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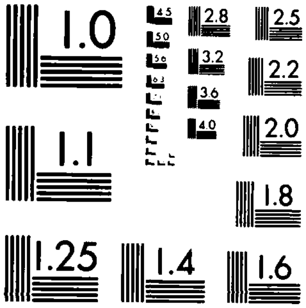

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An NRL remote sensing experiment was conducted in July 1982 to measure ocean surface manifestations of subsurface topography and hydrography. The central topographic feature in the operational area was Phelps Bank (40°50'N-69°20'W). This report presents the results of Eulerian current measurements made from a mooring on Phelps Bank during the field exercises.

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EULERIAN CURRENT MEASUREMENTS AT PHELPS BANK

INTRODUCTION

From July 5-25, 1982 scientists from NRL and other laboratories conducted a cooperative, remote sensing experiment. The general purpose of the experiment was to obtain information on oceanographic processes responsible for the surface expression of bathymetry (SEBEX) and hydrography in the wave field and radar imagery of relatively shallow seas. To this end, simultaneous and coordinated remote sensing, oceanographic, meteorological, hydrographic and bathymetric measurements were made. The site chosen as the central point for the experiment was Phelps Bank. The bank is a relatively isolated, subsurface, topographic feature located approximately 37 nautical miles southeast of Nantucket Island (40°50'N-69°20'W). Figure 1 shows where the bank appears on the navigational chart (NOAA, 1979).

The field exercise was under the direction of Dr. Davidson Chen (NRL Code 7912C) and Dr. Gaspar Valenzuela (NRL Code 4305). Mr. William Garrett (NRL Code 4333) served as senior scientist aboard the USNS HAYES. The overall plan of the NRL Remote Sensing Experiment has been submitted for publication by Valenzuela (1981) and a review of surface effects attributable to subsurface processes has been published by Chen (1982). This report summarizes the Eulerian current measurements made during the remote sensing experiment.

BACKGROUND

Among the first investigators to report that radar imagery of the surface waves of shallow seas included features that were related to the

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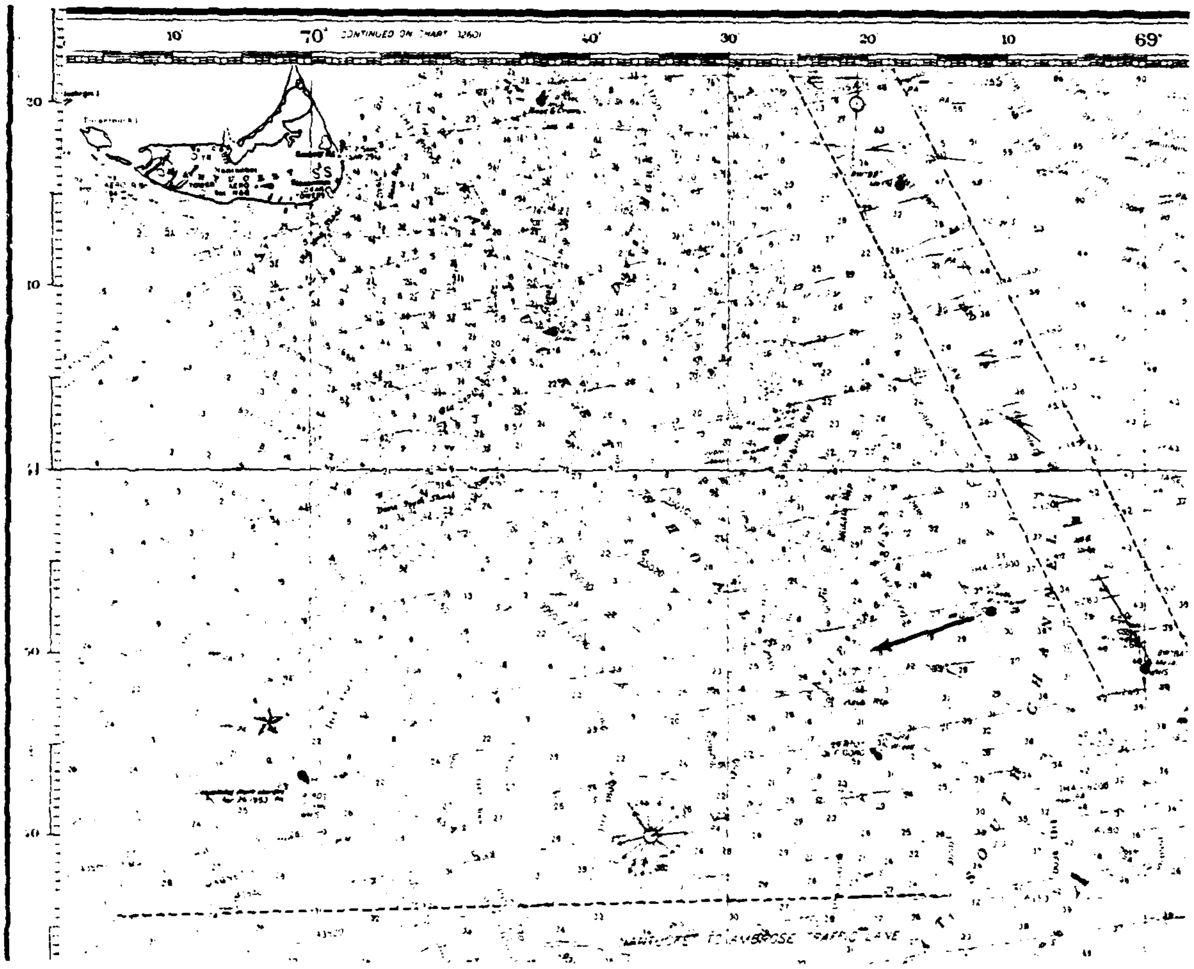

Fig. 1. - A section of National Ocean Survey Chart #13200 (NOAA, 1979) showing the location of Phelps Bank. The arrow indicates the site of the moored, current meters.

bottom topography were DeLoor and Brunsveld van Hulten (1978). The phenomenon has been treated in some detail in DeLoor's more recent work (DeLoor 1981). The bottom topography effect has been particularly noticeable in SAR (synthetic aperture radar) imagery from the SEASAT satellite (English Channel and Nantucket Shoals) although airborne SAR and SLAR (side-looking airborne radar) also show the effect. McLeish et al (1981) have published an interpretation of SLAR imagery of surface wave patterns in the North Sea which are related to sea-floor topography. General reviews of radar imagery of the ocean surface may be found in the recent book "Spaceborne synthetic aperature radar for oceanography" Beal et al. eds. (1981) and in Alpers et al. (1981).

In order to interpret surface manifestations of subsurface topography it is necessary to have information regarding the flow of current over and around the particular topographic feature (in this case Phelps Bank). Currents at the site were anticipated to be predominantly rotary tides (1 to 2 knots), based on data provided for the nearest locations in the NOAA Tidal Current Tables published by the U.S. Department of Commerce (NOAA, 1981). The locations provided by the tide tables are Nantucket Shoals 40°37'N-69°37'W; Davis Bank East 41°02'N-69°41'W; and Great South Channel 40°31'N-68°47'W. These locations are 15, 19 and 32 nautical miles respectively from Phelps Bank. The tidal predictions at the three sites are based on the time of maximum flood tide at Pollock Rip which is located approximately 48 nautical miles northwest of Phelps Bank. Progressive vector diagrams of the current speeds and directions were plotted for the three sites. The major axes of the resultant tidal ellipses varied in direction from 345° to 40° and the current speeds ranged between

0.8 and 1.7 kt. for the same tidal phase. This relatively large variation in both current speed and direction at the locations provided by standard tide tables clearly indicated the need for real-time current measurements at the specific site in question (Phelps Bank).

FIELD MEASUREMENTS

Currents in the vicinity of Phelps Bank were measured by an Eulerian method in addition to the Lagrangian drogue measurements that have been reported previously (Greenewalt and Gordon, 1982). The Eulerian technique consists of recording the speeds and directions of currents as they flow past a fixed point. In this case the fixed point was a moored array of three recording current meters. The mooring was located at a position approximately 1.2 naut. mi. east of the shallowest part of Phelps Bank (40° 50.07'N - 69° 19.81'W as marked in Figure 1.). The depth at the site is nominally 30 m with an uncertainty estimated to be ±2 m. The uncertainty accounts for errors in depth measurement and tide level range. The mooring system is shown schematically in Figures 2 and 3. The buoyancy (F_B approximately 110 lb.) was provided by two 17" diameter hollow glass spheres. This flotation supported a 1/4" diameter steel cable which was attached to a 250 lb. anchor. A surface buoy to aid in relocation and recovery of the mooring was connected to the subsurface flotation by 150' of polypropylene line. The recording current meters were attached to the steel cable at the positions shown in Figure 2. Under conditions of slow currents the meters designated at M_1, M_2, and M_3 were at nominal depths of 20.6, 11.4 and 3.4 meters respectively. In the presence of the stronger currents the actual depths of the current meters

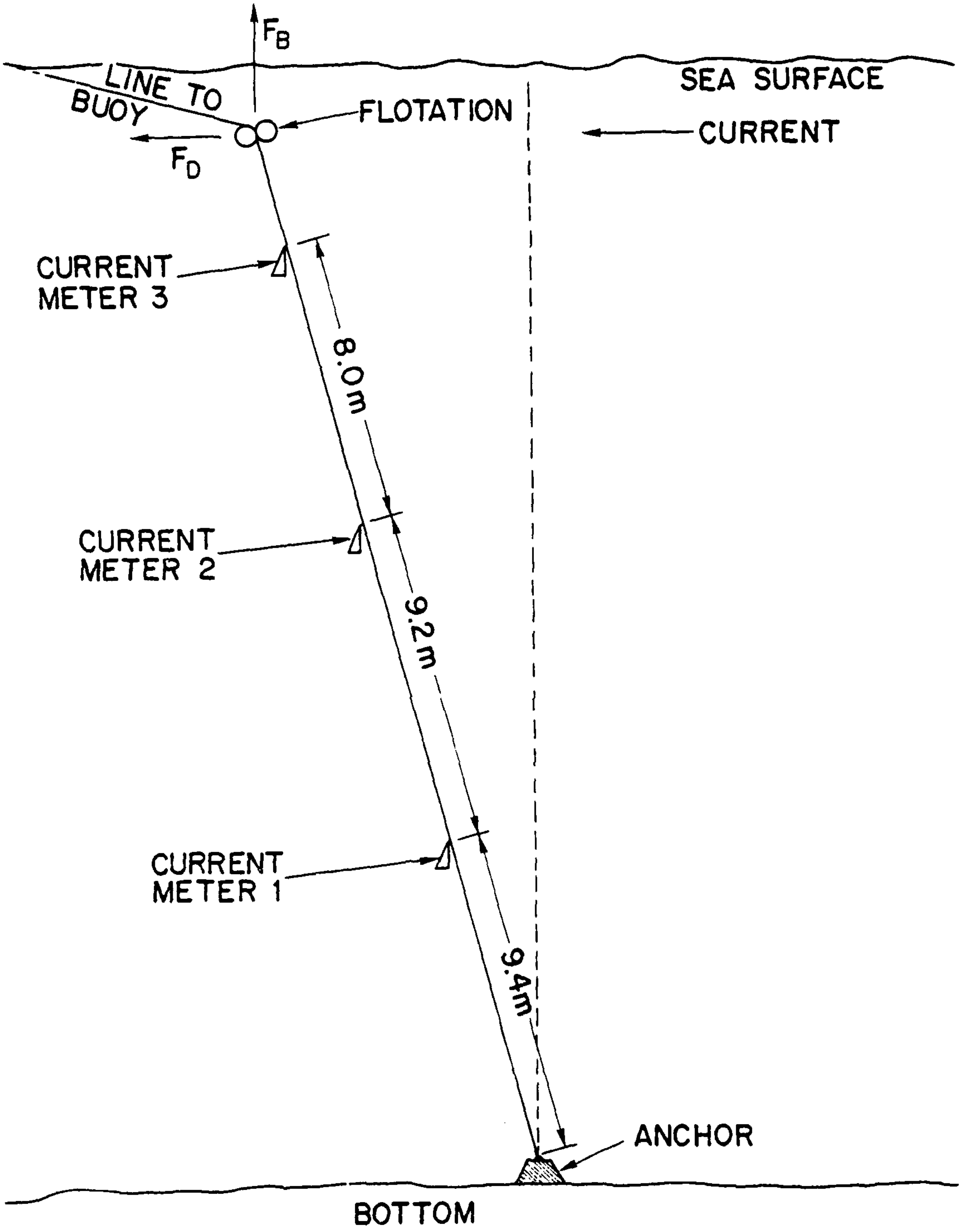

Fig. 2. - A schematic diagram of the forces acting on the current meter mooring.

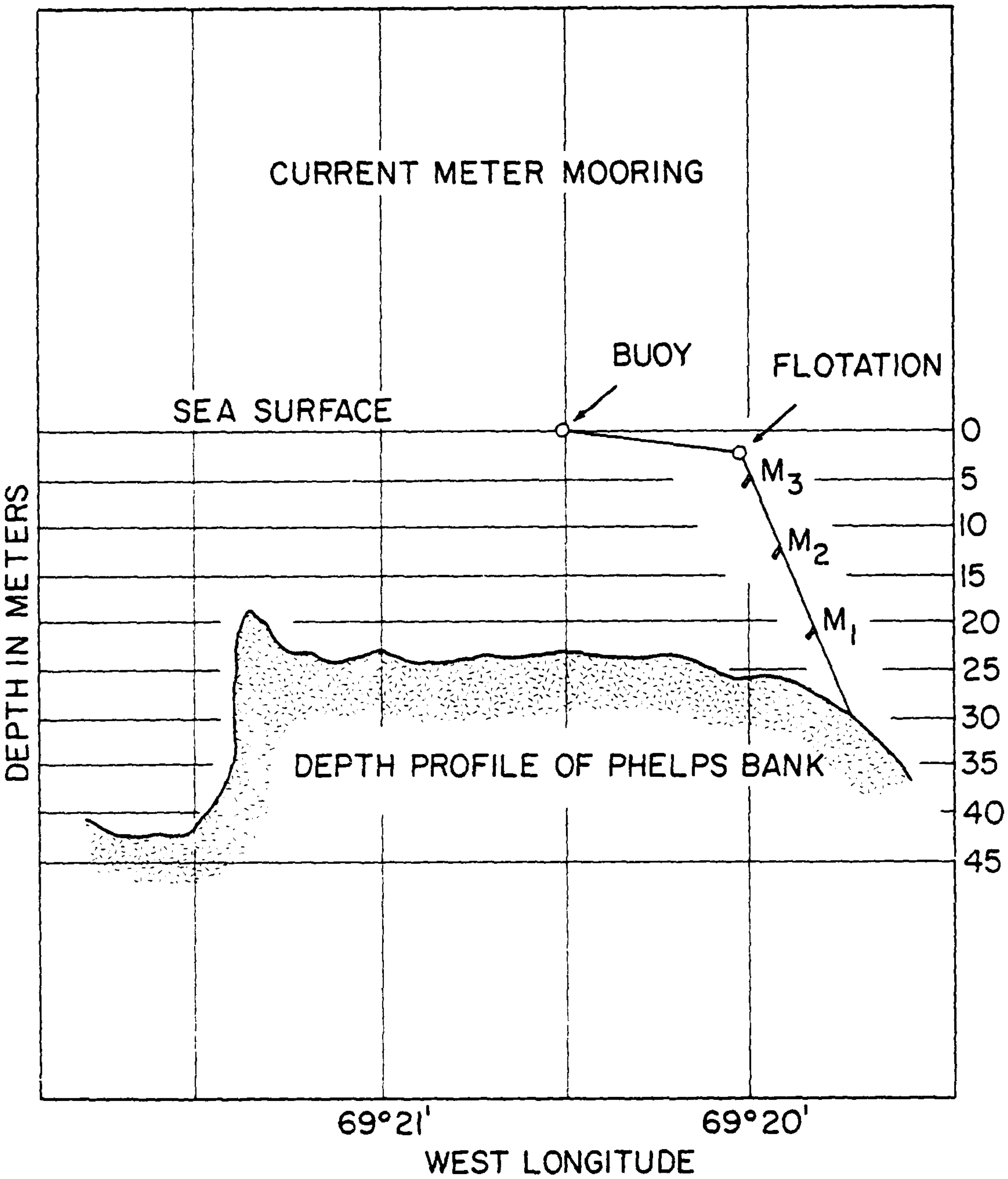

Fig. 3. - The general location of the current meter mooring with respect to the bathymetry of Phelps Bank. The vertical scale is exaggerated by a factor of X36.

will vary due to the angular displacement (Θ) of the mooring by hydrodynamic drag forces (F_D) on the entire system.

