FEASIBILITY STUDY ON THE UTILIZATION OF PARACHUTE DROGUES AND SHORE-BASED RADAR TO INVESTIGATE SURFACE CIRCULATION IN MONTEREY BAY

by

Howard Sanford Stoddard

United States
Naval Postgraduate School

THESIS

FEASIBILITY STUDY ON THE UTILIZATION OF
PARACHUTE DROGUES AND SHORE-BASED RADAR TO
INVESTIGATE SURFACE CIRCULATION IN MONTEREY BAY

by

Howard Sanford Stoddard

Thesis Advisor: W. W. Denner

March 1971

Feasibility Study on the Utilization of
Parachute Drogues and Shore-Based Radar to
Investigate Surface Circulation in Monterey Bay

by

Howard Sanford Stoddard
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1963

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
March 1971

ABSTRACT

An intensive study is presently being made of the current patterns in Monterey Bay. Up to this time, no means has been available to examine the flow over the entire Bay. The feasibility of utilizing radar systems installed at the Naval Postgraduate School to track free-floating parachute drogues was investigated. Radar transponders extended the tracking range of the radars to include the north end of the Bay, and eliminated shadow zones which had been present when tracking passive reflectors. An analysis of the drogue tracks indicated the importance of the oceanic currents as primary current driving mechanisms. Tides strongly influenced flow in the Bay's interior. Winds generally were a relatively unimportant driving mechanism, except when winds prevailed from one direction over an extended period of time.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Professor Warren W. Denner of the Department of Oceanography, Naval Postgraduate School, under whose direction this study was undertaken.

The author is further indebted to Mr. John C. Mellor and Mr. Robert Middleburg, oceanographic technicians at the Postgraduate School, and to Mr. Sheldon Lazanoff, the Naval Oceanographic Office Liaison with Fleet Numerical Weather Central, Monterey.

In addition, the author wishes to give special thanks ot the staff of the Electrical Engineering Department's Radar Laboratory, in particular Mr. Ross M. Seely, AT 1 Robert Eisenhower and FTG 1 James Nolan.

I. INTRODUCTION

A. PURPOSE OF STUDY

The surface circulation of Monterey Bay is being studied to determine the effectiveness of currents in the dispersal of effluents discharged into the Bay. An understanding of the current patterns of the Bay and the primary mechanisms driving these currents will permit state and local governments to regulate and control pollution of the Bay and its adjoining beaches. Toward this end, the purpose of this research project was to investigate the feasibility of utilizing the shore-based radar installations at the Naval Postgraduate School and parachute drogues to help determine the surface circulation in the Bay.

B. PARACHUTE DROGUES

One of the simplest and least expensive devices for measuring currents is the free-floating drogue. This Lagrangian method is one of the oldest current measuring techniques, having been used in the late nineteenth century by the Challenger Expedition [Thomson and Murray 1885]. Its utilization, though, appears to have been generally ignored until the early 1950's when the technique was used by Cromwell, Montgomery and Stroup [1954] and Stommel [1954], among others.

The use of parachute drogues for current measurements was first described by Volkmann, Krauss and Vine [1956]. Their drogue configuration has since been the model for drogues used in a number of current studies. The California Current [Jennings and Schwartzlose 1960], Peru-Chile Undercurrent [Wooster and Gilmartin 1961], California Countercurrent

[Reid 1962] and the Atlantic Equatorial Undercurrent [Neuman and Williams 1965 and Stalcup and Parker 1965] have all been studied with this drogue technique.

The parachute drogue technique has been utilized most frequently in open-ocean current studies. The movements of the drogues have been traced by either of two methods: tracking the drogues by shipborne radar, using standard navigational techniques to fix the ship's position; or, tracking the drogues with shipborne radar relative to some known reference point (e.g. a moored buoy). Either technique leads to positioning errors in the track as the result of inherent errors in navigation systems.

