCY (%)
LONGSHORE (cm/sec)
μ
0
10
20
-40
-20
0
20

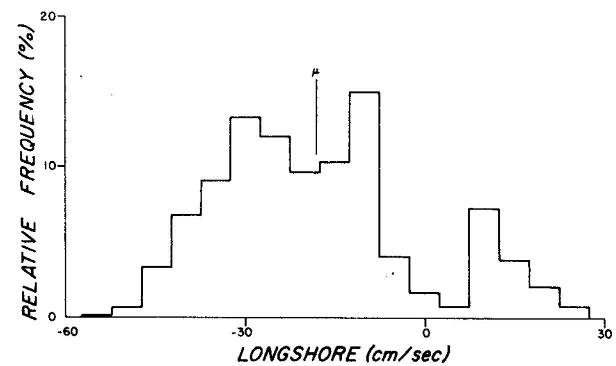

Longshore
28 March - 5 April 1969
CM-2, 135 m
RELATIVE FREQUENCY (%)
LONGSHORE (cm/sec)
μ
0
10
20
-40
-20
0
10



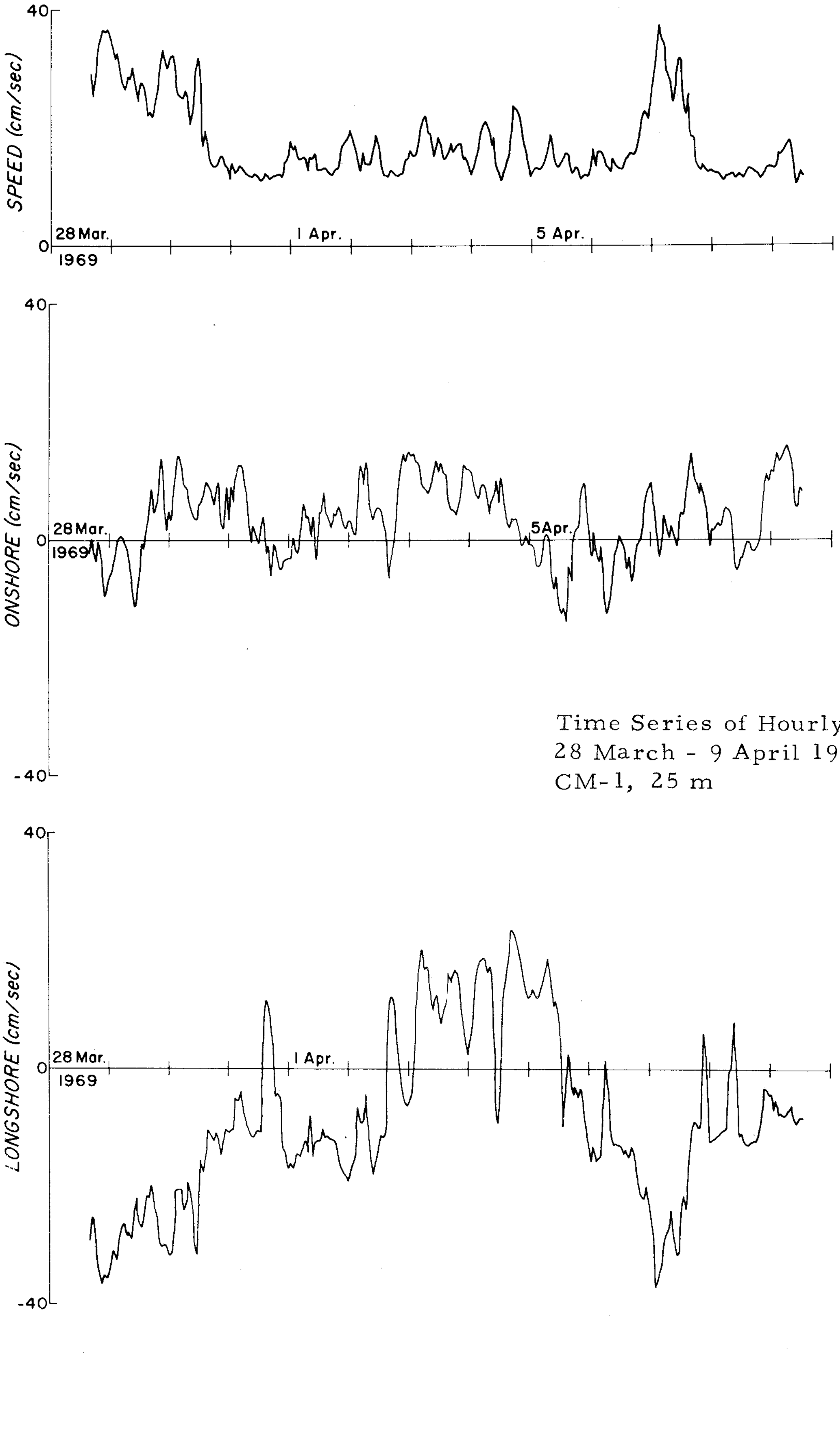
Longshore
29 March - 9 April 1969
CM-2, 25 m



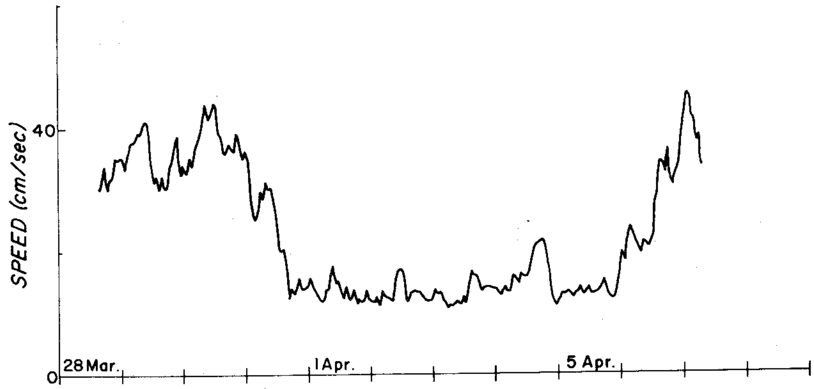
Longshore
28 March - 9 April 1969
CM-2, 50 m