In order to predict the amount of displacement at a particular current, it is necessary to estimate the drag force F_D. For present purposes it will be assumed that the drag is pressure drag as expressed by the formula

$$F_D = \frac{1}{2}\rho C_D A V^2$$

where ρ is the mass density of sea water, C_D is the experimental drag coefficient, A is the projected area of the drag forms and V is the current speed. For the mooring in question ρ is taken as 2 $\sec^2 \mathrm{ft}^{-4}$, C_D for the combination of suspended spheres and cylinders is taken as 0.75 and A is estimated to be about 8 ft^2. For purposes of simplifying the calculation it will be assumed that all the drag is concentrated at the flotation depth and that the line to the anchor is straight and weightless. Since the drag coefficients are imprecise estimates, this can be done without any overall sacrifice of accuracy. The displacement angle Θ of the mooring system can then be calculated as $\tan\Theta = F_D/F_B$. The resulting variations of the meter depths are then matters of simple geometry. The estimates of drag effects on the mooring are given in Table 1.

Table 1. The effect of drag on the mooring

CURRENT (KT)	DRAG (F_D LBS.)	DISPLACEMENT ANGLE (Θ DEG)	CURRENT METER DEPTH (M)		
			M_1	M_2	M_3
0.25	1.1	0.5	20.63	11.41	3.41
0.50	4.4	2.2	20.64	11.42	3.43
0.75	10.0	5.1	20.67	11.48	3.51
1.00	17.7	9.0	20.74	11.64	3.73
1.25	27.7	13.9	20.90	11.95	4.19
1.50	39.9	19.6	21.17	12.49	4.95
1.75	54.3	25.9	21.57	13.27	6.07
2.00	70.9	32.3	22.08	14.29	7.52
2.25	89.8	38.7	22.69	15.50	9.26

It should be noted that in Table 1 the significant figures for meter ths represent only the geometry and not absolute precision. It is seen f the table that under the given conditions meter M_3 may vary in depth as much as 4 meters in the current range from one to two knots. Below one knot the meters change depth very little. This is a consequence of the fact that the drag force is proportional to the square of the current, i.e., $F_D \sim V^2$. The major sources of uncertainty in the calculations for Table 1 are the drag coefficient C_D and the assumption that the drag is localized at the flotation. The overall error is estimated to be the order of ±20%.

The current meters attached to the mooring are of the pressure-vane type, that is, their suspension angle depends on the current roughly in proportion to V^2. The devices are film recording current meters, manufactured by General Oceanics, Inc. of Miami, Florida. Figure 4 is a cutaway drawing of the meter. In the words of the manufacturer it......

> ".....consists of a finned cylindrical housing containing a directional inclinometer and Super-8 cartridge camera which sense and record the inclination and compass heading of the instrument.

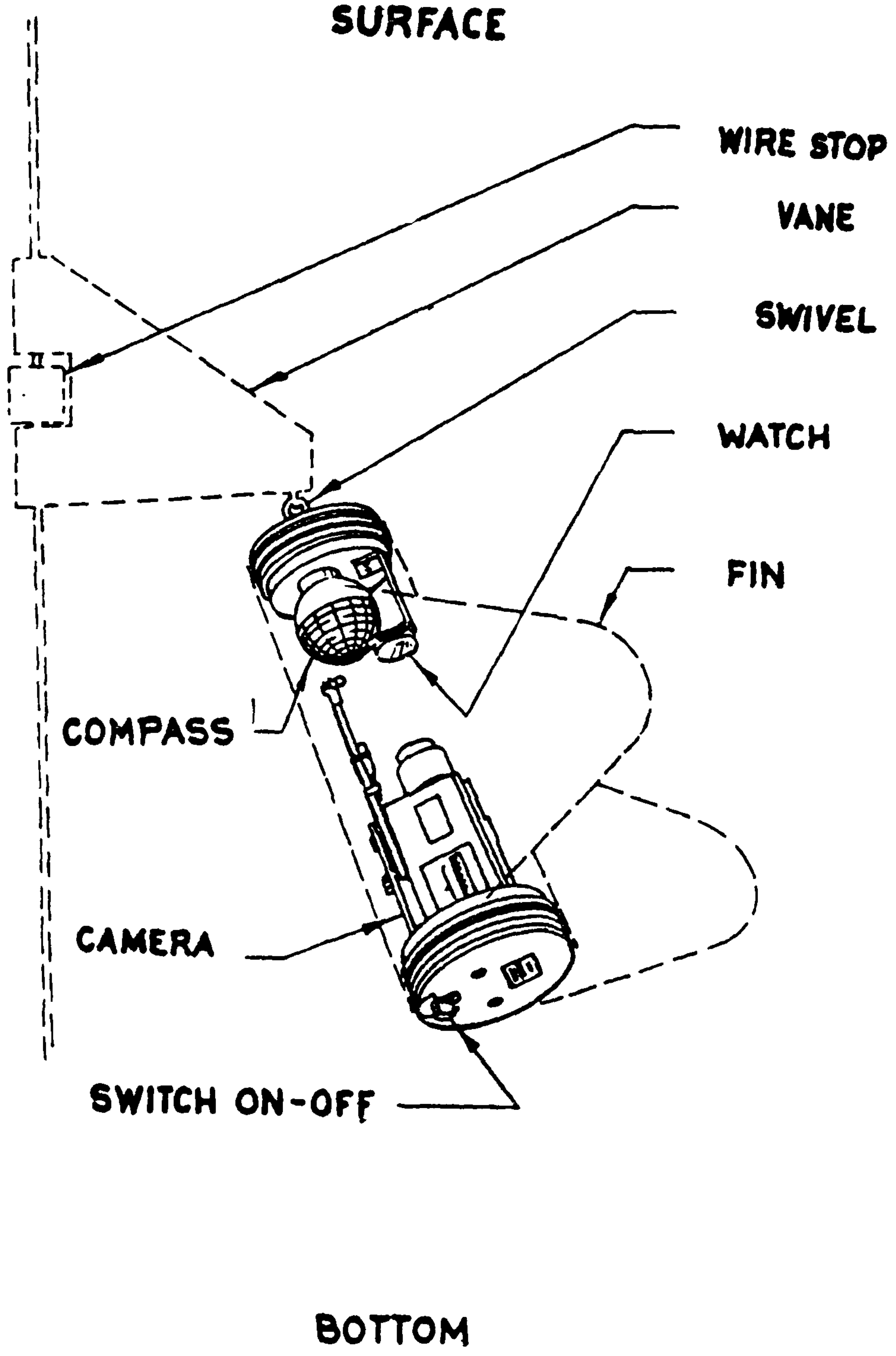

Fig. 4. - A cut-away drawing of the configuration of General Oceanics, vane current meter.

> Fins are affixed to the current meter housing to assist in directional orientation and stabilization. The fin-housing combination within the current stream creates a drag resulting in an inclination of the instrument from the vertical which changes in direct relation to the current velocity.
>
> The data recording camera is triggered to photograph the inclinometer by a quartz crystal controlled timing circuit contained within the camera. The self-contained battery supply and the film cartridge capacity enable up to 7200 data records to be taken over operating periods of up to ten months.
>
> The directional inclinometer is a spherically shaped component mounted on the inner face of the lower housing end cap. The inclinometer design utilizes a transparent fluid filled housing containing a negatively buoyant inner sphere floating on a bearing of liquid mercury. The inner sphere maintains a stable vertical attitude and magnetic north orientation because of an internal bar magnet whose mounting location gives the sphere a low center of gravity. A small circular target at the top of the transparent housing is viewed by the camera against a grid of precision latitude and longitude lines inscribed on the free inner sphere. When photographed by the camera, this target mark enables direct reading of the instrument attitude and azimuth by its position relative to the latitude and longitude lines.
>
> Also located on the lower end cap above and to one side of the directional inclinometer is a battery powered quartz crystal watch which provides the time, day and date for each data frame."

Needless to say the data interpretation procedure is rather tedious, that is, each frame of motion picture film provides only one reading of current speed and direction. The directional inclinometer is read as follows:

> "The inner sphere of the directional inclinometer is graduated in increments of 10°. Every circle of latitude is equal to 10°, starting at zero and finishing at 90°. The stamped circles, i.e., 3, 5, 7, & 9, indicate 30°, 50°, 70° and 90° respectively from the vertical.
>
> The lines of longitude are graduated in thirty-six 10° increments for a total of 360 degrees. Every letter indicates 30° of compass heading, e.g., "D" at 060°; "N" at 0° (or 360°)."

Figure 5 shows how the circular target appears between the lines of inclination and magnetic orientation. In Figure 5 the deflection is 65°

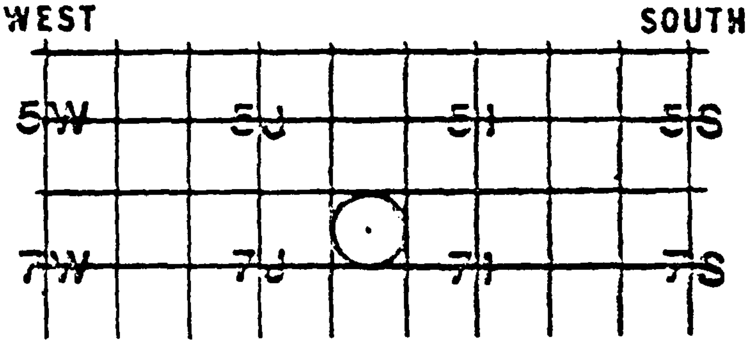

Fig. 5. - The general appearance of the photographic data record from the current meters.

and the magnetic orientation is 225°, i.e., between south and west. The 65° tilt or deflection angle is related to the current speed and can be converted to speed using the calibration curves provided by the manufacturer. Figure 6 is an example of such a calibration curve and using it the 65° deflection is found to be equivalent to a current speed of 52 cm/sec. It should be noted that during the measurements reported here the currents were relatively fast (1-2 knots) and the deflection angles of the current meters were near the maximum of their calibrated range. Because of this and variations in the mountings, the absolute accuracy of the measurements should be considered no better than ±10%.

For the measurements described here the current-meter mooring was deployed at about 0910 local time July 10, 1982 and recovered at 1800 local time on July 20. The duration of the measurement time series was, therefore, 249 hours. The cameras recorded 8 frames per hour in the three current meters for a total of about 6000 readings of current speeds and directions. All 6000 readings are not listed here in tabular form, however all the values have been stored on tape and can be made available. The following tables (Tables 2-4) list hour by hour averages of the current speeds and directions (8 data points) for the 10 days the mooring was deployed. The current averages include one half hour before and one half hour after the times given in the tables. For purposes of comparison with the current meter arrangement shown in Fig 2. Meter "X" was at a nominal depth of about 5 m and corresponds to M_3; "M" corresponds to M_2 at about 13 m and "N" corresponds to M_1 at 21 m. The times in the tables are in universal time (U.T.). To convert to local time (EST) subtract four hours or to obtain Daylight Saving Time (EDST) subtract 5 hours.

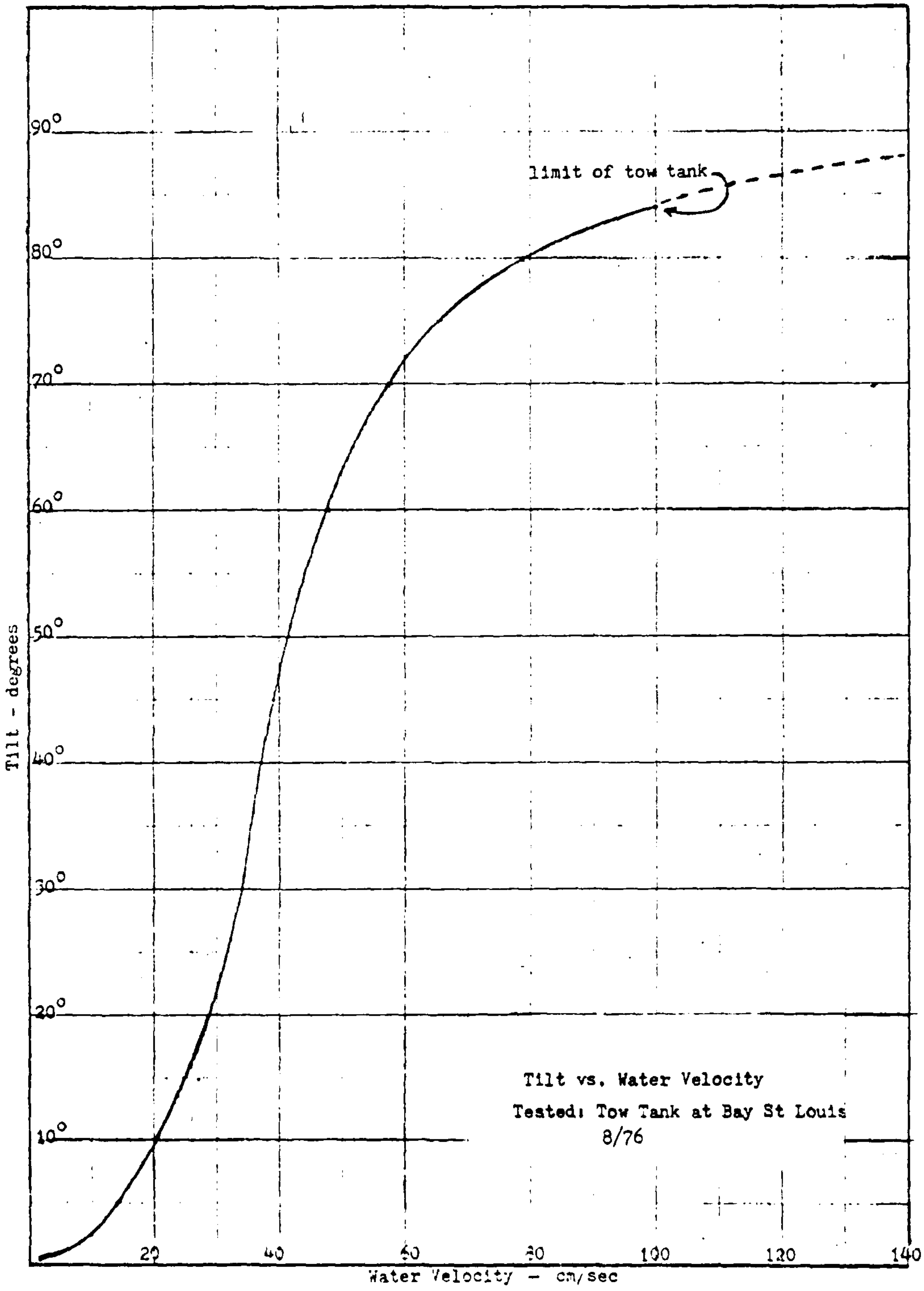

Fig. 6. - Calibration curve for a General Oceanics vane current meter.