If the radar platform used for tracking the drogue is fixed at a known location on land, then the navigation system error (i.e. the error involved with fixing the location of the floating radar platform or moored reference point) will be eliminated. Therefore the only remaining source of error for fixing the location of the free-floating drogue lies in the accuracy of the radar tracking system. Knapp [1951] and Robson [1955] both used shore-based radars to track drogues in near shore areas.

The unique location of the Naval Postgraduate School contiguous to Monterey Bay allows the possible application of this drogue tracking method. In conjunction with the School's electrical engineering curriculum, a number of naval search and fire control radar systems are installed on the roof of Spanagel Hall, a five-story structure on campus (Figure 1). It was felt that several of these radar systems could be utilized in a current study of the Bay. As a result, the following feasibility study was initiated.

Figure 1. Spanagel Hall

II. MONTEREY BAY

A. DESCRIPTION

Monterey Bay is situated on the central California coastline some 120 km south of San Francisco (Figure 2). It is a relatively unprotected embayment with free communication with the Pacific Ocean. It is semi-elliptical in shape stretching approximately 41 km from Soquel Cove in the north to Monterey Harbor in the south (Figure 3). The Bay measures about 17 km in width from a line connecting the two seaward headlands, Pt. Santa Cruz and Pt. Pinos, eastward to Moss Landing.

Most of the Bay lies inside the fifty fathom curve with the striking exception of the Monterey Submarine Canyon, which bisects the center of the Bay. The Canyon's axis is on an east-west line of bearing, with its head situated about two kilometers off of Moss Landing. Thus the Bay is topographically separated into two distinct zones.

B. CURRENT DRIVING MECHANISMS

The possible driving forces affecting the surface circulation in Monterey Bay are: (1) oceanic currents, (2) wind, (3) tides, (4) density structure and (5) river runoff.

River runoff can be virtually eliminated as a major driving mechanism with regard to the overall circulation of the Bay. There are no major rivers emptying into the Bay, and the discharges from minor sources, such as the Salinas and Pajaro Rivers, are virtually eliminated in the dry summer months.

Because of the Bay's open communication with the sea, oceanic currents can have a marked influence on the circulation patterns in the Bay. The