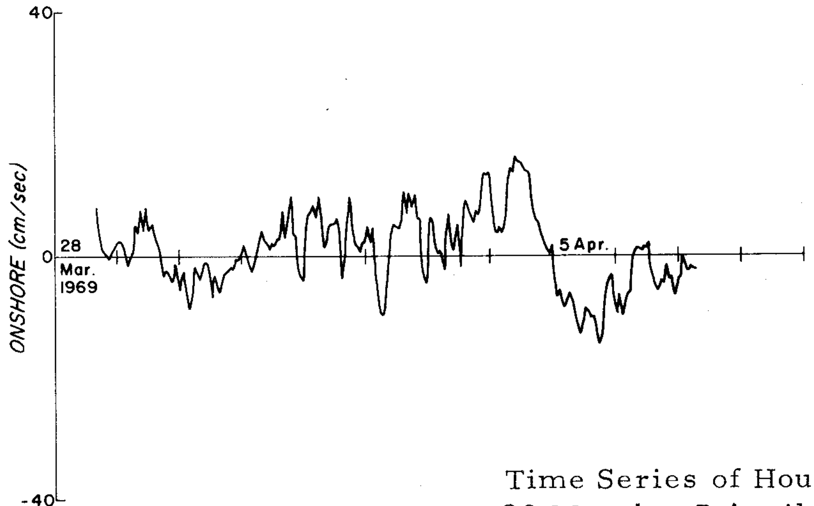


Longshore
28 March - 5 April 1969
CM-2, 135 m

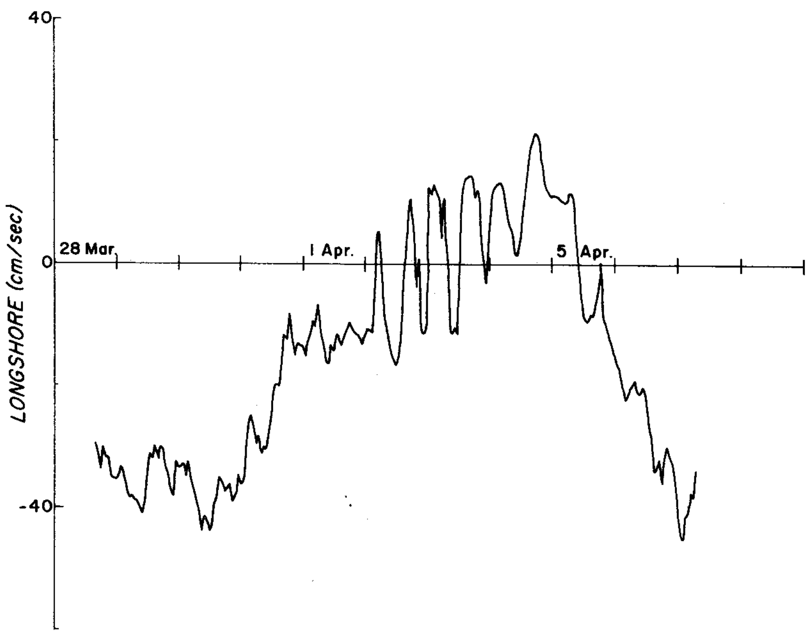


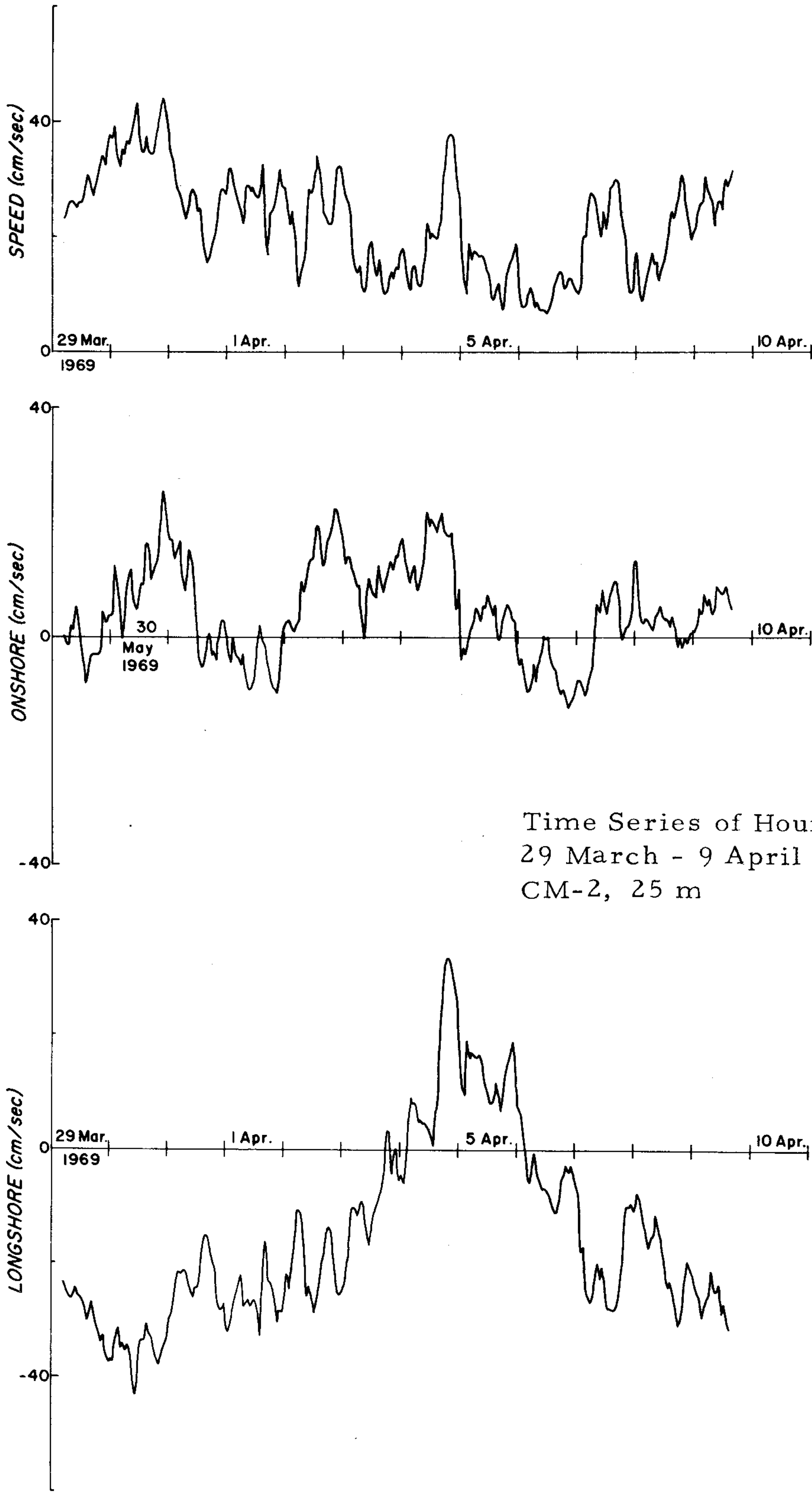
Time Series of Hourly Averages
28 March - 9 April 1969
CM-1, 25 m