Table 2. Current Measurements at Phelps Bank (40° 50.07'N - 69° 19.81'W).

TIDE TABLE DERIVED FROM CURRENT METER 'X' AT DEPTH OF FIVE METERS

Speeds and directions are averages of eight measurements.

The table gives hourly speeds and directions for the ten day period from July 10 to 20, 1982. Hours are in universal time. Subtract four hours for local time or five hours for Eastern Standard Time.

DAY 191 JULY 10 1982

HOUR ut	SPEED kts.	DIRECTION degrees
15	.96	5
16	1.20	48
17	1.48	78
18	1.49	100
19	1.39	132
20	1.31	165
21	1.27	188
22	1.54	207
23	1.38	226

DAY 192 JULY 11 1982

0	1.20	246
1	1.46	257
2	1.00	272
3	.54	305
4	.55	11
5	.60	49
6	.68	118
7	.75	150
8	1.14	187
9	1.70	209
10	1.65	223
11	1.77	235
12	1.47	243
13	1.31	258
14	1.04	284
15	.85	338
16	1.10	26
17	1.30	70
18	1.44	92
19	1.43	115
20	1.27	138
21	1.30	168
22	1.40	195
23	1.29	214

DAY 193 JULY 12 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.41	236
1	1.30	246
2	1.17	257
3	1.01	267
4	.53	333
5	.54	9
6	.54	70
7	.74	126
8	.90	170
9	1.27	199
10	1.38	219
11	1.65	230
12	1.52	237
13	1.36	248
14	1.19	272
15	1.07	306
16	85	356
17	1.15	45
18	1.40	77
19	1.38	95
20	1.23	121
21	1.31	147
22	1.32	177
23	1.32	202

DAY 194 JULY 13 1982

0	1.37	222
1	1.31	245
2	1.15	259
3	.83	284
4	.53	322
5	.58	36
6	.67	79
7	.80	143
8	.93	177
9	1.23	208
10	1.65	219
11	1.67	234
12	1.65	242
13	1.79	257
14	1.28	272
15	.75	318
16	1.02	8
17	1.33	34
18	1.41	78
19	1.25	101
20	1.45	131
21	1.21	160
22	1.41	190
23	1.75	209

Table 2. (Continued)

DAY 195 JULY 14 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.50	232
1	1.48	243
2	1.60	254
3	1.15	266
4	.77	305
5	.75	348
6	.74	30
7	.82	97
8	.79	138
9	1.09	175
10	1.31	201
11	1.44	220
12	1.58	235
13	1.55	247
14	1.44	263
15	1.36	286
16	.99	330
17	1.06	3
18	.98	45
19	1.41	88
20	1.29	111
21	1.39	137
22	1.51	171
23	1.52	200

DAY 196 JULY 15 1982

0	1.50	216
1	1.66	236
2	1.61	243
3	1.50	256
4	1.15	276
5	.80	305
6	.79	339
7	.75	25
8	.77	86
9	.91	136
10	.90	164
11	1.19	194
12	1.51	215
13	1.56	231
14	1.65	243
15	1.67	255
16	1.23	279
17	.90	325
18	.92	2
19	1.21	60
20	1.46	88
21	1.41	113
22	1.25	142
23	1.34	175

DAY 197 JULY 16 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.62	203
1	1.67	223
2	1.68	237
3	1.67	241
4	1.47	258
5	1.24	276
6	.79	323
7	.82	4
8	.91	49
9	1.14	95
10	1.07	128
11	1.14	164
12	1.21	193
13	1.50	213
14	1.42	230
15	1.40	245
16	1.39	259
17	1.04	279
18	.65	328
19	.89	26
20	1.32	69
21	1.32	96
22	1.22	122
23	1.25	154

DAY 198 JULY 17 1982

0	1.30	184
1	1.54	210
2	1.65	229
3	1.67	239
4	1.76	248
5	1.49	265
6	1.12	296
7	.86	341
8	.94	20
9	1.34	75
10	1.22	100
11	1.20	135
12	1.18	162
13	1.35	194
14	1.44	212
15	1.53	231
16	1.38	247
17	1.25	257
18	1.03	279
19	.73	335
20	.99	33
21	1.26	76
22	1.23	96
23	1.18	136

Table 2. (Continued)

DAY 199 JULY 18 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.19	150
1	1.47	198
2	1.71	221
3	1.87	236
4	1.87	246
5	1.58	255
6	1.34	272
7	.90	313
8	1.09	2
9	1.34	49
10	1.45	76
11	1.40	90
12	1.24	118
13	1.37	153
14	1.32	188
15	1.55	207
16	1.38	229
17	1.35	250
18	1.06	271
19	.94	285
20	.70	353
21	1.49	50
22	1.43	77
23	1.59	94

DAY 200 JULY 19 1982

0	1.37	118
1	1.31	164
2	1.61	203
3	1.77	225
4	1.89	235
5	1.76	238
6	1.72	253
7	1.53	274
8	1.19	326
9	1.21	6
10	1.43	59
11	1.53	76
12	1.63	97
13	1.39	129
14	1.33	163
15	1.47	194
16	1.71	211
17	1.53	235
18	1.33	253
19	1.41	268
20	.90	301
21	.86	22
22	1.24	61
23	1.41	79

DAY 201 JULY 20 1982

HOUR ut	SPEED kts	DIRECTION degrees
0	1.22	100
1	1.29	138
2	1.35	156
3	1.62	201
4	1.82	227
5	1.91	234
6	1.83	242
7	1.72	258
8	1.32	280
9	1.13	338
10	1.35	23
11	1.43	66
12	1.65	78

Table 3. Current Measurements at Phelps Bank (40° 50.07'N - 69° 19.81'W).

TIDE TABLE DERIVED FROM
CURRENT METER 'M' AT DEPTH OF
THIRTEEN METERS
Speeds and directions are averages of eight measurements.

The table gives hourly speeds and directions for the ten day period from July 10 to 20,1982. Hours are in universal time. Subtract four hours for local time or five hours for Eastern Standard Time.

DAY 191 JULY 10 1982

HOUR ut	SPEED kts.	DIRECTION degrees
16	1.23	19
17	1.27	50
18	.98	81
19	1.22	119
20	1.23	159
21	1.35	185
22	1.37	190
23	1.31	218

DAY 192 JULY 11 1982

0	1.15	259
1	1.01	281
2	.79	280
3	.51	327
4	.49	25
5	.63	53
6	.67	99
7	.79	143
8	1.03	181
9	1.41	210
10	1.56	223
11	1.71	256
12	1.11	268
13	.74	308
14	.86	6
15	1.23	44
16	1.26	64
17	1.23	81
18	1.20	104
19	1.20	138
20	1.25	167
21	1.34	203
22	1.37	219
23	1.22	244

DAY 193 JULY 12 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.03	261
1	.86	270
2	.58	289
3	.53	9
4	.63	35
5	.71	72
6	.70	123
7	.82	165
8	1.24	201
9	1.42	216
10	1.62	232
11	1.75	252
12	1.36	260
13	.95	285
14	.72	330
15	.94	23
16	1.30	58
17	1.25	68
18	1.29	94
19	1.22	115
20	1.23	151
21	1.30	182
22	1.46	207
23	1.37	224

DAY 194 JULY 13 1982

0	1.20	249
1	1.08	262
2	.86	277
3	.52	299
4	.60	15
5	.74	59
6	.73	86
7	.73	144
8	1.02	183
9	1.22	216
10	1.67	224
11	1.55	244
12	1.59	254
13	1.23	273
14	.82	310
15	.79	351
16	1.12	30
17	1.27	63
18	1.22	67
19	1.13	97
20	1.10	126
21	1.23	158
22	1.38	198
23	1.42	215

Table 3. (Continued)

DAY 195 JULY 14 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.34	236
1	1.17	252
2	1.07	265
3	.85	291
4	.63	337
5	.70	30
6	.68	58
7	.73	91
8	.78	136
9	.90	180
10	1.23	214
11	1.52	224
12	1.57	242
13	1.57	256
14	1.14	269
15	.94	307
16	.91	357
17	1.11	19
18	1.19	59
19	1.11	76
20	1.07	104
21	1.18	136
22	1.25	174
23	1.52	206

DAY 196 JULY 15 1982

0	1.55	216
1	1.57	250
2	1.55	254
3	1.23	263
4	.79	295
5	.68	344
6	.78	19
7	.87	60
8	.80	92
9	.83	138
10	1.06	174
11	1.25	209
12	1.37	228
13	1.53	248
14	1.37	258
15	1.19	267
16	.84	310
17	.94	350
18	1.03	26
19	1.24	57
20	1.19	87
21	1.18	113
22	1.27	148
23	1.31	183

DAY 197 JULY 16 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.63	211
1	1.70	223
2	1.85	251
3	1.55	257
4	1.11	269
5	.81	312
6	.83	356
7	1.02	30
8	1.06	66
9	.83	80
10	.86	125
11	1.07	170
12	1.24	202
13	1.35	222
14	1.36	244
15	1.31	257
16	1.06	270
17	.74	309
18	.82	1
19	1.12	46
20	1.22	73
21	1.35	92
22	1.26	124
23	1.24	157

DAY 198 JULY 17 1982

0	1.51	196
1	1.72	212
2	1.75	241
3	1.85	253
4	1.66	257
5	1.04	261
6	.56	291
7	.86	353
8	1.12	38
9	1.22	65
10	1.12	82
11	1.01	126
12	1.16	169
13	1.49	200
14	1.51	215
15	1.49	243
16	1.45	259
17	1.07	268
18	.78	305
19	1.70	2
20	1.16	46
21	1.19	70
22	1.11	97
23	1.11	131

Table 3. (Continued)

DAY 199 JULY 18 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.32	167
1	1.70	204
2	1.92	213
3	1.87	248
4	1.91	250
5	1.71	260
6	1.15	276
7	.85	332
8	1.12	16
9	1.36	58
10	1.25	63
11	1.21	87
12	1.15	117
13	1.27	163
14	1.38	198
15	1.45	213
16	1.56	235
17	1.28	258
18	1.05	273
19	.74	308
20	.81	16
21	1 17	56
22	1.23	65
23	1.22	92

DAY 200 JULY 19 1982

0	1.15	125
1	1.22	169
2	1.66	207
3	1 89	223
4	1.81	245
5	1 90	251
6	1.65	261
7	1.13	279
8	.93	337
9	1.18	20
10	1.26	58
11	1.35	67
12	1.25	88
13	1.24	119
14	1.27	163
15	1 51	195
16	1 60	211
17	1.75	236
18	1.59	255
19	1 14	270
20	.76	305
21	.86	19
22	1.22	54
23	1.31	65

DAY 201 JULY 20 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.19	89
1	1.26	116
2	1.34	168
3	1.73	208
4	1.86	212
5	1.93	242
6	1.87	249
7	1.77	258
8	1.16	278
9	.97	336
10	1.19	27
11	1.38	59
12	1.47	59
13	1.32	85
14	1.38	124
15	1.36	165
16	1.58	197
17	1.66	210
18	1.69	236
19	1.80	258

Table 4. Current Measurements at Phelps Bank (40° 50.07'N - 69° 19.81'W).

TIDE TABLE DERIVED FROM CURRENT METER 'N' AT DEPTH OF TWENTY-ONE METERS
Speeds and directions are averages of eight measurements
The table gives hourly speeds and directions for the ten day period from July 10 to 20, 1982
Hours are in universal time. Subtract four hours for local time or five hours for Eastern Standard Time.

DAY 191 JULY 10 1982

HOUR ut	SPEED kts	DIRECTION degrees
15	.67	341
16	1.01	27
17	1.12	49
18	.87	52
19	.81	88
20	.95	133
21	1.09	155
22	1.39	178
23	1.23	210

DAY 192 JULY 11 1982

0	1.12	220
1	.81	244
2	.65	277
3	.47	315
4	.56	17
5	.78	37
6	.73	76
7	.66	113
8	.81	142
9	.97	196
10	1.70	218
11	1.74	223
12	1.89	226
13	1.72	230
14	.98	262
15	.65	311
16	.73	12
17	1.10	21
18	.97	62
19	1.04	77
20	.94	93
21	1.07	146
22	1.12	172
23	1.22	201

DAY 193 JULY 12 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.39	211
1	1.07	219
2	.80	268
3	.62	274
4	.43	315
5	.54	16
6	.77	45
7	.64	87
8	.53	127
9	.75	155
10	.97	210
11	1.44	223
12	1.54	213
13	1.78	219
14	1.27	239
15	.77	289
16	.67	346
17	.91	22
18	1.09	25
19	.96	50
20	1.05	76
21	1.02	94
22	1.14	154
23	1.27	197

DAY 194 JULY 13 1982

0	1.36	216
1	1.03	232
2	.79	275
3	.64	272
4	.47	358
5	.62	31
6	.71	71
7	.66	89
8	.68	122
9	.84	166
10	1.18	217
11	1.41	212
12	1.52	222
13	1.73	225
14	1.10	257
15	.75	307
16	.72	5
17	1.15	19
18	1.15	22
19	.97	73
20	.95	89
21	.81	123
22	.93	155
23	1.22	207

Table 4. (Continued)

DAY 195 JULY 14 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.49	209
1	1.38	220
2	.83	247
3	.96	261
4	.63	298
5	.54	347
6	.77	35
7	.90	81
8	.64	96
9	.76	137
10	.92	162
11	1.17	207
12	1.46	211
13	1.49	214
14	1.39	243
15	1.11	259
16	.75	320
17	.88	4
18	1.14	33
19	1.16	64
20	1.12	77
21	.80	105
22	.99	148
23	1.12	200

DAY 196 JULY 15 1982

0	1.31	213
1	1.43	212
2	1.64	220
3	1.24	256
4	.89	269
5	.69	307
6	.70	1
7	.97	30
8	.88	67
9	.57	102
10	.64	127
11	.91	159
12	1.15	211
13	1.43	208
14	1.38	222
15	1.29	254
16	.96	268
17	.70	313
18	.88	9
19	1.11	36
20	1.10	51
21	.95	74
22	.99	135
23	1.01	163

DAY 197 JULY 16 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.20	193
1	1.65	201
2	1.56	207
3	1.68	224
4	1.52	235
5	.94	270
6	.67	317
7	.73	8
8	.99	30
9	.95	58
10	.67	83
11	.75	131
12	.98	168
13	1.18	214
14	1.34	214
15	1.36	229
16	1.19	261
17	.94	280
18	.65	325
19	.90	21
20	1.10	28
21	1.00	43
22	1.06	64
23	1.21	138