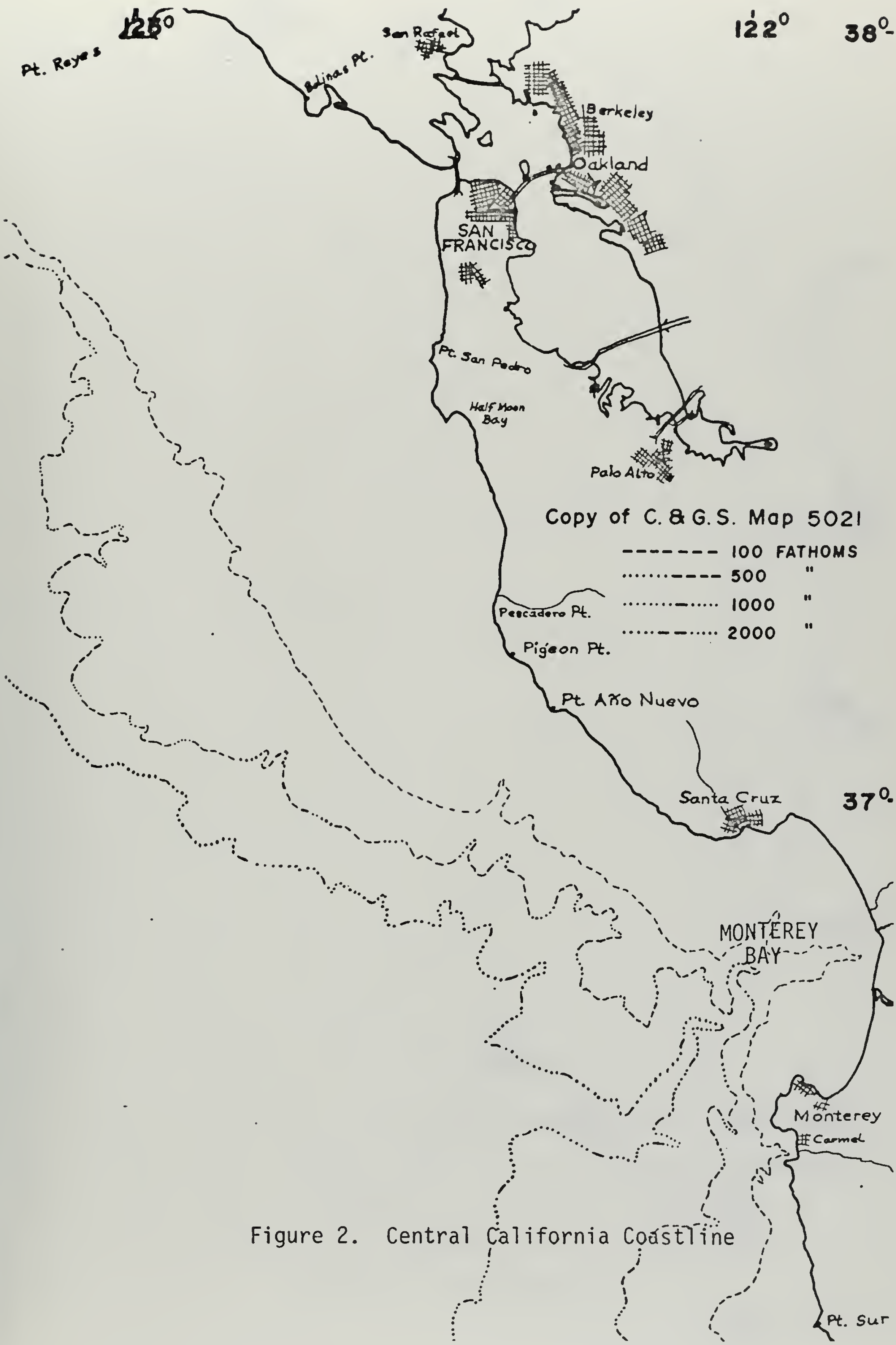

Figure 2. Central California Coastline

Figure 3. Monterey Bay

* NAVAL POSTGRADUATE SCHOOL

major offshore oceanic current system is the California Current, which comprises the easterly leg of the general North Pacific clockwise gyre. The location of its southerly flow relative to the California coastline will vary depending on the season. During certain months of the year, another current predominates along the California coast. This is the Davidson Current, with a general northerly drift.

Skogsberg [1936], in a hydrographic survey of Monterey Bay, described the water structure of the Bay by dividing it into three seasonal phases related to the existing thermal conditions: (1) an upwelling period from mid-February to late August, (2) an oceanic period from late August to late October and (3) a Davidson Current period from mid-November to mid-February. The upwelling phase was characterized by an upsurge of deep cold waters into the coastal region. The oceanic phase was distinguished by a sharp diminishment in the upwelling and a shift in flow of the California Current in toward the coastline. The Davidson Current was characterized by a northerly current flow during the winter months.

The prevailing wind conditions for the area tend to correspond with the direction of the oceanic current flow. During the winter months, when the Davidson Current predominates, the prevalent winds are from the south or southwest. During the balance of the year, when the southerly flowing California Current predominates, the winds blow normally out of the north or northwest.

The tidal cycle plays an important contributing role in the surface circulation in Monterey Bay. The tides generally exhibit a semidiurnal inequality. The tides have a mean range of 1.16 m, and a mean diurnal range of 1.68 m.

C. PREVIOUS CURRENT STUDIES OF MONTEREY BAY

The first detailed discussion of currents in Monterey Bay was done by Skogsberg [1936]. He analyzed thermal structure data collected in the Bay over a five year period (1929-1933) to determine circulation patterns. In conjunction with this research, he utilized a type of free-floating drogue to study the effects of tidal variation upon Bay currents off of the Hopkins Marine Station in Pacific Grove. Stevenson (1964) also used drogues (tracked with transits) to aid in a study of the near shore circulation in the southern periphery of Monterey Bay.

Caster [1969] and others have studied the effects of the Monterey Canyon upon circulation utilizing current meters.