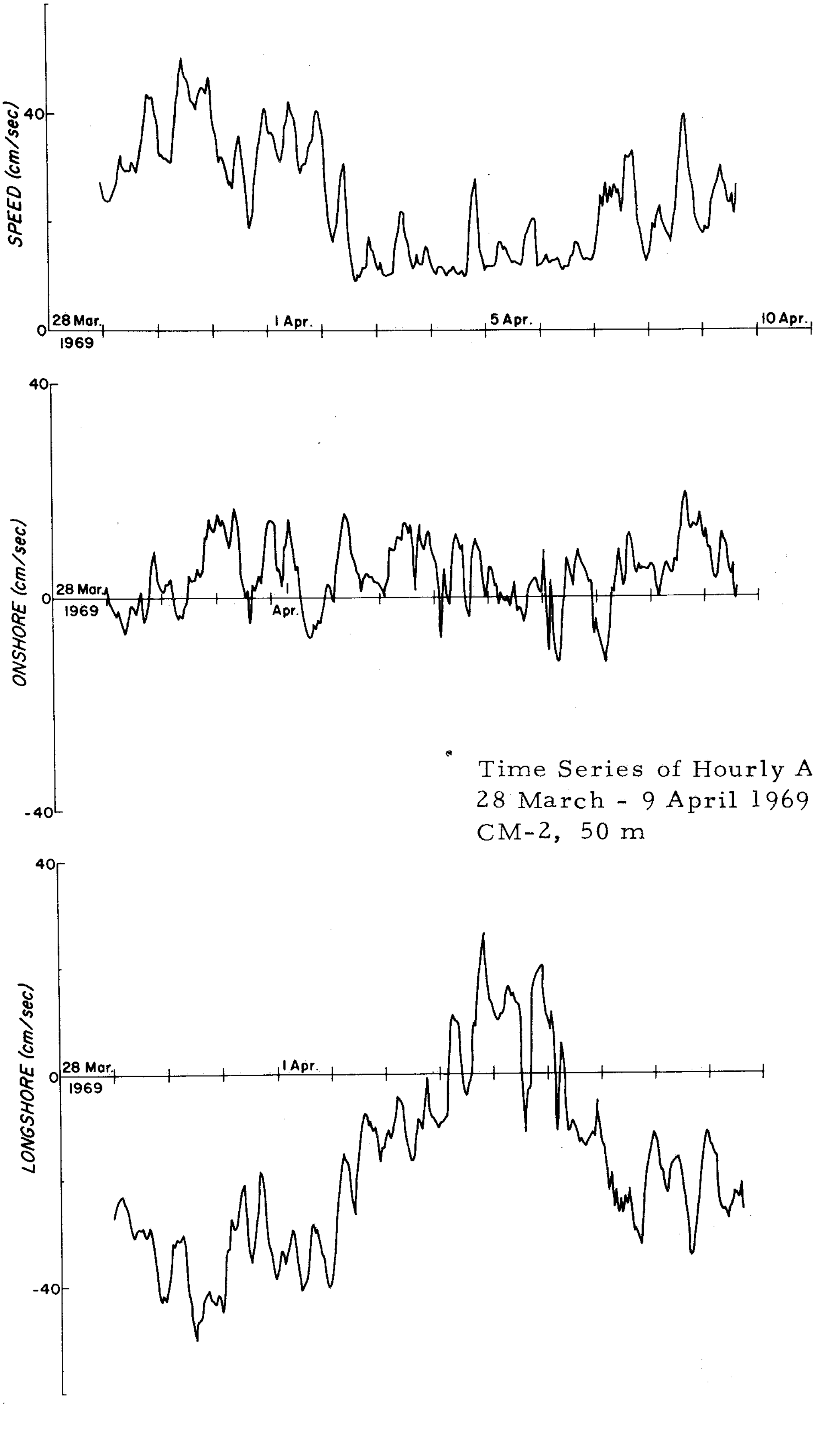


Time Series of Hourly Averages
28 March - 7 April 1969
CM-1, 50 m

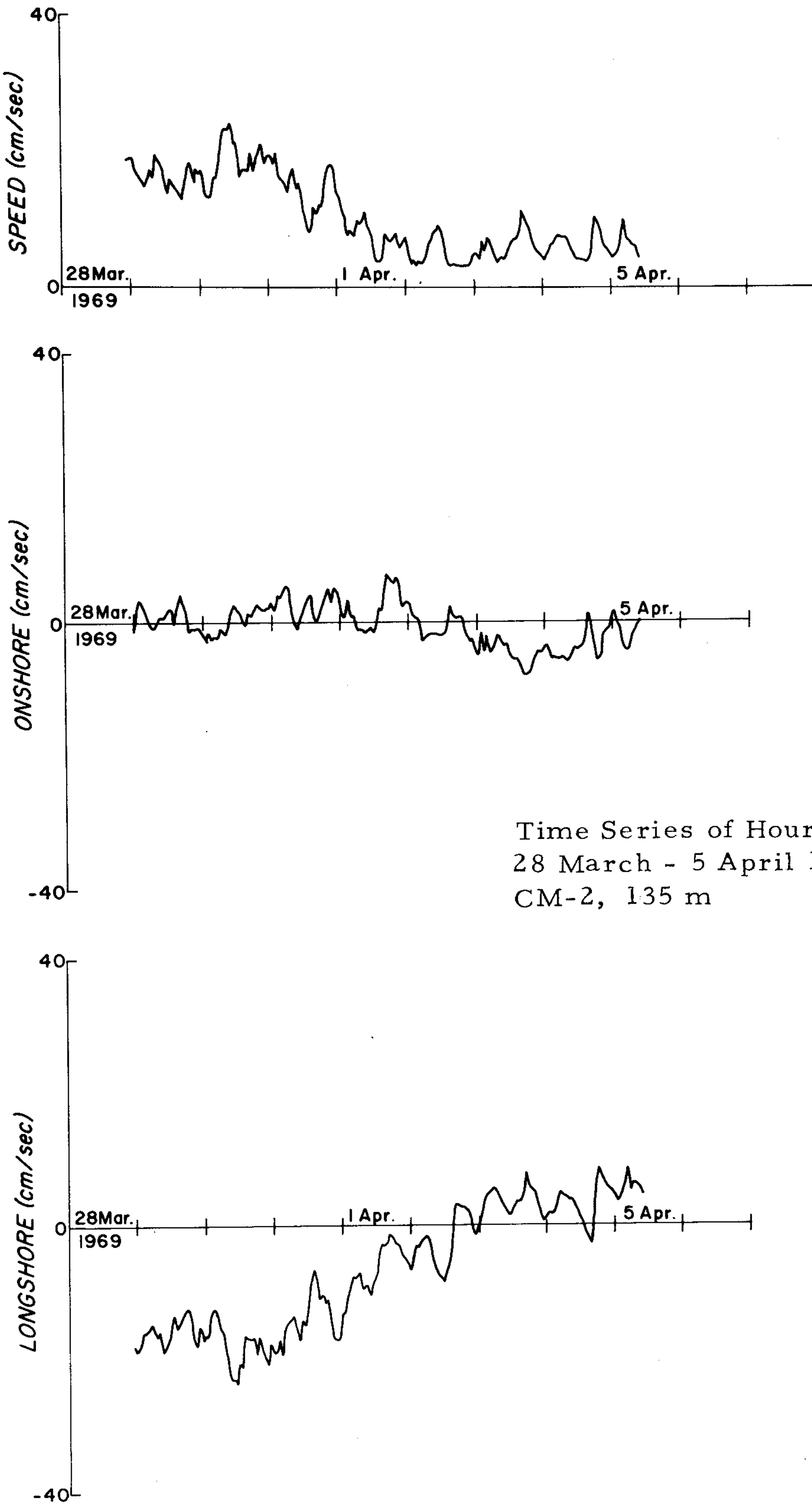




Time Series of Hourly Averages
29 March - 9 April 1969
CM-2, 25 m



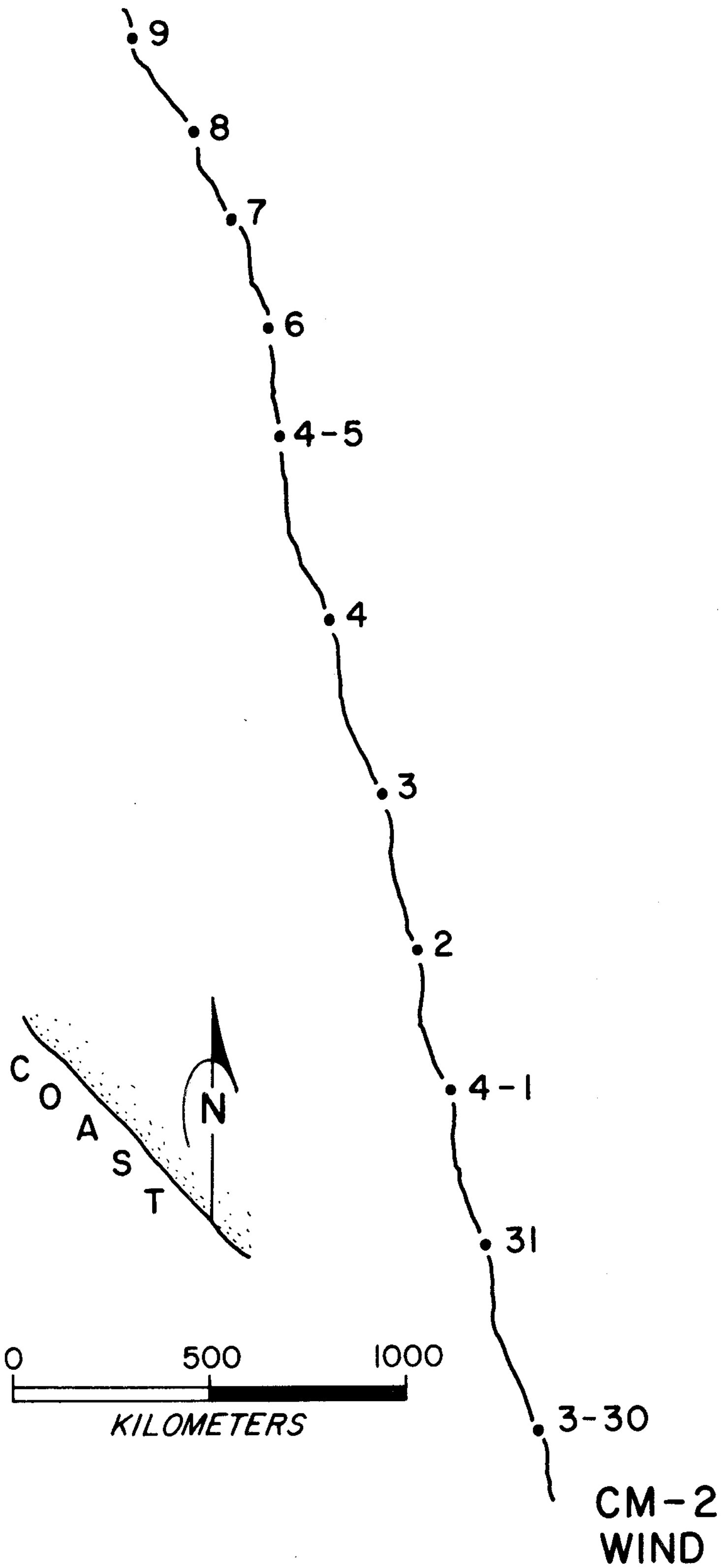
Time Series of Hourly Averages
28 March - 9 April 1969
CM-2, 50 m



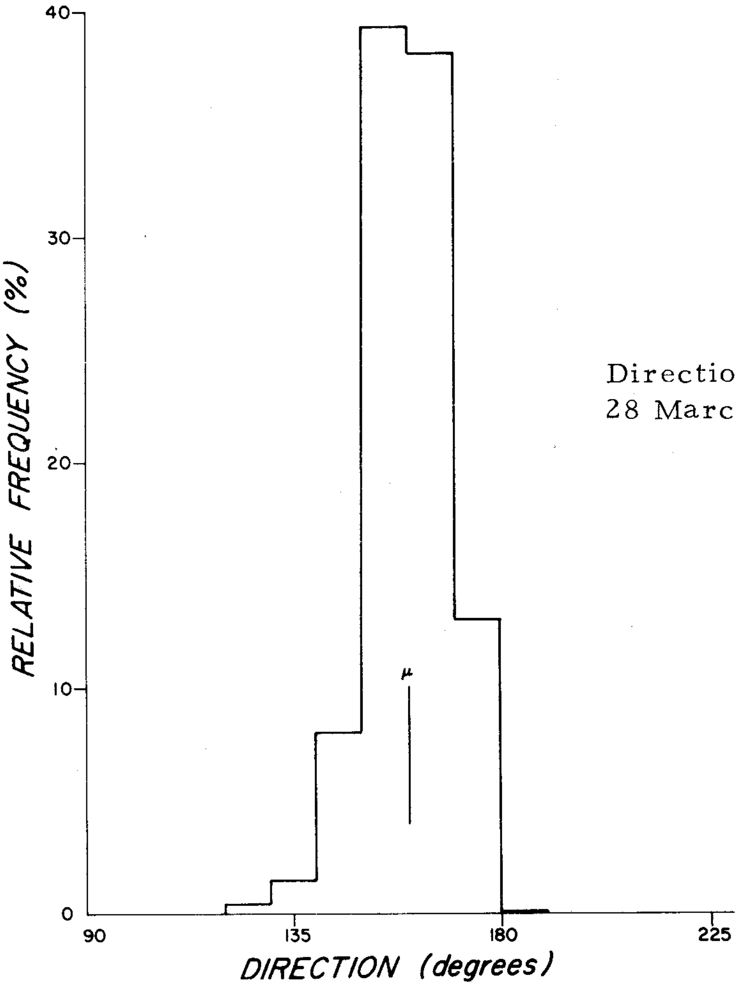
Time Series of Hourly Averages
28 March - 5 April 1969
CM-2, 135 m

WIND INSTALLATION DETAILS

Histogram Wind Recorder #497001
Position: 15°06.3'S, 75°36.5'W
Height: 2 meters above surface
Set at 2222 GMT, 28 March, 1969 by R/V THOMPSON
Retrieved at 1538 GMT, 9 April, 1969 by R/V THOMPSON
Data Interval: 2300 GMT, 28 March - 1120 GMT, 9 April, 1969