DAY 198 JULY 17 1982

0	1.26	179
1	1.36	204
2	1.75	200
3	1.89	220
4	1.92	218
5	1.53	240
6	.87	270
7	.69	341
8	.98	15
9	1.10	46
10	.89	55
11	.79	87
12	.86	126
13	1.17	202
14	1.29	213
15	1.40	212
16	1.40	222
17	1.29	259
18	.88	265
19	.66	318
20	.83	19
21	.94	33
22	.90	67
23	.92	82

Table 4. (Continued)

DAY 199 JULY 18 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.04	149
1	1.34	189
2	1.51	207
3	1.87	213
4	1.93	216
5	1.83	221
6	1.32	253
7	.84	288
8	.74	347
9	1.08	24
10	1.14	22
11	1.09	62
12	1.06	76
13	.84	131
14	1.05	177
15	1.33	208
16	1.53	210
17	1.50	216
18	1.13	257
19	.85	266
20	.66	327
21	.89	16
22	1.06	21
23	1.25	66

DAY 201 JULY 20 1982

HOUR ut	SPEED kts.	DIRECTION degrees
0	1.17	62
1	1.08	73
2	1.10	134
3	1.45	198
4	1.84	196
5	1.88	206
6	1.92	217
7	1.86	246
8	1.65	257
9	.90	297
10	.86	3
11	1.17	18
12	1.12	56

DAY 200 JULY 19 1982

0	.96	90
1	1.08	137
2	1.28	186
3	1.80	203
4	1.87	207
5	1.81	213
6	1.58	247
7	1.36	262
8	.87	292
9	.78	346
10	1.10	11
11	1.23	40
12	1.10	45
13	1.02	68
14	1.21	138
15	1.32	184
16	1.43	212
17	1.50	208
18	1.59	218
19	1.25	256
20	.85	273
21	.54	320
22	.96	24
23	1.14	50

Two qualitative aspects of the currents can be established from simple inspection of the tables. First of all, it is seen that the current direction varies continuously in a clockwise manner at a rate of approximately 29° per hour. That is, the current at Phelps Bank is dominated by a rotary tidal component with a period of about 12-1/2 hours. It is also seen from the tables that the tidal current is fairly strong, occasionally reaching values of 1.8-1.9 knots (.92-.98 $msec^{-1}$). The slowest currents fall in the range of 0.50 knots (.26 $msec^{-1}$). The high currents are associated with directions in the 210°-260° range while the slow currents are correlated with directions between 290° and about 110°. This indicates that the trajectory of the water during a tidal cycle is generally elliptical.

The information in Tables 2-4 is presented graphically in Fig. 7, A-C, which shows the hourly averaged values of current speed and direction for all three meters during the 10 days the mooring was in place. Perhaps the most striking feature of Fig. 7 is that the current meters at different depths show no gross differences in their speeds and directions. For example, the speed maxima and minima have very nearly the same values. The most noticeable, consistent variation is that the direction of the deep meter (N) almost always lags behind the upper two meters by approximately 30°. The only other obvious consistency is that the current speed measured by the deep current meter is always about 1/4 kt. slower than the upper meters when the flow direction is in the 100°-140° range. The physical mechanisms responsible for these effects are not clear but they may be related to veering due to bottom drag or to local topographic influence.

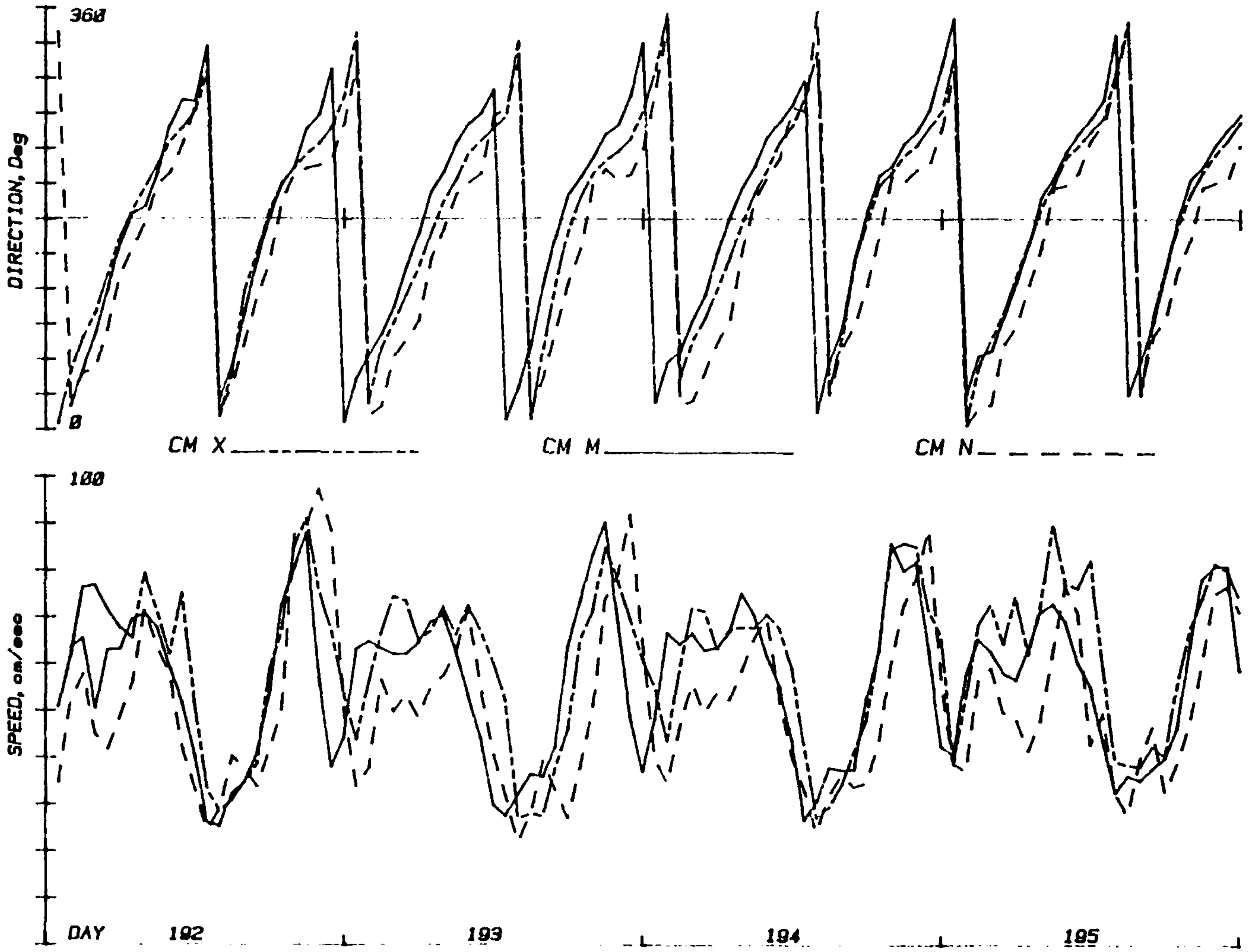

Fig. 7A. - Hourly averaged current speeds and directions for the three moored current meters, July 10-20, 1982 at Phelps Bank. X - 5 m, M - 13 m, N - 21 m. Times are in Julian days.

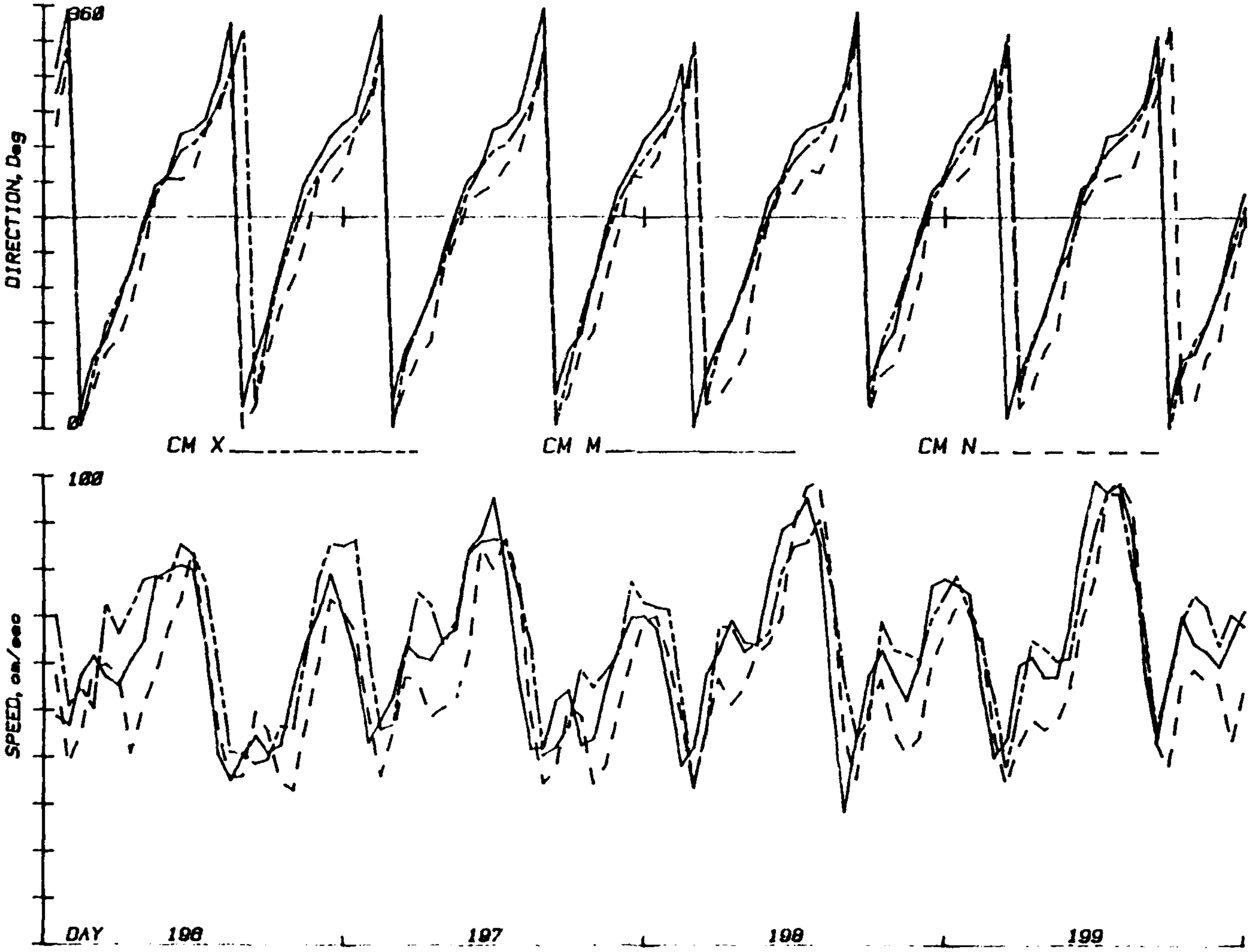

Fig. 7B. - Hourly averaged current speeds and directions for the three moored current meters, July 10-20, 1982 at Phelps Bank. X - 5 m, M - 13 m, N - 21 m. Times are in Julian days.

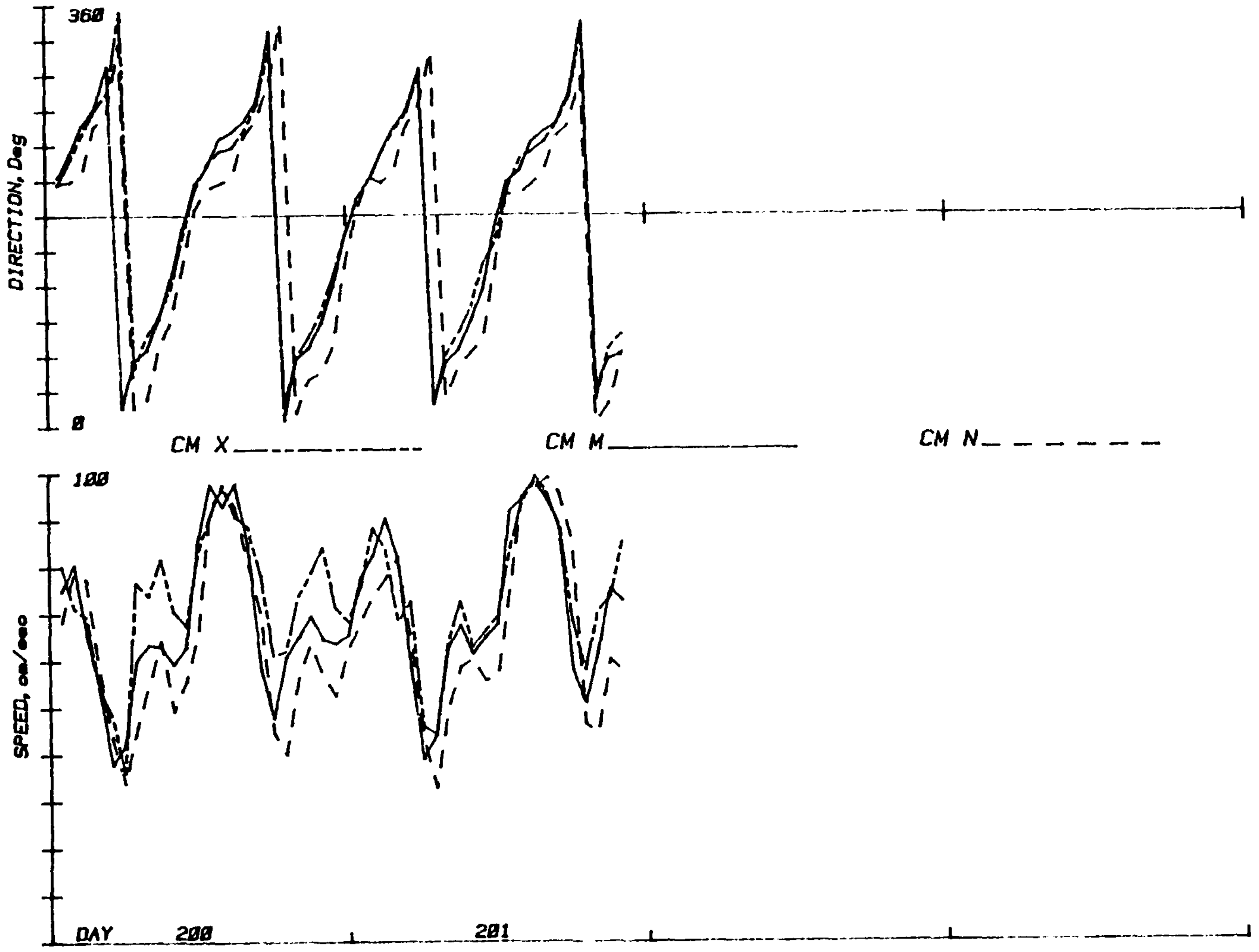

Fig. 7C. - Hourly averaged current speeds and directions for the three moored current meters, July 10-20, 1982 at Phelps Bank. X - 5 m, M - 13 m, N - 21 m. Times are in Julian days.