III. PROJECT EQUIPMENT

A. PARACHUTE DROGUE SYSTEM

The drogues utilized in this study were similar in design to those described by Volkmann, Knauss and Vine [1956]. The drogue system was basically comprised of a standard circular aviator's parachute suspended as a sea anchor beneath a surface float. The float supported a mast upon which was mounted a radar reflector (Figure 4).

The parachutes were obtained through the Naval Supply System as over-age surplus. The diameter of the parachute was 8.5 m, giving an effective cross-section area of 56.3 m^2 when completely deployed. Each parachute was shackled via a ten meter length of nylon line to the bottom of the buoy mast, which pierced the surface float. A swivel device was placed between the bitter end of the line and the parachute to counter twisting of the shroud lines. A dead weight 60 lb (weight in water) anchor was also suspended from the lower end of the line to keep the parachute properly deployed at depth and to keep the mast in an upright position.

The surface float was composed of a .76 m x .61 m x .25 m section of styrofoam sandwiched by metal packing straps between two sheets of plywood. It was felt that a styrofoam float would be more durable than the often used inner tubes [Jennings and Schwartzlose 1960, Reid 1962 et al], which are subject to puncture and abrasion.

The mast consisted of a five meter length of 6.35 cm diameter aluminum piping (.16 cm wall thickness) internally reinforced by 6.1 cm diameter wooden doweling. The mast penetrated through the styrofoam