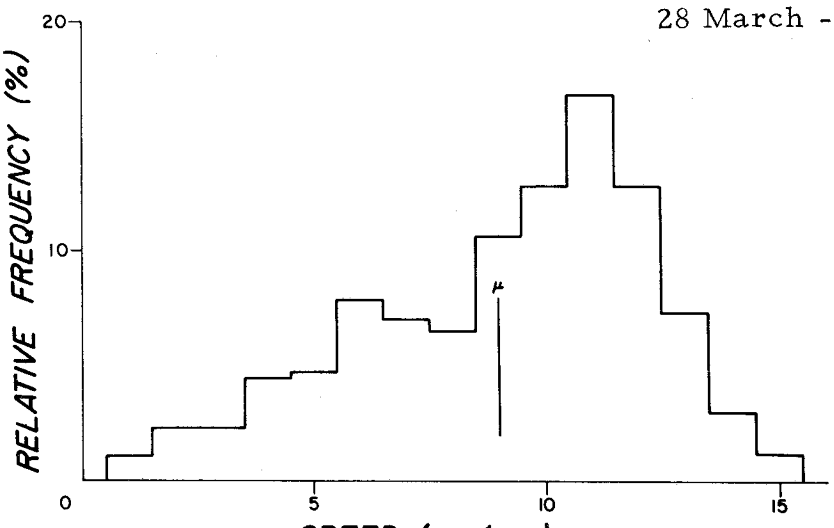


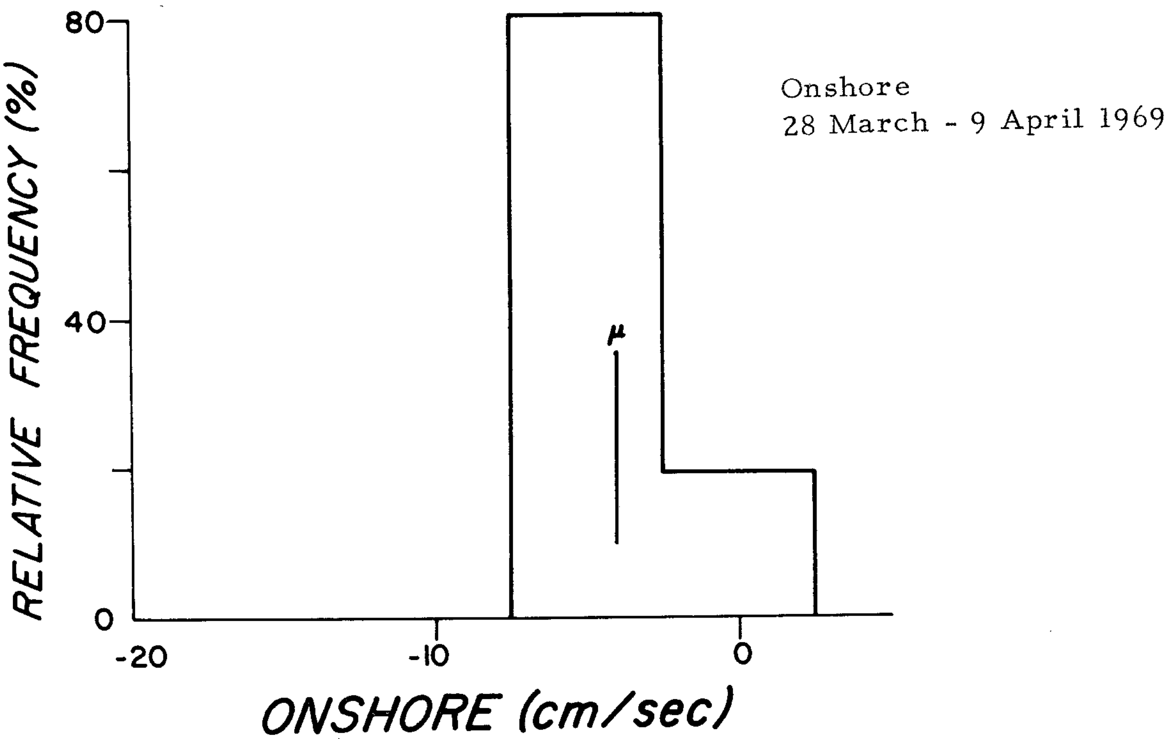
Progressive vector diagram of the recorded wind. Symbols refer to 00 hours (GMT) on the indicated date.