Current measurements from a fixed mooring can also be represented graphically as progressive vector diagrams. This is the traditional method for producing a current "quasi-trajectory" based on measurements made at a fixed site. This is accomplished by considering each measured speed and direction as a vector and sequentially adding these vectors to each other in a time series. An example of this approach is shown in Fig. 8. Here all the current plus direction records (8 per hour) from the near-surface current meter X (~ 5 m depth) are vectorially added for the 10 day duration of the deployment.

When the data are presented in this way, two additional aspects of the current at this location become evident. The first and most obvious is that there is a progressive drift toward the southwest (220°), that is, the current includes a relatively steady component in addition to the rotary tidal motion mentioned earlier. The second noticeable feature is that the relative amplitudes of sequential, 12.5-hour rotary tides change along the time series from July 10 to July 20 (Julian day 191 to 201). This pattern is typical of semi-diurnal tides and is associated with the tilt of the earth's axis of rotation relative to the ecliptic, the latitude of the observations and the time in the lunar month. Detailed discussions of this tidal phenomenon are available in most standard oceanographic reference texts (Hansen, 1962) and it will not be pursued here.

We will now return to a consideration of the long-term flow over Phelps Bank. It is seen from Fig. 8 that there is some variability in the speed and direction of the drift current with an average speed of approximately 0.47 kt (22 cm sec^{-1}). It should be noted here that the other two current meters at 13 (M, M_2) and 21 m (N, M_1) depth do not record the

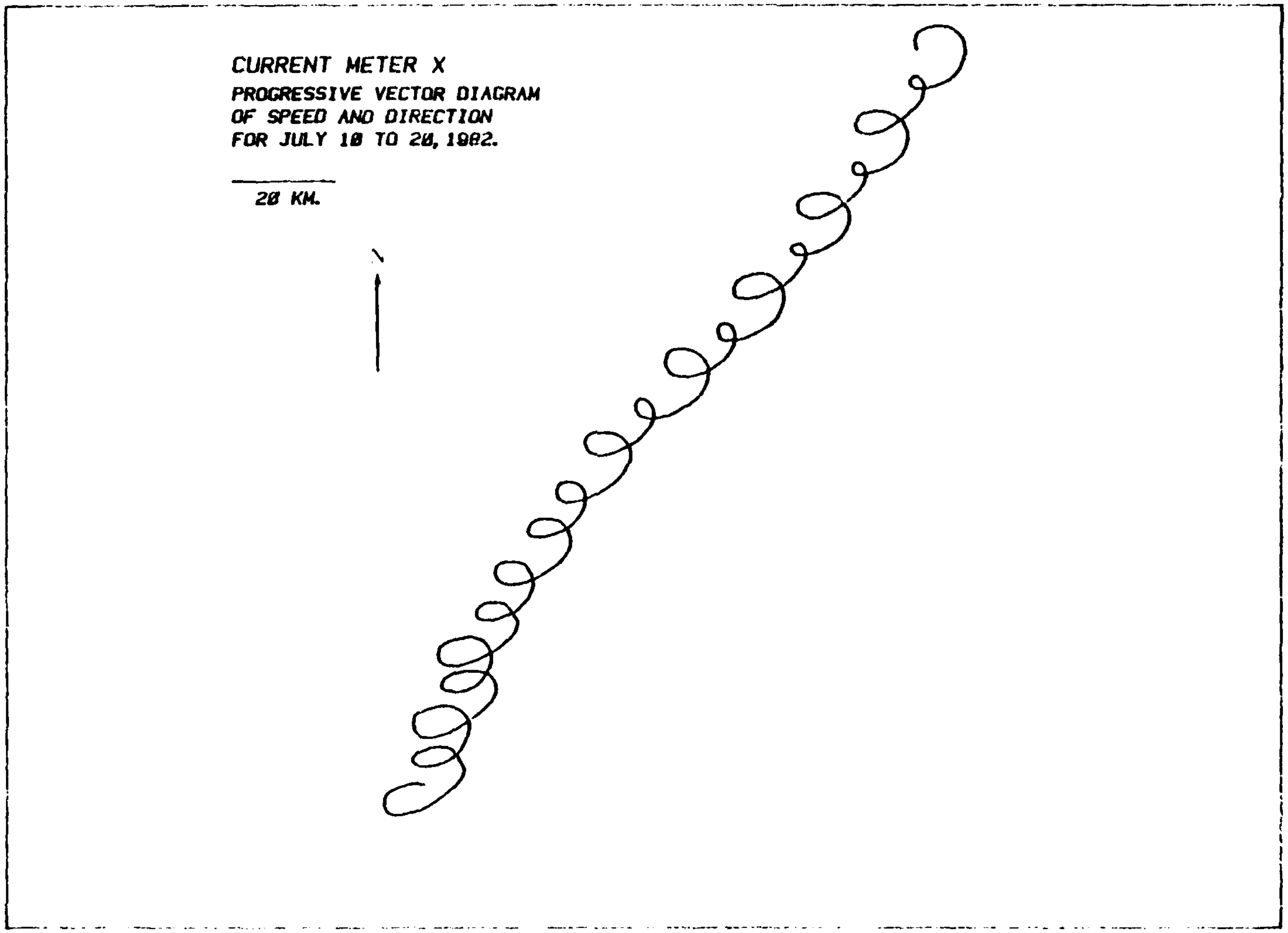

Fig. 8. - Progressive vector diagram or "quasi-trajectory" for the current meter record at 5 m depth.

same "steady" component as meter X (M_3) at 5 m, which is shown in Fig. 8. The relative, quasi-trajectories of the steady components of current as recorded by the 3 meters are illustrated in Fig. 9 and listed in Table 5. It can be seen that the drift current indicated by the mid-depth meter (M, 13 m) is in approximately the same direction (220°) as that recorded by the near-surface meter (X, 5 m) but it is slower by about .12 kt. The deep meter (N, 21 m) records the same current speed as the mid-depth meter but the direction of the flow differs by about 10° (210°). Whether this latter effect is due to veering as a result of bottom drag, local topography or instrumental error is not demonstrable from the limited data available. What is clear is that there is a considerable vertical shear in the steady drift current. The shear between meters X (5 m) and M (13 m) is approximately 8.5×10^{-3} sec^{-1} and is primarily a result of speed differences. Between meters M (13 m) and N (21 m) the shear is about 3.2×10^{-3} sec^{-1} and is mainly attributable to differences in direction. These shears are relatively large but not atypical of those measured in the upper ocean.

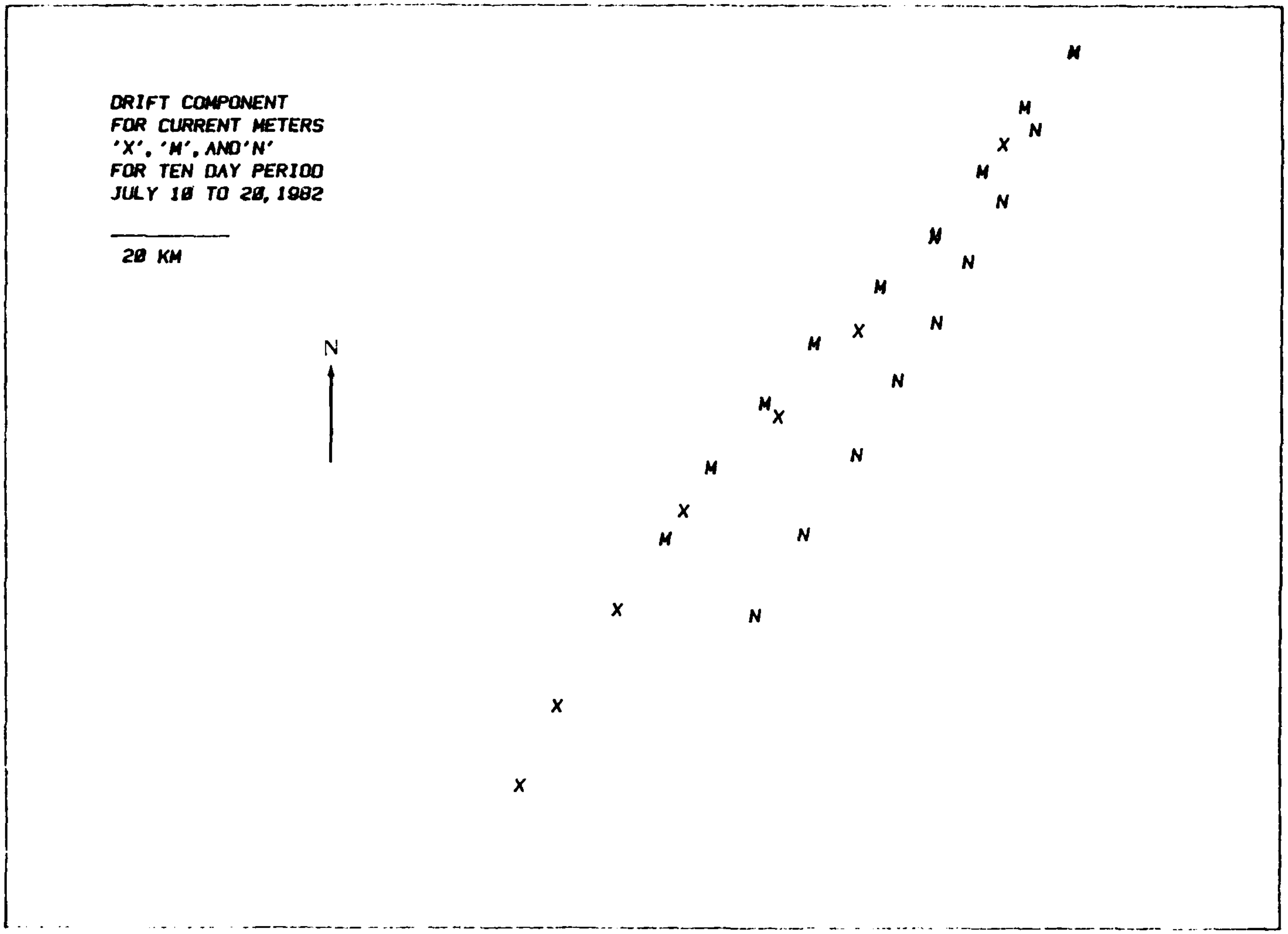

Fig. 9. - The steady component or drift current for the three moored current meters. The letters indicate successive 25 hour intervals on the progressive vector diagrams. X - 5 m, M - 13 m, N - 21 m.

Table 5. Drift current speeds and directions recorded by the 3 current meters for the 25 hour intervals shown in Figure 9

	Meter X (5 m)		Meter M (13 m)		Meter N (21 m)	
	Speed (cmsec^{-1})	Direction (deg)	Speed (cmsec^{-1})	Direction (deg)	Speed (cmsec^{-1})	Direction (deg)
	22.4	217	14.2	221	16.8	206
	22.3	216	14.8	212	15.2	204
	23.1	218	15.1	216	13.2	208
	22.6	222	14.6	226	13.3	207
	25.6	224	16.6	228	13.5	213
	22.9	213	15.0	219	16.3	207
	22.0	211	16.2	219	18.6	213
	17.1	204	16.3	212	18.3	210
	17.7	198	16.3	213	16.8	212
Avg	21.8 (.42kt)		15.4 (.30kt)		15.8 (.31kt)	

The daily, averaged drift currents listed in Table 5 can be subtracted from the total currents to obtain the rotary tidal component. The result for the near-surface current meter (X, 5 m) is shown in Fig. 10. The plot is disconcertingly reminiscent of the classical "NIDUS RATTI" but does serve to illustrate the rotary tidal flow and makes it possible to produce tide tables for the specific location. This is accomplished by averaging the speeds and directions of the tidal currents and expressing them in terms of the time after maximum flood tide at Pollock Rip. The tidal current at the Phelps Bank mooring site can then be predicted for any time in the future by using the Pollock Rip data from published tide tables (NOAA, 1981 or equivalent) and Table 6 given here. The procedure for obtaining past or future tides at various locations on Nantucket Shoals are described in detail in the National Ocean Survey, Tidal Current Tables (NOAA, 1981).

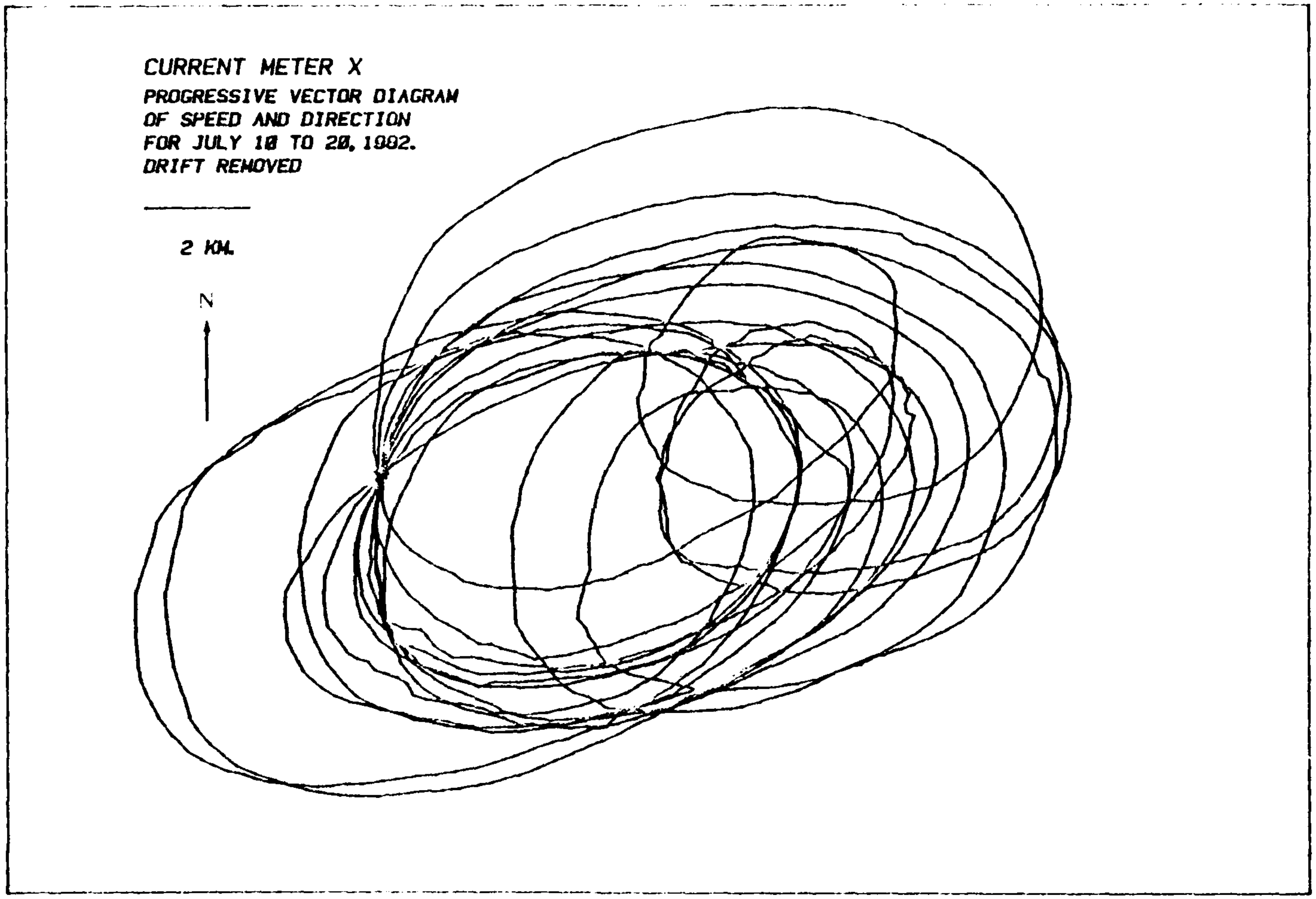

Fig. 10. - The rotary tidal component of the currents recorded by meter X (5 m) during the deployment. This represents the progressive vector diagram of Fig. 8 when the drift current in Fig. 9 is subtracted each 25 hours.