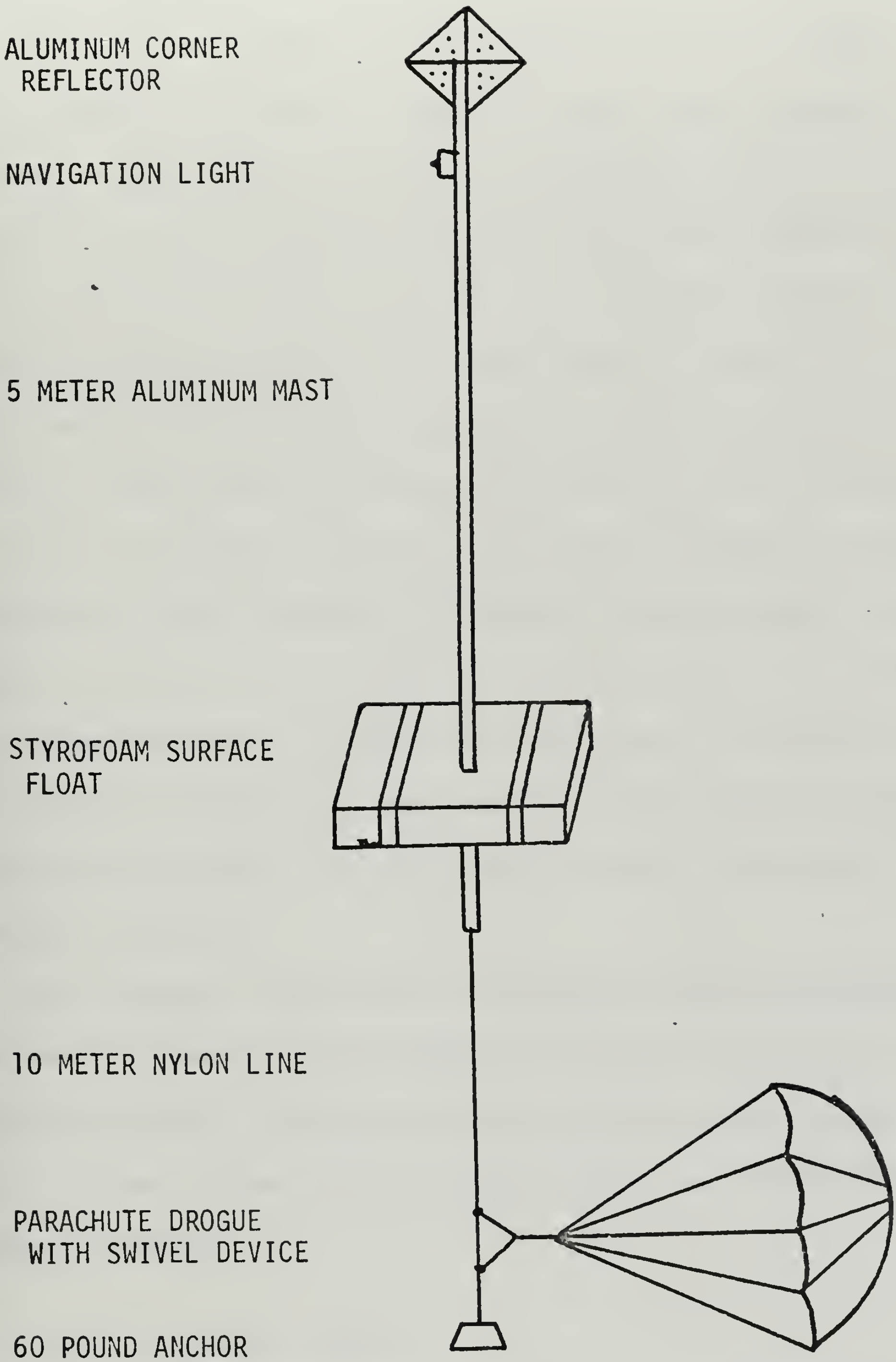

Figure 4. Parachute Drogue Assembly

float with four meters of mast remaining above the water line (Figure 5). The mast was color-coded for easy identification, and it was equipped with a navigation warning light.

The radar reflector, used to increase the echo strength of the buoy, was secured to the top of the mast. Several radar reflectors were tested for this study. A spherical reflector (ECCO Reflector, model 2B-105) supplied by the Naval Oceanographic Office gave excellent near shore performance, but was severely range-limited (maximum range approximately 15,500 m) (Figure 6). A fabricated aluminum corner reflector gave much better results, increasing range coverage out to approximately 28,000 m under ideal sea and weather conditions. The fundamental property of corner reflectors is that, within certain limits of inclination, a ray entering the corner will be reflected back specularly in exactly the opposite direction. The reflector used was actually an octahedral cluster of corner reflectors, designed to ensure equally strong echo returns from all sides of the buoy to compensate for drogue movement (Figure 7). The aluminum framework of the reflector was heavily perforated to cut down on wind resistance.

The shipboard launchings of the drogue system were accomplished successfully by first jettisoning the parachute (Figure 8). As the parachute opened, the buoy and the weight were placed overboard (Figure 9). Only one drogue did not properly deploy out of the total of 39 drogues launched.

B. AN/SPS-10E RADAR SYSTEM

The primary tracking radar used in this study was the AN/SPS-10E radar system. The radar was designed primarily for shipboard use in the