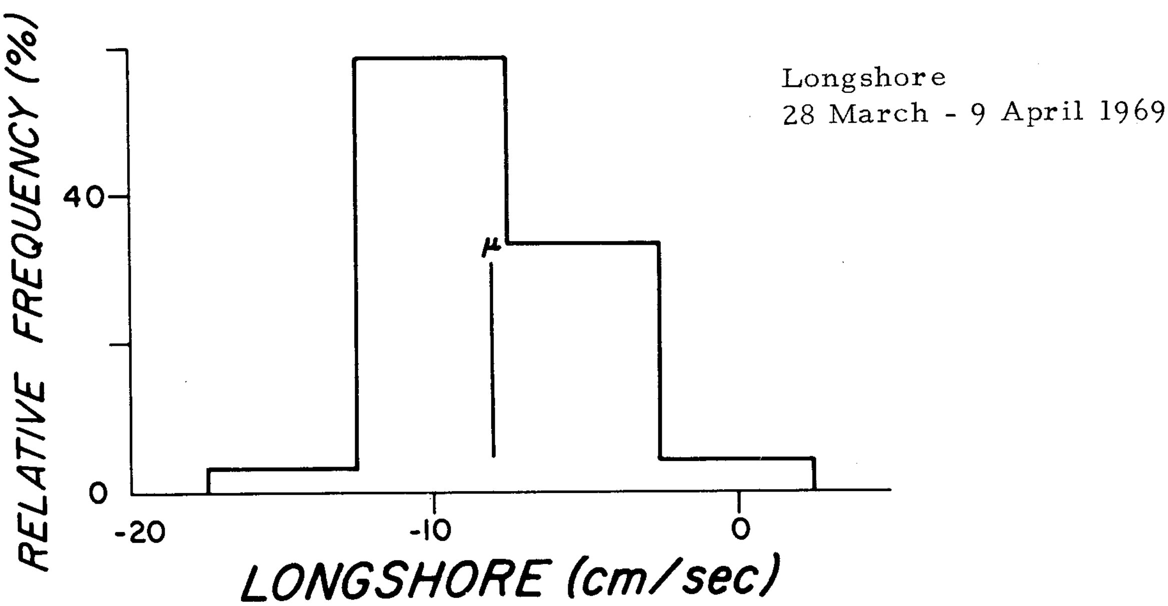


Direction
28 March - 9 April 1969

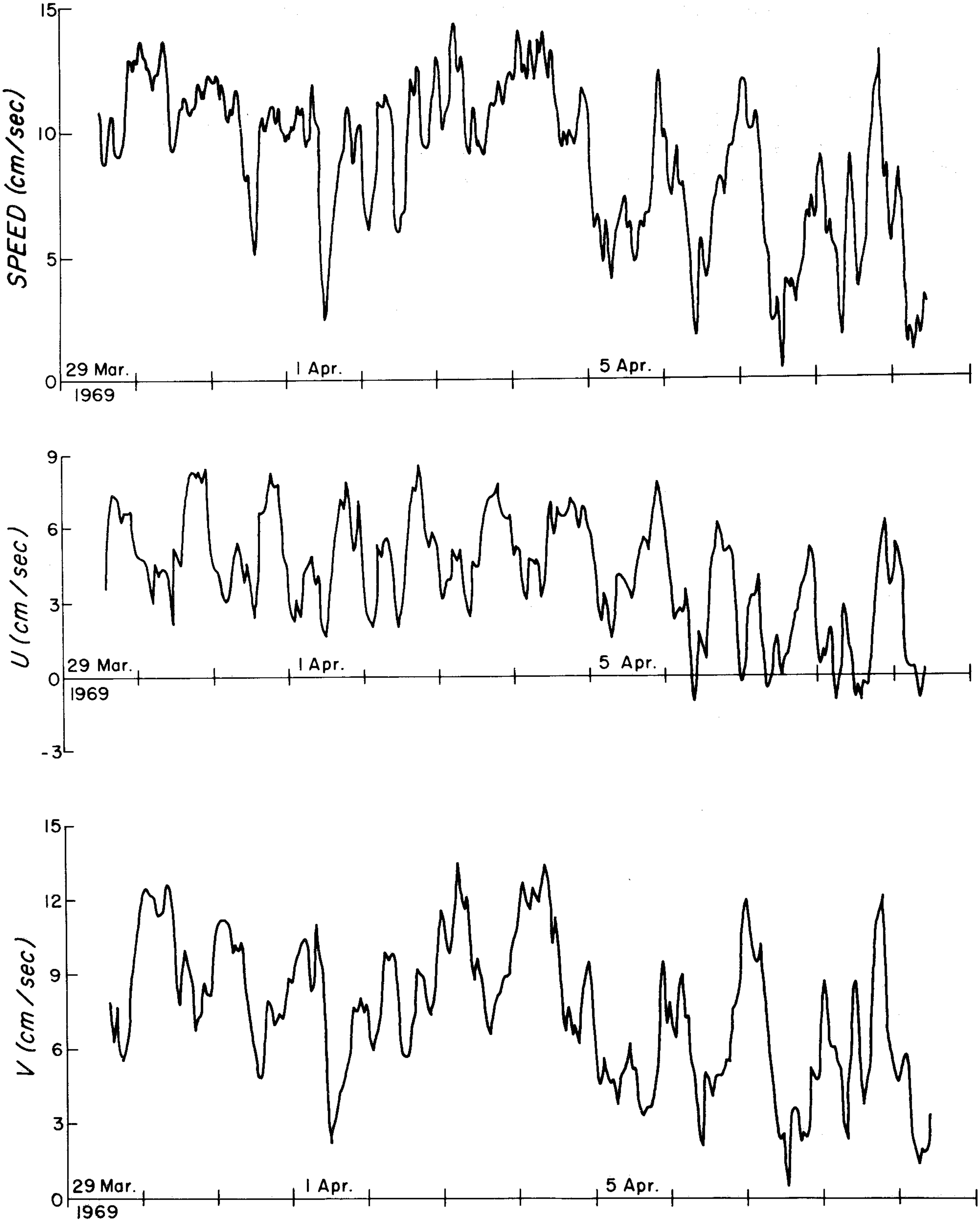
Speed
28 March - 9 April 1969




80
40
0
RELATIVE FREQUENCY (%)
μ
-20
-10
0
ONSHORE (cm/sec)
Onshore
28 March - 9 April 1969


40
0
RELATIVE FREQUENCY (%)
μ
-20
-10
0
LONGSHORE (cm/sec)
Longshore
28 March - 9 April 1969

Time Series of Hourly Averages
28 March - 9 April 1969
CM-2



HYDROGRAPHIC SECTIONS

Two hydrographic lines were run from the coast to about 100 km offshore, as shown in Figure 1. The first section, off Punta San Juan, was taken on 31 March and 1 April; the second section, off Cabo Nazca, was taken on 3, 4 April. The vertical distributions of sigma-t for these sections are shown in Figure 4. A data report on hydrography and productivity has been prepared by the University of Washington, Department of Oceanography (Special Report no. 42).

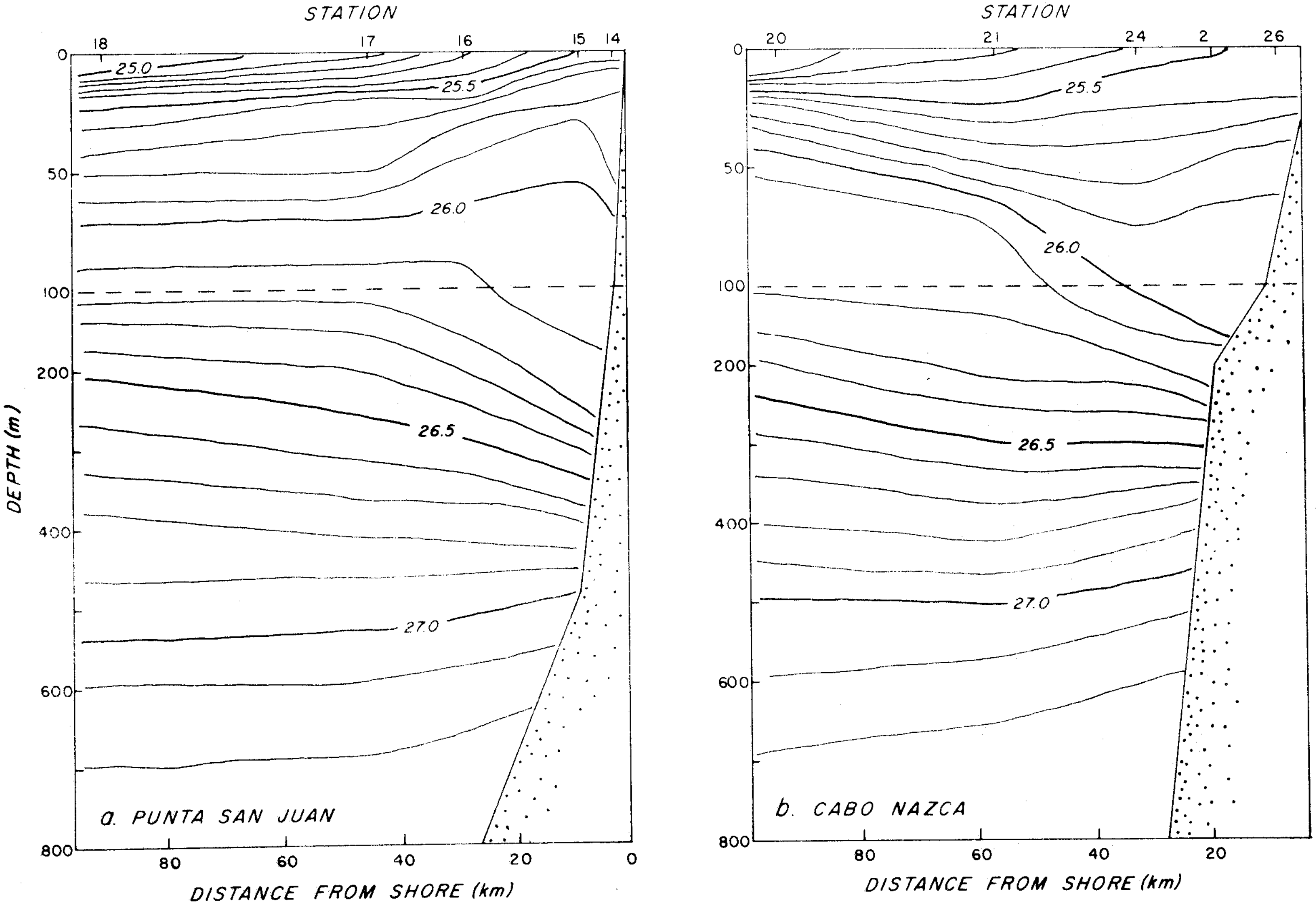


Figure 4. Vertical distributions of density anomaly (sigma-t).

DROGUES

Drogues and pertinent wind data have been listed in the order of launch, in Table 2. Due to the pursuit of other scientific activities, the drogues could not be tracked between launch and recovery; radar fixes at launch and recovery, based on points of land, yielded a net displacement for each drogue. An intermediate fix for drogue three resulted in two successive displacements, '3a' and '3b'. Single wind readings were obtained from the ship's aerovane at each launch; the mean wind speed and direction for each drogue displacement were computed from the recorded wind data at the offshore mooring. (Direction is given in accordance with meteorological convention, i.e. direction from which the wind blows.)

Table 2. Drogue statistics.

Drogue	Date	Depth (m)	Total time (hours)	Drogue speed (cm/sec)	Drogue direction (degrees)	Ship's wind speed (knots	Ship's wind direction (degrees)	Average wind speed (knots)	Average wind direction (degrees)
1	3-30	3.5	4.0	21	050	17	170	11.0	169
2	4-5	10	2.5	19	337	6	190	6.8	173
3a	4-5	10	2.0	26	360	10	180	9.9	167
3b	4-5	10	3.5	16	180	10	180	8.3	158
4	4-6	10	5.0	19	350	12	160	9.0	163
5	4-7	10	5.7	5	205	5	140	7.4	156
6	4-8	10	8.0	9	335	12	170	9.5	159
7	4-8/9	10	28.0	17	168	5	150	5.6	166

PERSONNEL

All work presented in this report was performed aboard the R/V THOMAS G. THOMPSON, under Dr. Richard Dugdale (University of Washington) as chief scientist. In particular, the moored instrument phase of the study was conducted by Oregon State University under Dr. June G. Pattullo and Dr. Robert L. Smith as principal investigators, with the technical assistance of Mr. Dale Pillsbury, Mr. Thomas Hopkins, and Mr. David Enfield.