Table 6. Rotary tidal currents at the mooring site on Phelps Bank
(40° 50.07'N-69° 19.81'W)
Times are given in hours after maximum flood current
at Pollock Rip Channel

I. Meter X, nominal depth 5 m.

TIME hours	DIRECTION degrees	SPEED knots
0	35	1.30
1	61	1.44
2	83	1.36
3	111	1.13
4	146	.93
5	188	.96
6	216	1.11
7	237	1.14
8	254	1.16
9	272	1.11
10	301	1.00
11	347	.96

II. Meter M, nominal depth 13 m.

TIME hours	DIRECTION degrees	SPEED knots
0	39	1.24
1	63	1.28
2	85	1.16
3	119	.98
4	162	.93
5	200	1.10
6	223	1.19
7	247	1.26
8	263	1.22
9	284	.94
10	327	.78
11	9	.97

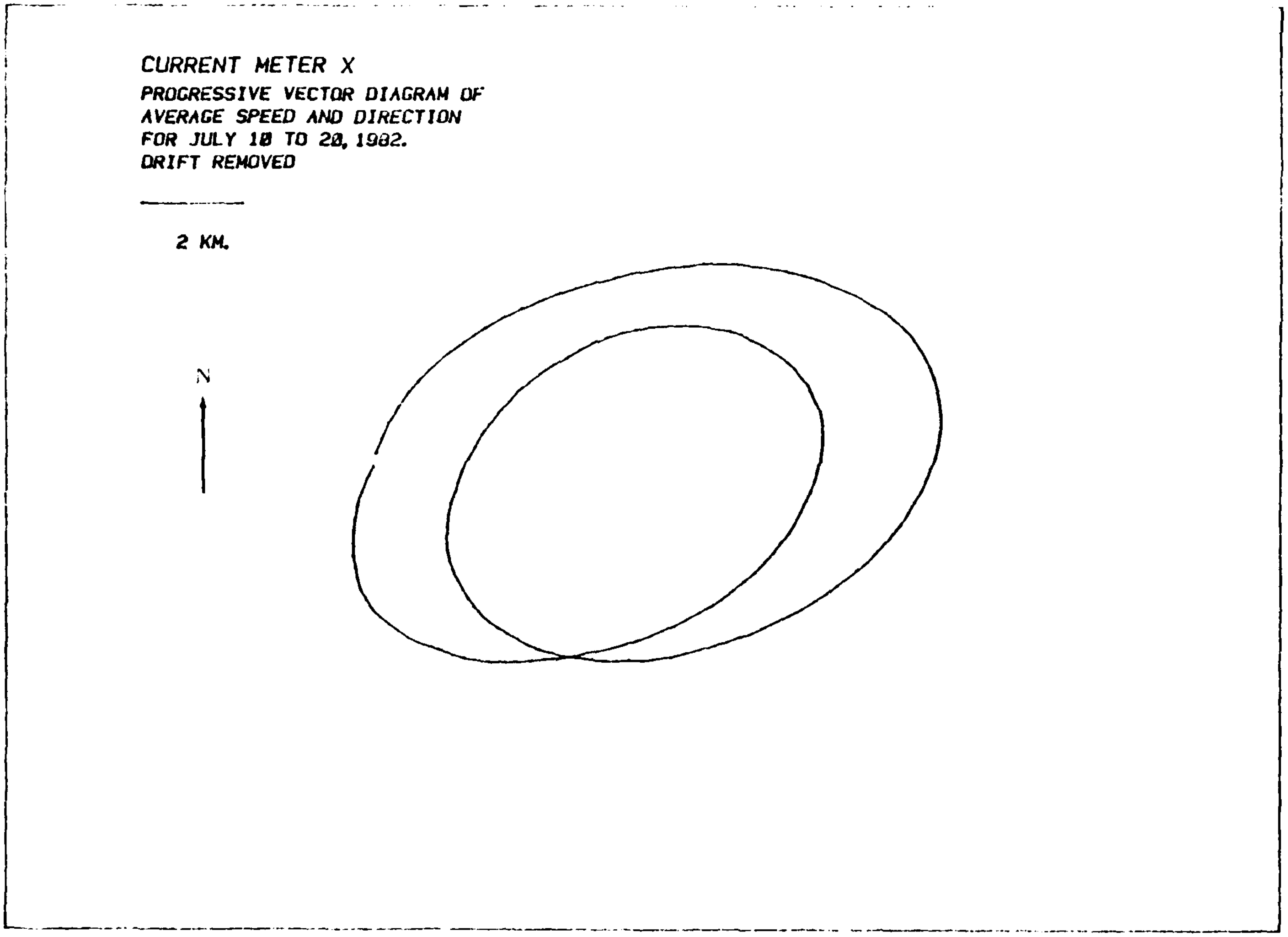

Fig. 11. - The rotary tidal component of the progressive vector diagrams in Fig. 10 averaged over 25 hour cycles.

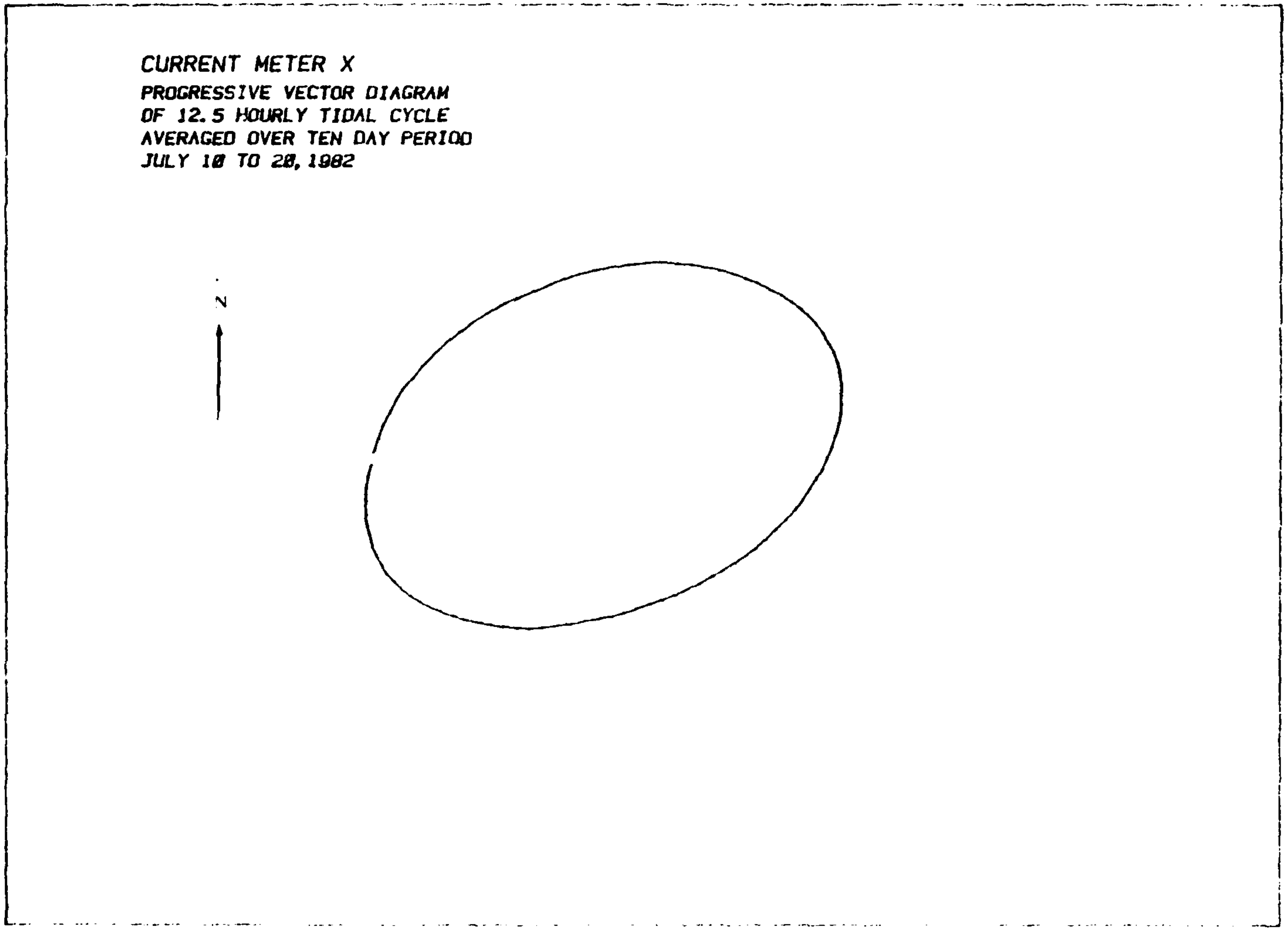

Fig. 12. - The rotary tidal component of the current at meter X (5 m) averaged over 12.5 hour cycles.

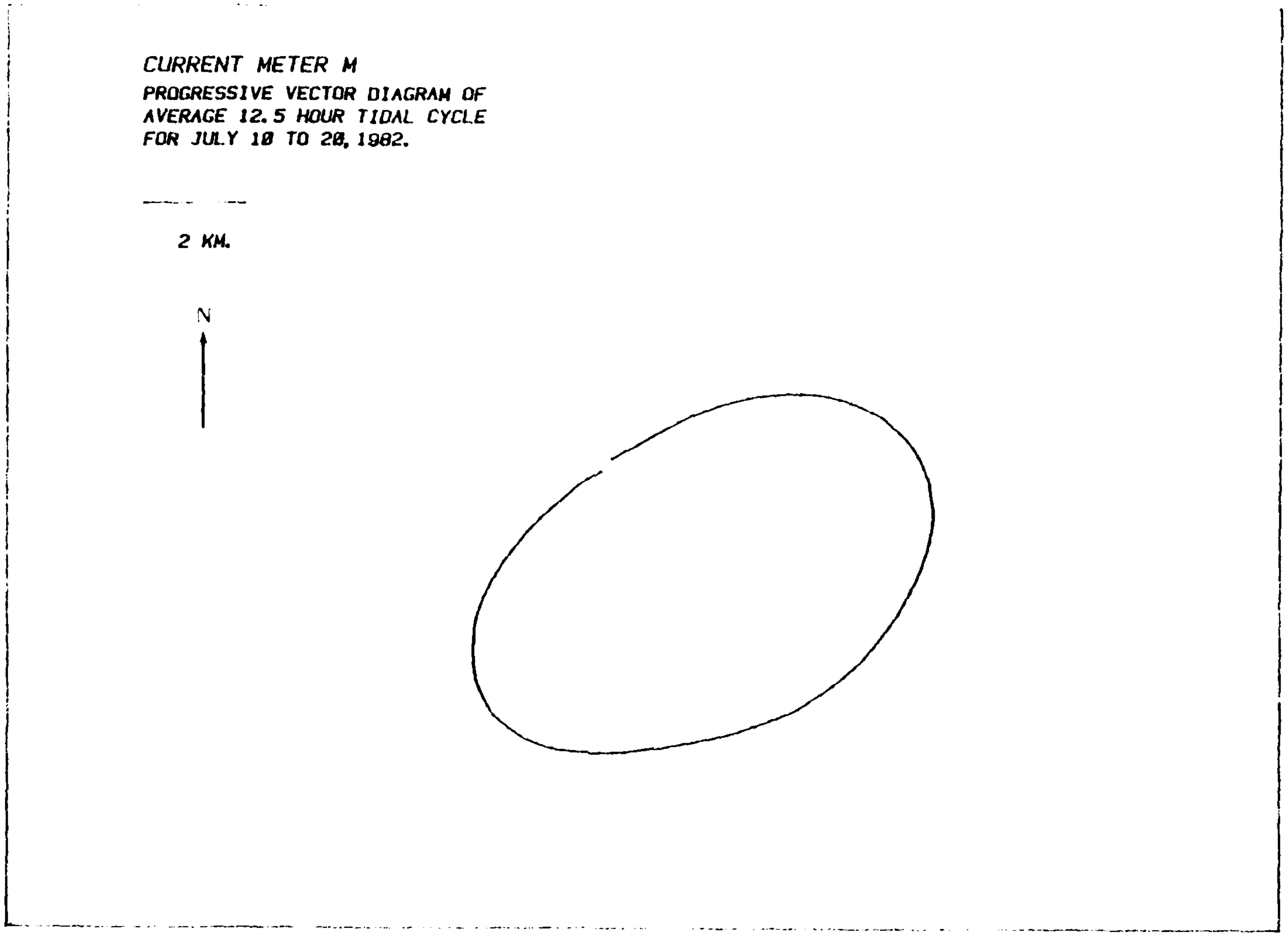

Fig. 13. - The rotary tidal component of the current at meter M (13 m) averaged over 12.5 hour cycles.

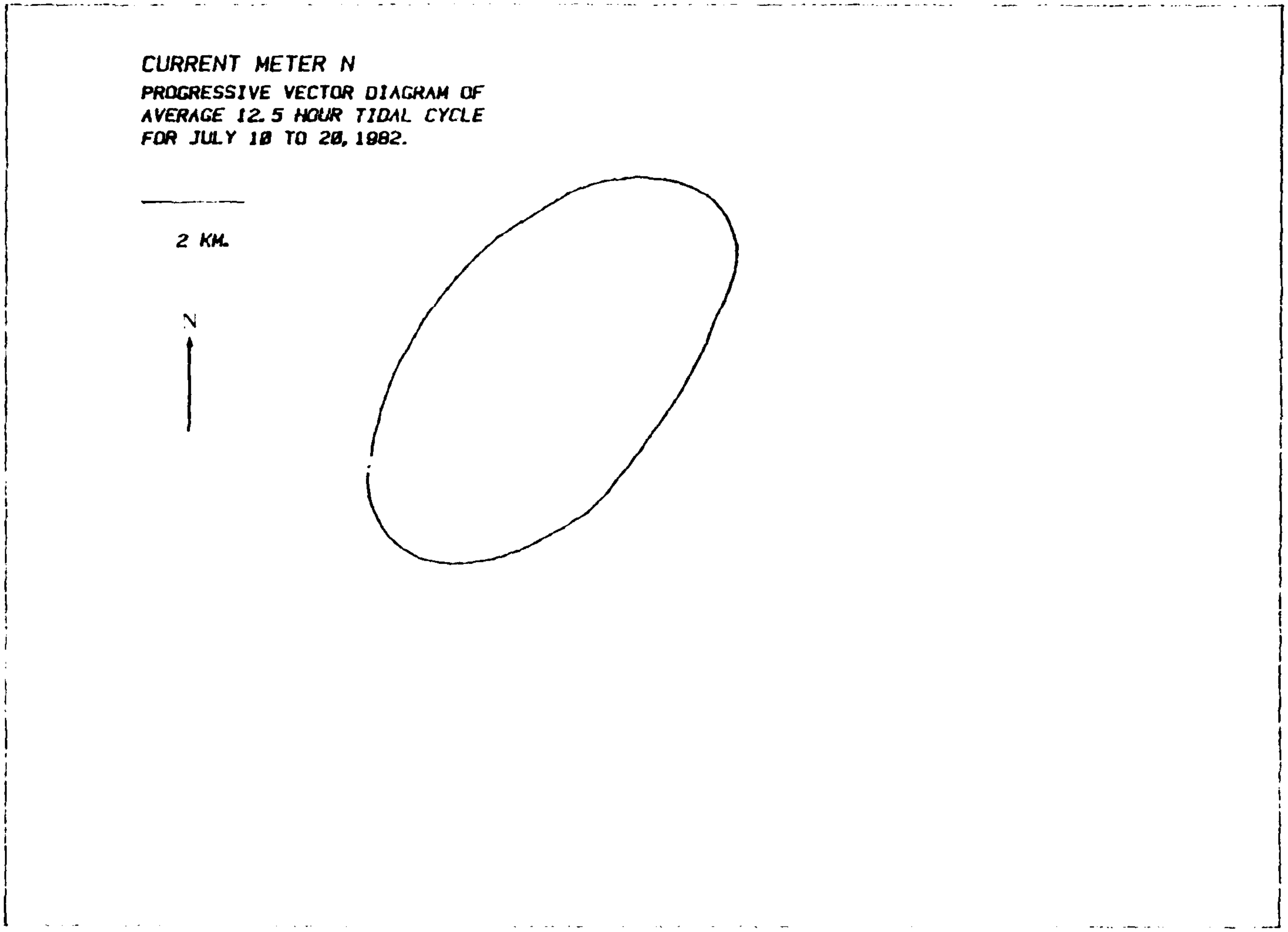

Fig. 14. - The rotary tidal component of the current at meter N (21 m) averaged over 12.5 hour cycles.