Data processing was performed by Miss Lillie Muller, Miss Susan Van Dyke, Mr. Nathan Keith and Mr. Mark Ebersole, under the direction of Mr. David Enfield. Additional computer processing for this report was performed by Mr. Joseph Bottero. Miss Marilynne Hakanson has edited and collated the materials for this report. Mr. William Gilbert, Mr. Ronald Hill, and Miss Marilynne Hakanson drafted the figures.

A further analysis of the data in this report has been presented in a M. S. thesis by Mr. David Enfield.

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APPENDIX

Braincon Histogram Wind Recorder

DESCRIPTION

The operation of the Type 497 Histogram Wind recorder is in principle the same as that of the Braincon current meters, Types 316 (Sunbald, 1965) and 381 (Braincon Corporation, 1968). The interior sensor and recorder assemblies are identical to those of the Type 381 Histogram Current Meter. Only the casing, rotor and vane have been changed in order to accommodate atmospheric conditions.

Speed is sensed by a single, brass-allow savonius rotor; coupling to the interior is achieved by means of a small bar magnet on the outside and a magnetic follower inside.

The vane assembly used to sense direction consists of two fiber-glass sheets measuring about 18'' on a side. These are rigidly mounted to either side of two long flanges which extend out from the casing, and are attached by means of 3/16'' aluminum rods (see Figure A-1). The separation of the two vanes is made greater than the diameter of the casing to avoid the turbulence of the casing wake. The vanes are splayed outward in the downwind direction to improve the stabilizing characteristics of the instrument.

The rotor revolutions sensed by the magnetic follower are geared down within the casing so that one revolution of a luminous dot in a twenty-minute period corresponds to a wind speed of approximately 50 knots. During a 19-1/2 minute recording period, the traverse of the luminous dot causes an arc to be registered on film, the length of the arc being proportional to the total revolutions of the rotor.

The entire instrument is oriented into the wind by the fixed vane assembly. The position of a luminous dot at the tip of a damped magnetic compass disc provides the direction reference. This dot will usually be registered on the film as a small arc, while the position of the arc with respect to a fixed (luminous) casing mark determines the orientation of the instrument during the recording period.

A luminous dot at the center of the compass disc is a vertical reference intended for the determination of instrument tilt. The separation between this dot and another, fixed at the center of the compass bubble, is a measure of the tilt.

After a 19-1/2 minute film exposure, during which speed, direction and tilt are registered as concentric arcs, the 20 minute recording cycle is completed by a 30 second film advance governed by a D.C. motor and Accutron* timer.

Data are recorded on 16 mm Kodak Tri-X Reversal Film in a standard 50 foot film magazine containing enough film to record for about 50 days with the 20 minute sampling interval.

PERFORMANCE

The Braincon Corporation provided the following specifications of sensor and recording characteristics:

Speed range: 0 to 50 knots
Calibration threshold: 3 knots
Speed sensitivity: 1.0 knot
Speed arc accuracy: ± 1% of full scale
Direction range: 0° to 360°
Direction sensitivity: 10° at minimum calibrated velocity of 3 knots
Direction arc accuracy: ±1.0°
Tilt range: 0° to 30°
Tilt sensitivity: ±1.0°
Tilt arc accuracy: ±1.0°

Several prominent shortcomings in performance were noted:

a. Insufficient luminosity of the direction dot causes difficulty in determining the orientation of the arc. This condition can be partially remedied by over-developing the film, but it is preferable to increase the luminosity of the dot.

b. The instrument is provided with the same tilt indicator as used in the Type 381 Current Meter. Unlike the current meter, however, the wind recorder undergoes many different tilting motions during a sampling interval, so that the indicator does not remain in any one place long enough to expose the film. It is doubtful that increased luminosity would improve the readability of this tilt indicator.

* Registered trademark of the Bulova Watch Company

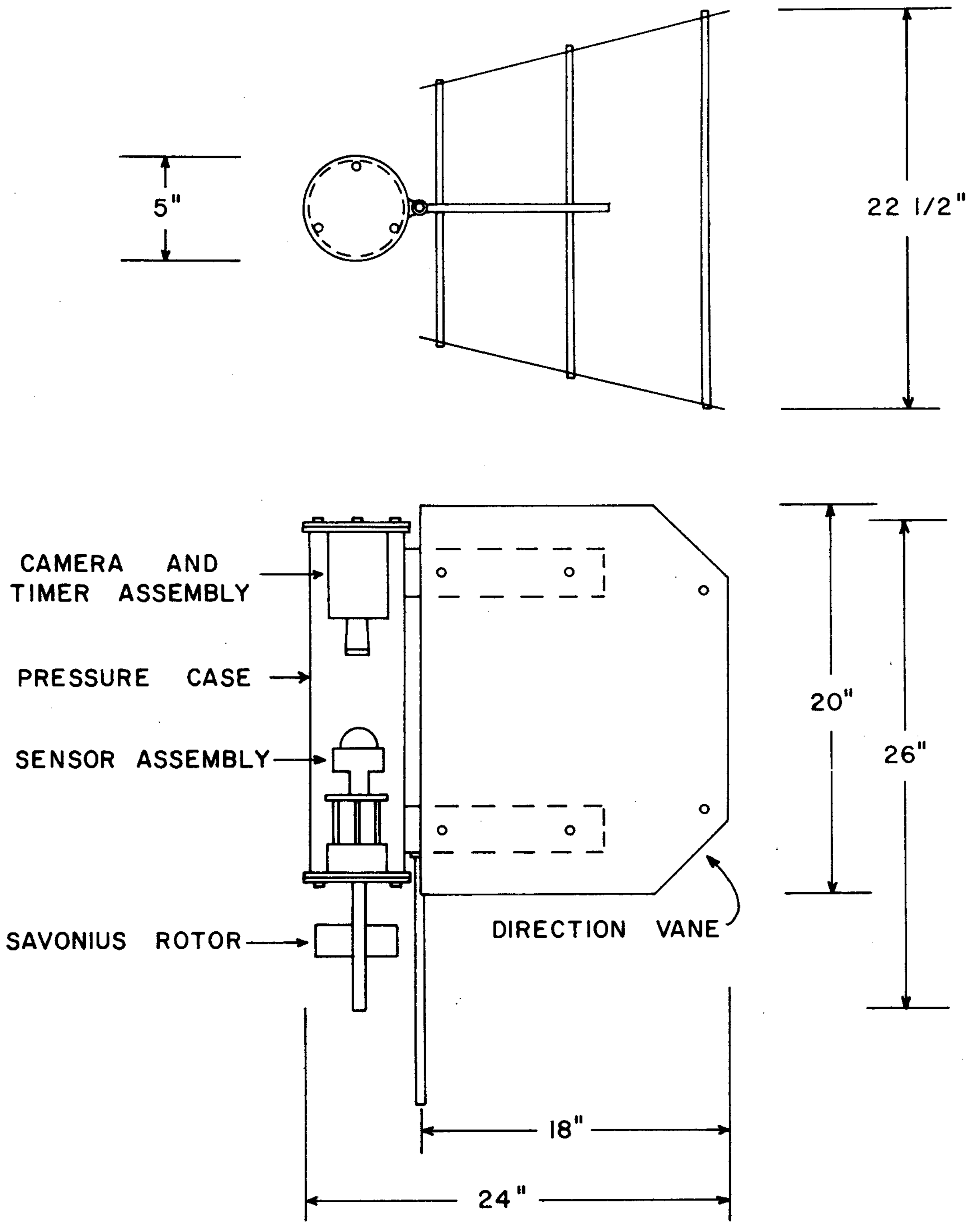

Fig. A-1 Braincon Histogram Wind Recorder.

c. During a preliminary test under actual conditions, the instrument was mounted six feet above a four foot toroid buoy which was moored over the continental shelf. When recovered, the vanes were found battered or torn completely from their aluminum braces. The recorded (average) wind speed at the believed time of the vane failure was about 16 knots. Thus, the original vane design appears to have been inadequate to withstand moderate marine conditions.