III. Meter N, nominal depth 21 m.

TIME hours	DIRECTION degrees	SPEED knots
0	19	1.11
1	35	1.24
2	54	1.21
3	80	.94
4	115	.76
5	168	.73
6	201	1.00
7	211	1.18
8	223	1.22
9	248	1.05
10	283	.78
11	333	.75

The progressive averaging of the data in Fig. 10 over 25-hour and 12.5-hour tidal cycles is shown graphically in Figs. 11 and 12 respectively. It is seen that the 12.5 hour averaging required to produce Table 6 removes the sequential asymmetry associated with the relative earth-moon positions that was mentioned earlier. The equivalent 12.5-hour averaged rotary tides for the deeper meters (M at 13 m, N at 21 m) are plotted in Figs. 13 and 14. A comparison of Figs. 12, 13 and 14 indicates that the rotary tidal component of the current is almost identical at depths of 5 and 13 m while the east-west tidal amplitude is somewhat reduced at 21 m depth. This difference shows that there is some shear in the rotary tidal component of the current as well as in the "steady" component discussed earlier. At 13 m and shallower the rotary component moves essentially as a slab. Below 13 m the east-west current is somewhat slower. The data set is not adequate to attribute this effect to any specific hydrographic or hydrodynamic cause.

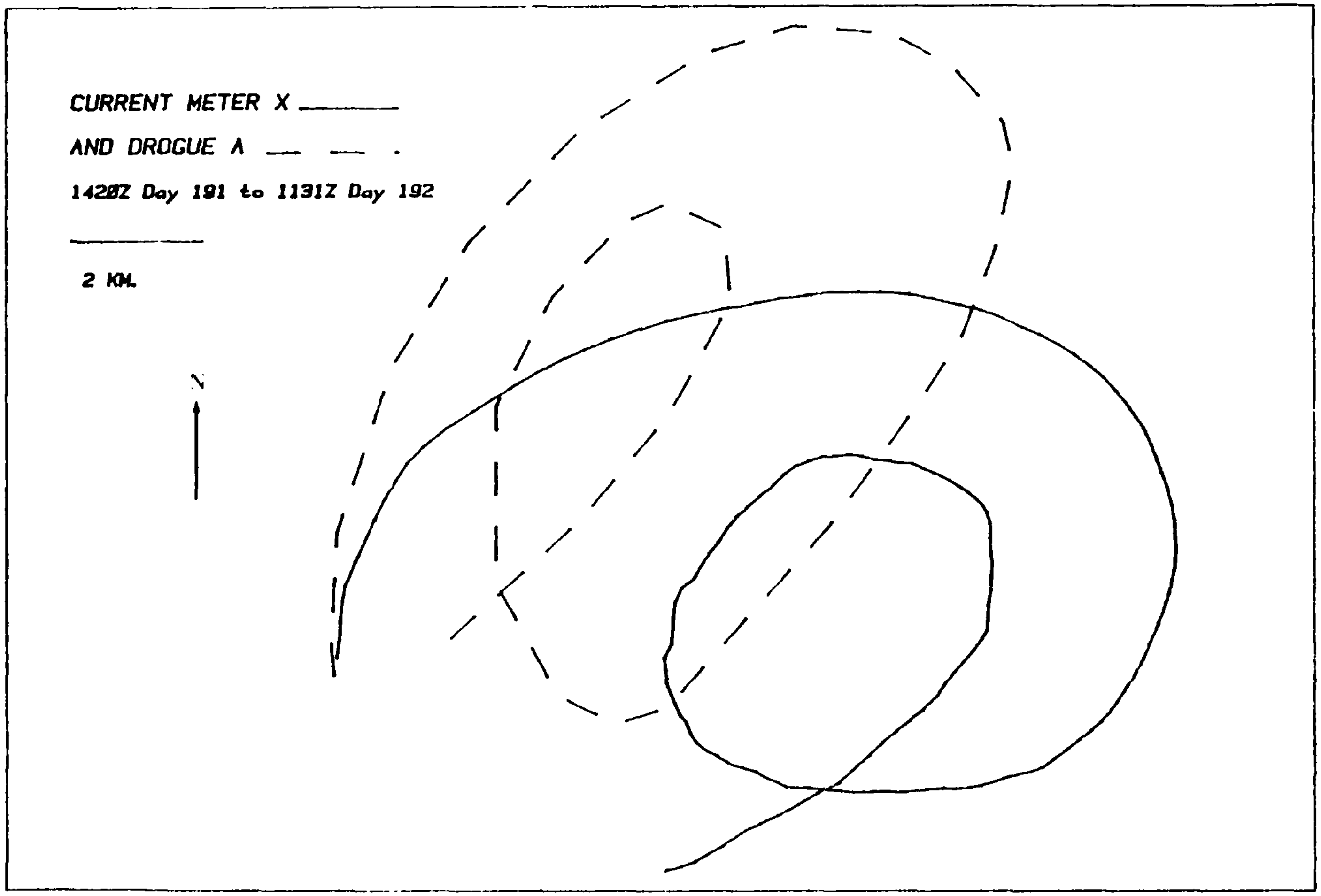

Fig. 15. - Comparison of the trajectory of a current following drogue (5m, dashed curve) 4.5 nautical miles west of Phelps Bank with the "quasi-trajectory" (progressive vector diagram, continuous curve) recorded by meter X (5 m) moored at the bank for July 10-11, 1982.

COMPARISON TO LAGRANGIAN METHOD

When reviewing and interpreting the information presented in this report, it is instructive to compare and contrast these results with our previously published results of current measurements in the vicinity made by Lagrangian methods (Greenewalt and Gordon, 1982). The two reports should be considered complementary. The most striking distinction between currents measured on the bank by Eulerian methods and those measured east and west of the bank by drogue following (Lagrangian technique) is graphically illustrated in Fig. 15. The plot shows the trajectory of a current-following drogue (A) at 6 m depth at a location centered about 4.5 nautical miles west of Phelps Bank compared to the "quasi-trajectory" (progressive vector diagram) of currents measured at the same time by Eulerian technique at the mooring (Meter X). The meter array was deployed near the east side of the bank (nominal depth = 5 m, July 10-11, 1982). Both tracks show the elliptical shape typical of rotary tides, however, the ellipse measured off the bank where the sea was about 40 m deep has a major axis in a roughly North-South direction while for the ellipse measured over the bank (~ 30 m depth or less) the East-West dimension is extended. The result shown in Fig. 15 is a typical one and applies to all cases when there were simultaneous current measurements by Eulerian methods at the bank and Lagrangian methods in the vicinity of the bank. We have interpreted this enhancement of current flow across the short dimension of Phelps Bank as a topographic effect of the bank itself, namely, an acceleration of the flow due to the vertical reduction of its "channel depth". This interpretation is also consistent with current speed changes across the bank measured by using the ship (USNS HAYES) as a Lagrangian drifter. Whether the interpretation can be quantitatively confirmed depends on more detailed measurements of the local bathymetry and current speeds across the topographic feature. Elementary continuity analysis of the current speed and depth measurements across the bank (Greenewalt and Gordon, 1982) indicate that the situation may be somewhat more complex than simple channel constraint, i.e., the product of depth and current speed is not constant over Phelps Bank.

SUMMARY

The primary purpose of this report was to supply the participants in the NRL Remote Sensing Experiment (July 5-25, 1982) with hour by hour measurements of current at Phelps Bank to aid in their interpretation of hydrographic, radar, wave, IR, photographic and other simultaneous measurements in the vicinity. A second objective was to provide a means of predicting currents at Phelps Bank at some future time for purposes of operational planning. Both these tasks have been accomplished with the data listings and tide tables produced.

Comparison to current measurements made by Lagrangian methods indicates that the "channel depth constraint" of Phelps Bank causes the East-West component of the rotary tidal currents to be enhanced as it flows over the topographic feature.

For purposes of planning future field exercises of a similar nature, it is recommended that current meters be moored on both sides of Phelps Bank as well as on the central crest of the bank. Current meters should be deployed in at least 6 locations: 2 east, 2 west and 2 on top of Phelps

Bank. The measurements by Eulerian methods must be accompanied by simultaneous Lagrangian measurements for purposes of mutual calibration and interpretation of the hydrodynamics of the flow regime.

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APPENDIX

This appendix includes the computer programs developed for the data treatment. The language is BASIC and the documentation is self-explanatory.

PROGRAM "RITECM"

THIS PROGRAM IS USED TO ENTER CURRENT METER SPEEDS AND DIRECTIONS FROM KEYBOARD AND STORE THEM ON TAPE. DATA MAY BE CORRECTED AFTER EVERY 16 ENTRIES

```
 10 OPTION BASE 1
 20 DEG
 30 DIM S(16),D(16)
 40 C$="CM2EXP"
 50 D$="CM2DAT"
 60 DISP "THIS PROGRAM STORES C-
    M SPEEDS  AND DIRECTIONS IN
    FORM SS.DDD"
 70 DISP "IN 5 FILES OF 32 NUMBE
    RS. AN    ADDITIONAL FILE,'C
    M-EXP' GIVES"
 80 DISP "DATES START TIME, AND
    TIME       INTERVAL"
 90 CREATE C$,1
100 CREATE D$,5
110 ASSIGN# 1 TO D$
120 ASSIGN# 2 TO C$
130 C=1
140 DISP
150 DISP "ENTER DATE AS JULIAN D
    AY"
160 INPUT D
170 DISP "ENTER START TIME,AS HH
    .MM"
180 INPUT T1,T2
190 DISP "ENTER TIME INTERVAL"
200 INPUT D1
210 T1=T1*60+T2
220 PRINT# 2 ; T1,D,D1
230 FOR J=1 TO 10
240 DISP "SEGMENT";J;"SEQ NO";C
250 DISP "ENTER 16 SPEEDS,DIRECT
    IONS"
260 FOR I=1 TO 16
270 INPUT S(I),D(I)
280 C=C+1
290 NEXT I
300 IMAGE DD,5X,DDD,5X,DDD
310 DISP
320 DISP "NO.     SPD      DIR "
330 FOR I=1 TO 16
340 DISP USING 300 ; I,S(I),D(I)
350 NEXT I
360 DISP
370 DISP "ANY CORRECTIONS"
380 INPUT A$
390 IF A$#"YES" THEN 430
400 DISP "ENTER LINE NO.,CORRECT
     SPEED,   CORRECT DIRECTION"
410 INPUT I,S(I),D(I)
420 GOTO 320
430 FOR I=1 TO 16
440 D(I)=D(I)/1000
450 E=S(I)+D(I)
460 PRINT# 1 ; E
470 NEXT I
480 NEXT J
490 DISP "ENTER END DATE AS JD"
500 INPUT D
510 DISP "ENTER END TIME,HH.MM"
520 INPUT T1,T2
530 T1=T1*60+T2
540 PRINT# 2 ; D,T1
550 ASSIGN# 1 TO *
560 ASSIGN# 2 TO *
570 DISP "C-M DATA ENTERED"
580 END
```

PROGRAM "TRNTD"

THIS PROGRAM TRANSFERS CURRENT METER DATA FROM TAPE TO DISC

```
 10 OPTION BASE 1
 20 DEG
 40 C$="CM2EXP:D700"
 50 D$="CM2DAT:D700"
 60 DISP "THIS PROGRAM STORES C-
    M SPEEDS  AND DIRECTIONS IN
    FORM SS.DDD ON DISC FROM TAP
    E"
 70 DISP "IN 15FILES OF 32 NUMBE
    RS  AN    ADDITIONAL FILE,'C
    M-EXP' GIVES"
 80 DISP "START TIME, END TIME,
    DATE AND  INTERVAL BETWEEN D
    ATA"
 90 CREATE C$,1
100 CREATE D$,15
110 ASSIGN# 1 TO D$
120 ASSIGN# 2 TO C$
130 T$=":T"
140 DATA CM4DAT,CM5DAT,CM6DAT
141 ASSIGN# 3 TO "CM4EXP:T"
142 READ# 3 ; A,B
143 ASSIGN# 3 TO "CM6EXP:T"
144 READ# 3 ; F,G,C,D,E
161 PRINT# 2 ; A,B,C,D,E
162 FOR J=1 TO 3
170 READ F$
180 ASSIGN# 3 TO F$&T$
230 FOR I=1 TO 160
240 READ# 3 ; C
242 PRINT# 1 , C
250 NEXT I
290 NEXT J
320 DISP "DATA TRANSFERED"
460 END
```

PROGRAM "VSUM3"

THIS PROGRAM PLOTS THE PROGRESSIVE VECTOR DIAGRAM FOR CURRENT METER M FROM SPEED AND DIRECTION DATA FILED IN "CM0DAT" THROUGH "CM4DAT".

```
 10 OPTION BASE 1
 11 PLOTTER IS 705
 20 DEG
 21 X0,Y0=0
 22 DATA CM0DAT,160,CM-DAT,224,C
    M1DAT,480,CM2DAT,480
 23 DATA CM3DAT,480,CM4DAT,144
 31 SCALE -30000,6000,-26000,100
    0
 32 GCLEAR
 33 MOVE X0,Y0
 34 FOR J=1 TO 6
 35 READ D$,N
 60 ASSIGN# 1 TO D$
 80 FOR I=1 TO N
 90 READ# 1 ; C
 91 S=IP(C) @ D=FP(C)*1000
100 X=S*SIN(D) @ Y=S*COS(D)
110 X0=X0+X @ Y0=Y0+Y
130 PLOT X0,Y0
140 PENUP
150 NEXT I
160 NEXT J
170 END
```

PROGRAM "RITEDRFT"

THIS PROGRAM CALCULATES THE EAST AND NORTH COMPONENTS OF DRIFT OF THE PROGRESSIVE VECTOR DIAGRAM OVER A 25 HOUR PERIOD FOR CURRENT METER X AND STORES THESE IN THE FORM OF SPEEDS (cm/sec) IN FILE 'DRIFT-X"

```
 10 OPTION BASE 1
 20 DEG
 30 DATA CX1DAT,CX2DAT,CX3DAT
 40 ASSIGN# 1 TO "CX0DAT"
 50 CREATE "DRIFT-X",1
 60 ASSIGN# 2 TO "DRIFT-X"
 70 FOR J=1 TO 9
 80 X0,Y0=0
 90 FOR I=1 TO 200
100 READ# 1 ; C
110 S=IP(C) @ D=FP(C)*1000
120 X=S*SIN(D) @ Y=S*COS(D)
130 X0=X0+X @ Y0=Y0+Y
140 IF J=3 AND I=80 THEN GOSUB 2
    20
150 IF J=5 AND I=160 THEN GOSUB
    220
160 IF J=8 AND I=40 THEN GOSUB 2
    20
170 NEXT I
180 X0=X0/200 @ Y0=Y0/200
190 PRINT# 2 ; X0,Y0
200 NEXT J
210 STOP
220 READ D$
230 ASSIGN# 1 TO D$
240 RETURN
250 END
```

```
PROGRAM "VSUM6"

IN THIS PROGRAM, THE PROGRESSIVE
VECTOR DIAGRAM FOR CURRENT METER
X IS PLOTTED, BUT WITH THE DRIFT
REMOVED FOR EACH 25 HOUR (200
POINTS) PERIOD. THE RESULT IS A
SERIES OF OVERLAPPING TIDAL
LOOPS (nidus ratti).

 10 OPTION BASE 1
 20 PLOTTER IS 705
 30 DEG
 31 SCALE -1600,4000,-2100,2100
 32 GCLEAR
 40 DATA CX1DAT,CX2DAT,CX3DAT
 50 ASSIGN# 1 TO "CX0DAT"
 51 ASSIGN# 2 TO "DRIFT-X"
 52 PENUP
 60 FOR J=1 TO 9
 61 READ# 2 ; X1,Y1
 70 X0,Y0=0
 80 FOR I=1 TO 200
 90 READ# 1 ; C
100 S=IP(C) @ D=FP(C)*1000
120 X=S*SIN(D)-X1 @ Y=S*COS(D)-Y
    1
130 X0=X0+X @ Y0=Y0+Y
131 PLOT X0,Y0
140 IF J=3 AND I=80 THEN GOSUB 3
    40
150 IF J=5 AND I=160 THEN GOSUB
    340
160 IF J=8 AND I=40 THEN GOSUB 3
    40
190 NEXT I
210 NEXT J
340 READ D$
350 ASSIGN# 1 TO D$ •
360 RETURN
370 FRAME
380 MOVE -1000,1800
390 CSIZE 3, 7,10
400 LABEL "CURRENT METER X"
410 CSIZE 2.5, 7,10
420 LABEL "PROGRESSIVE VECTOR DI
    AGRAM"
430 LABEL "OF SPEED AND DIRECTIO
    N"
440 LABEL "FOR JULY 10 TO 20,198
    2."
450 LABEL "DRIFT REMOVED"
460 MOVE -1000,1200
470 DRAW -556,1200
471 MOVE -1000,1000
480 LABEL "   2 KM."
490 END
```

PROGRAM "VSUM9"

A 25 HOUR TIDAL CYCLE IS PRODUCED BY CALCULATING THE AVERAGE VALUES FOR POINTS 1 TO 200 FOR THE TEN DAY CURRENT METER M RECORDS. THESE POINTS ARE PLOTTED AS PROGRESSIVE VECTOR DIAGRAMS. THE 25 HOUR AVERAGES ARE THEN FURTHER AVERAGED INTO A 12.5 HOUR (100 POINT) TIDAL CYCLE, AND THESE POINTS ARE STORED IN FILE "MTIDE

```
 10 OPTION BASE 1
 11 DIM X(200),Y(200)
 20 PLOTTER IS 705
 30 DEG
 31 SCALE -1600,4000,-2100,2100
 32 GCLEAR
 33 FOR I=1 TO 200
 34 X(I),Y(I)=0
 35 NEXT I
 40 DATA CM-DAT,CM1DAT,CM2DAT,CM
    3DAT,*
 50 ASSIGN# 1 TO "CM0DAT"
 51 ASSIGN# 2 TO "DRIFT-M"
 52 PENUP
 60 FOR J=1 TO 9
 61 READ# 2 ; X1,Y1
 80 FOR I=1 TO 200
 90 READ# 1 ; C
100 S=IP(C) @ D=FP(C)*1000
120 X(I)=X(I)+S*SIN(D)-X1 @ Y(I)
    =Y(I)+S*COS(D)-Y1
140 IF J=1 AND I=160 THEN GOSUB
    340
150 IF J=2 AND I=194 THEN GOSUB
    340
160 IF J=5 AND I=64 THEN GOSUB 3
    40
170 IF J=7 AND I=144 THEN GOSUB
    340
180 NEXT I
210 NEXT J
211 X0,Y0=0
220 FOR I=1 TO 200
230 X(I)=X(I)/9 @ Y(I)=Y(I)/9
240 X0=X0+X(I) @ Y0=Y0+Y(I)
250 PLOT X0,Y0
260 NEXT I
270 GOTO 370
340 READ D$
350 ASSIGN# 1 TO D$
360 RETURN
370 FRAME
380 MOVE -1000,1800
390 CSIZE 3,.7,10
400 LABEL "CURRENT METER M"
410 CSIZE 2.5,.7,10
420 LABEL "PROGRESSIVE VECTOR DI
    AGRAM OF"
430 LABEL "AVERAGE SPEED AND DIR
    ECTION"
440 LABEL "FOR JULY 10 TO 20,198
    2 "
450 LABEL "DRIFT REMOVED"
460 MOVE -1000,1200
470 DRAW -556,1200
471 MOVE -1000,1000
480 LABEL "    2 KM."
490 CREATE "MTIDE",7
500 ASSIGN# 1 TO "MTIDE"
510 FOR I=1 TO 100
520 X=(X(I)+X(I+100))/2
530 Y=(Y(I)+Y(I+100))/2
540 PRINT# 1 ; X,Y
550 NEXT I
560 END
```

PROGRAM "TABLE-T"

THIS PROGRAM USES THE 12.5 HOUR TIDAL CYCLE DATA STORED IN "MTIDE" TO PRINT A TIDE TABLE FOR CURRENT METER M

```
 10 OPTION BASE 1
 20 DEG
 30 DIM S(12),D(12)
 40 ASSIGN# 1 TO "MTIDE"
 50 READ# 1 ; A,A
 60 PRINT "   CURRENT METER M"
 70 PRINT "      TIDE TABLE"
 80 PRINT
 90 PRINT "TIME  DIRECTION  SPEE
    D"
100 PRINT "hours  degrees   knot
    s"
110 PRINT
120 FOR J=1 TO 12
130 X0,Y0=0
140 FOR I=1 TO 8
150 READ# 1 ; X,Y
160 X0=X0+X @ Y0=Y0+Y
170 NEXT I
180 X0=X0/8 @ Y0=Y0/8
190 S=SQR(X0^2+Y0^2)
200 S(J)=S*.0194
210 D(J)=ATN2(X0,Y0)
220 IF D(J)<0 THEN D(J)=D(J)+360
230 NEXT J
240 J=0
250 PRINT USING 290 ; J,D(12),S(
    12)
260 FOR J=1 TO 11
270 PRINT USING 290 ; J,D(J),S(J
    )
280 NEXT J
290 IMAGE 2X,DD,4X,DDD,4X,D.DD
300 ASSIGN# 1 TO *
310 END
```

PRUGRAM "TIDEHOUR"

THIS PROGRAM CALCULATES AVERAGE CURRENT METER SPEEDS AND DIRECTIONS FOR EACH HOUR (FROM 1/2 HOUR BEFORE TO 1/2 HOUR AFTER THE HOUR) AND LISTS THESE FOR THE 10 DAYS OF OPERATION.

```
 10 DEG
 20 OPTION BASE 1
 30 DATA CN1DAT,CN2DAT,CN3DAT
 40 ASSIGN# 1 TO "CN0DAT"
 41 READ# 1 ; C,C,C,C
 50 D9=190 @ N=9 @ T=15
 60 PRINT "TIDE TABLE DERIVED FR
    OM"
 70 PRINT "CURRENT METER 'N' AT
    DEPTH OF"
 80 PRINT "TWENTY ONE METERS"
 90 PRINT "Speeds and directions
     are"
100 PRINT "averages of eight mea
    surements"
110 PRINT "   The table gives ho
    urly speeds"
120 PRINT "and directions for th
    e ten day"
130 PRINT "period from July 10 t
    o 20,1982"
140 PRINT "Hours are in universa
    l time."
150 PRINT "Subtract four hours f
    or local"
160 PRINT "time or five hours fo
    r Eastern"
170 PRINT "Standard Time."
180 PRINT
190 K=1
200 GOSUB 400
210 FOR J=1 TO 239
220 X0,Y0=0
230 FOR I=1 TO 8
240 READ# 1 , C
250 S=IP(C) @ D=FP(C)*1000
260 X=S*SIN(D) @ Y=S*COS(D)
270 X0=X0+X @ Y0=Y0+Y
271 IF J=59 AND I=4 THEN GOSUB 5
    10
272 IF J=119 AND I=4 THEN GOSUB
    510
273 IF J=179 AND I=4 THEN GOSUB
    510
274 IF J=239 AND I=4 THEN 540
280 NEXT I
290 X0=X0/8 @ Y0=Y0/8
300 S=SQR(X0^2+Y0^2)
301 S=S*.0194
310 D=ATN2(X0,Y0)
320 IF D<0 THEN D=D+360
330 PRINT USING 390 ; T,S,D
340 T=T+1
350 IF T=24 THEN GOSUB 391
360 NEXT J
390 IMAGE 5X,DD,5X,D DD,5X,DDD
391 T=0
400 D9=D9+1 @ N=N+1
410 K=K*-1
420 PRINT @ PRINT @ PRINT
430 IF K=-1 THEN PRINT @ PRINT @
     PRINT @ PRINT
440 PRINT "       DAY";D9;"JULY";N
    ;"1982"
441 PRINT
450 IF K=1 THEN 480
460 PRINT "       HOUR  SPEED  DIR
    ECTION"
470 PRINT "        ut    kts.    deg
    rees"
471 PRINT
480 RETURN
510 READ F$
520 ASSIGN# 1 TO F$
530 RETURN
540 END
```

PROGRAM "PLTCM"

EIGHT VALUES OF SPEED AND DIRECTION FOR CURRENT METER X ARE CONVERTED TO X AND Y AND AVERAGED, THEN RECONVERTED TO GIVE HOURLY SPEEDS AND DIRECTION THESE ARE PLOTTED ACROSS THREE SHEETS OF PAPER. PROGRAM EDITING ALLOWS CURRENT METERS M AND N TO BE SIMILARLY TREATED

```
 10 DEG
 20 OPTION BASE 1
 21 PLOTTER IS 705
 30 DATA CX1DAT,CX2DAT,CX3DAT
 40 ASSIGN# 1 TO "CX0DAT"
 50 READ# 1 ; C,C,C,C
 60 D9=190 @ N=9 @ T=16
 70 SCALE -4,100,-100,100
 80 LINETYPE 1
 90 XAXIS -100,24,0,96
100 XAXIS 55,24,0,96
110 K=0
120 YAXIS 0,10,-100,0
130 YAXIS 0.7.5,10,100
140 LINETYPE 8,4
150 PENUP
220 FOR J=1 TO 239
230 X0,Y0=0
240 FOR I=1 TO 8
250 READ# 1 ; C
260 S=IP(C) @ D=FP(C)*1000
270 X=S*SIN(D) @ Y=S*COS(D)
280 X0=X0+X @ Y0=Y0+Y
281 IF J=59 AND I=4 THEN GOSUB 5
    70
290 IF J=119 AND I=4 THEN GOSUB
    570
300 IF J=179 AND I=4 THEN GOSUB
    570
330 IF J=239 AND I=4 THEN 600
340 NEXT I
350 X0=X0/8 @ Y0=Y0/8
360 S=SQR(X0^2+Y0^2)
380 D=ATN2(X0,Y0)
390 IF D<0 THEN D=D+360
400 ! PLOT J-K,S-100
410 PLOT J-K,D/4+10
420 IF J=96 THEN GOSUB 440
421 IF J=192 THEN GOSUB 440
430 NEXT J
440 BEEP
441 DISP "CHANGE PAPER"
442 DISP "PRESS CONTINUE"
450 PAUSE
451 LINETYPE 1
460 XAXIS -100,24,0,96
461 XAXIS 55,24,0,96
462 K=K+96
463 YAXIS 0,10,-100,0
464 YAXIS 0.7.5,10,100
465 LINETYPE 8,4
466 PENUP
470 RETURN
570 READ F$
580 ASSIGN# 1 TO F$
590 RETURN
600 END
```

PROGRAM "X-W-DROGUE"

THIS PROGRAM PLOTS A PROGRESSIVE VECTOR DIAGRAM FOR CURRENT METER X FOR THE FIRST TWENTY ONE HOURS FOR COMPARISON WITH THE TRACK OF DROGUES DEPLOYED WEST OF PHELPS BANK.

```
 10 DEG
 20 PLOTTER IS 705
 30 ASSIGN# 1 TO "CX0DAT"
 40 ASSIGN# 2 TO "DRIFT-X"
 50 READ# 2 ; X1,Y1
 60 READ# 1 ; C,C,C,C
 70 X0,Y0=0
 80 GCLEAR
 90 SCALE -6000,14000,-4500,1050
    0
100 FOR I=1 TO 170
110 READ# 1 ; C
120 S=IP(C) @ D=FP(C)*1000
130 X=S*SIN(D) @ Y=S*COS(D)
140 X=(X-X1)*4.5 @ Y=(Y-Y1)*4.5
150 X0=X0+X @ Y0=Y0+Y
160 PENUP
170 PLOT X0,Y0
180 NEXT I
190 MOVE -5000,-4000
200 CSIZE 3,.7,10
210 LABEL "CURRENT METER X
    "
220 CSIZE 2.5,.7,10
230 LABEL "1420Z Day 191 to 1131
    Z Day 192"
240 END
```

PROGRAM "PLA-BOY"

THIS PROGRAM PLOTS [illegible] POSITIONS FOR DROGUE A [illegible] D IN FILE"A-BOY") ON THE SAME SCALE AS THE PLOT FROM PROGRAM "X-W-DROGUE"

```
  1 OPTION BASE 1
 20 SCALE -5000,15000,-4000,1100
    0
 30 PLOTTER IS 705
 31 ASSIGN# 1 TO "A-BOY"
 32 DISP "WHAT KIND LINE (1-8)"
 33 INPUT L
 34 LINETYPE L
 40 FOR I=1 TO 30
 50 READ# 1 ; X,Y
 51 PLOT X,Y
 60 NEXT I
 70 BEEP
 80 END
```

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