To assess the possible error introduced by tilt, static wind tunnel tests were conducted with the rotor tilted by angles of up to 25°. At 25° tilt, the revolution rate decreased by only a very small amount, indicating that a constant tilt is not a serious source of error.

Following the vane failure, the original aluminum braces were replaced by specially machined 1/4" stainless steel rods, using large double nuts and beveled 1/2" teflon washers to fasten the vanes to the rods. This arrangement proved satisfactory on the two subsequent occasions of actual use. Twenty minute averages of up to 20 knots were recorded for one of these periods.

CALIBRATION

Two calibrations have been performed on the wind recorder (Figure A-2): one by the Braincon Corporation (curved line) and the other by the Coastal Currents Project at Oregon State University (straight line). The straight-line relation was obtained by mounting the instrument in a wind tunnel and measuring both rotor revolutions and film arc for known wind tunnel speeds.

The Coastal Currents Project has used the linear calibration in reducing wind data. The two curves are not very different in the range of frequently encountered wind speeds (5 to 15 knots); nor is there a clear advantage in choosing the Braincon curve, since it is not known how the calibration was done.

SOURCES OF ERROR

(i) Atmospheric turbulence (gusty winds) and buoy motions cause the rotor to undergo successive accelerations and decelerations. An inherent aspect of the rotor design is that an increasing wind induces a faster response (acceleration) than does a decreasing wind (deceleration), so that turbulent conditions have a "pumping" effect on the rotor. Unless the rotor is calibrated under typical atmospheric conditions, an overestimate

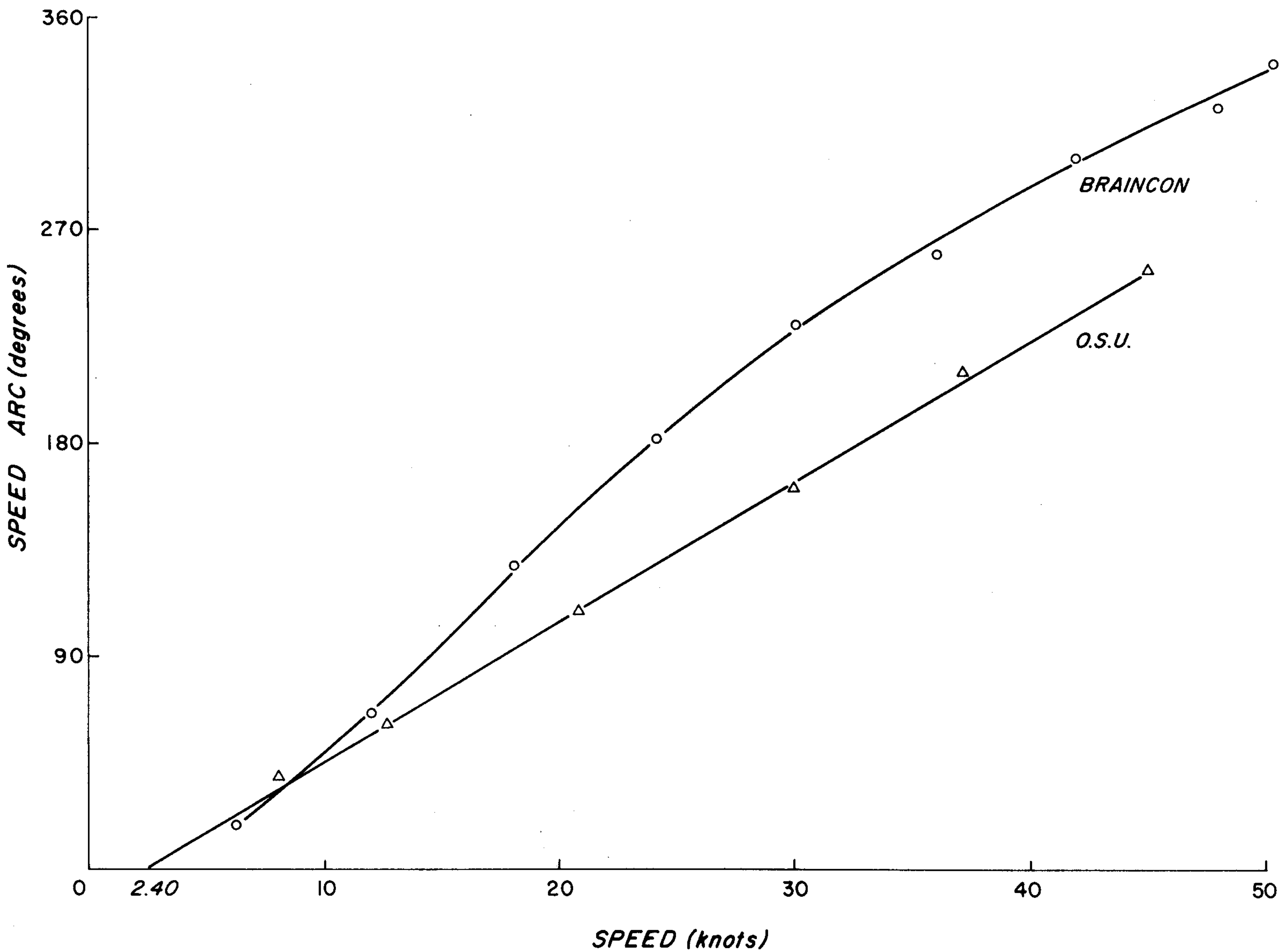

Fig. A-2 Calibration curve for Braincon Histogram Wind Recorder.

of the mean speed will result. Turbulence, and therefore the error induced by it, will increase with increasing mean speeds. Thus, for high wind speeds, a calibration curve such as the Braincon curve (Figure A-2) might give more realistic results than the straight-line relation now used by the Coastal Currents Project.

(ii) In using the analog film output, the length of the speed arc is assumed to be proportional to the average wind speed during the sampling interval; the direction mode, indicated by the brightest part of the direction arc, is usually taken to be the mean direction. An implicit hypothesis in the use of such data is that the mean speed and direction so determined are representative of the vector mean velocity during the sampling interval. Such an hypothesis is valid only to the extent that there is little directional variation during the interval. Considerable overestimates of the true velocity can result at speeds of four knots or less, due to variability of direction. If the luminosity of the direction dot is increased to an acceptable level, it may be possible to estimate this effect by measuring the total length of the direction arc, as well as the position of its center.

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13. ABSTRACT

A summary of moored instruments over the continental shelf of Peru is presented. Measurements of variables were made in an upwelling zone between Pisco and San Juan, from 28 March to 9 April, 1969. Time series of temperature and horizontal current and wind velocities were obtained at several depths and locations by an array of moored, recording instruments. Supplementary hydrographic and drogue measurements were also made.

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