Figure 5. Mast Configuration

Figure 6. ECCO Radar Reflector

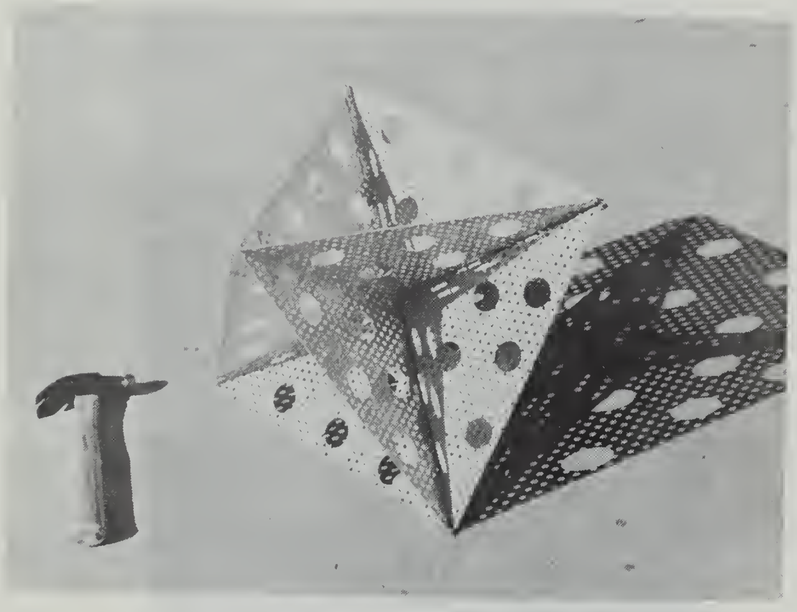

Figure 7. Octahedral Cluster Reflector

Figure 8. Jettisoning Parachute Drogue

Figure 9. Launching Surface Float Assembly

detection, ranging and tracking of surface targets, and to a lesser extent low flying aircraft. This equipment is installed in many types of American and foreign vessels, including auxiliaries and men-of-war.

The Naval Postgraduate School has a number of search and fire-control radars installed on the roof of a five-story academic building to serve as educational aids for the School's Electrical Engineering Department. The platform for the AN/SPS-10E radar antenna is located approximately 36.6 m above ground level and affords coverage of most of Monterey Bay (Figure 10).

This search-type radar is omni-directional, thus permitting continual tracking of multiple targets. It operates in the "S" frequency band at 5450-5825 MHz. A summary of the radar's specifications is given in Table I. The maximum range for this radar for surface targets is generally somewhat greater than the optical horizon as viewed from the radar antenna (The optical horizon in miles equals 1.22 times the square root of the antinna height; in this case 13.4 miles or 22.4 km). The strength of the returning echo though normally depends upon the size and shape of the target, its distance and height, its reflecting qualities, sea and weather conditions, antenna height and pulse length. Long pulse (1.3 microseconds) gives greater range than does short pulse (.25 microseconds). The long pulse length was used in this study.

The radar presentation is shown on the PPI (plan position indicator) of the AN/SPA-25 radar repeater, which gives a 360 degree sweep coverage. From this presentation it is possible to obtain target position with a range resolution (long pulse) of 251.5 m and bearing resolution of less than one degree. A typical radar presentation for minimum sea return conditions (sea state 1) is shown in Figure 11. The range scale for this presentation is 50,000 yards (45,700 m).

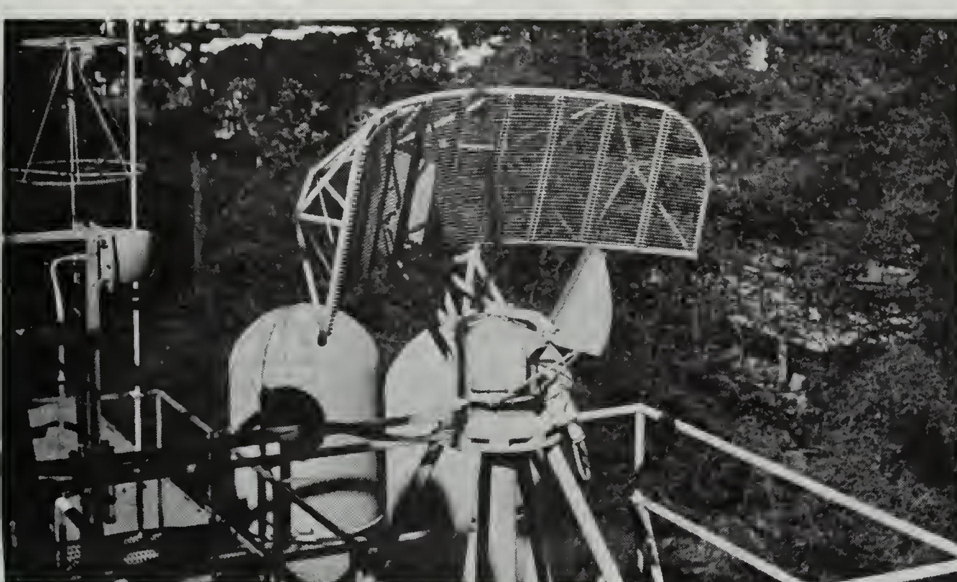

Figure 10. AN/SPS-10 Radar Antenna

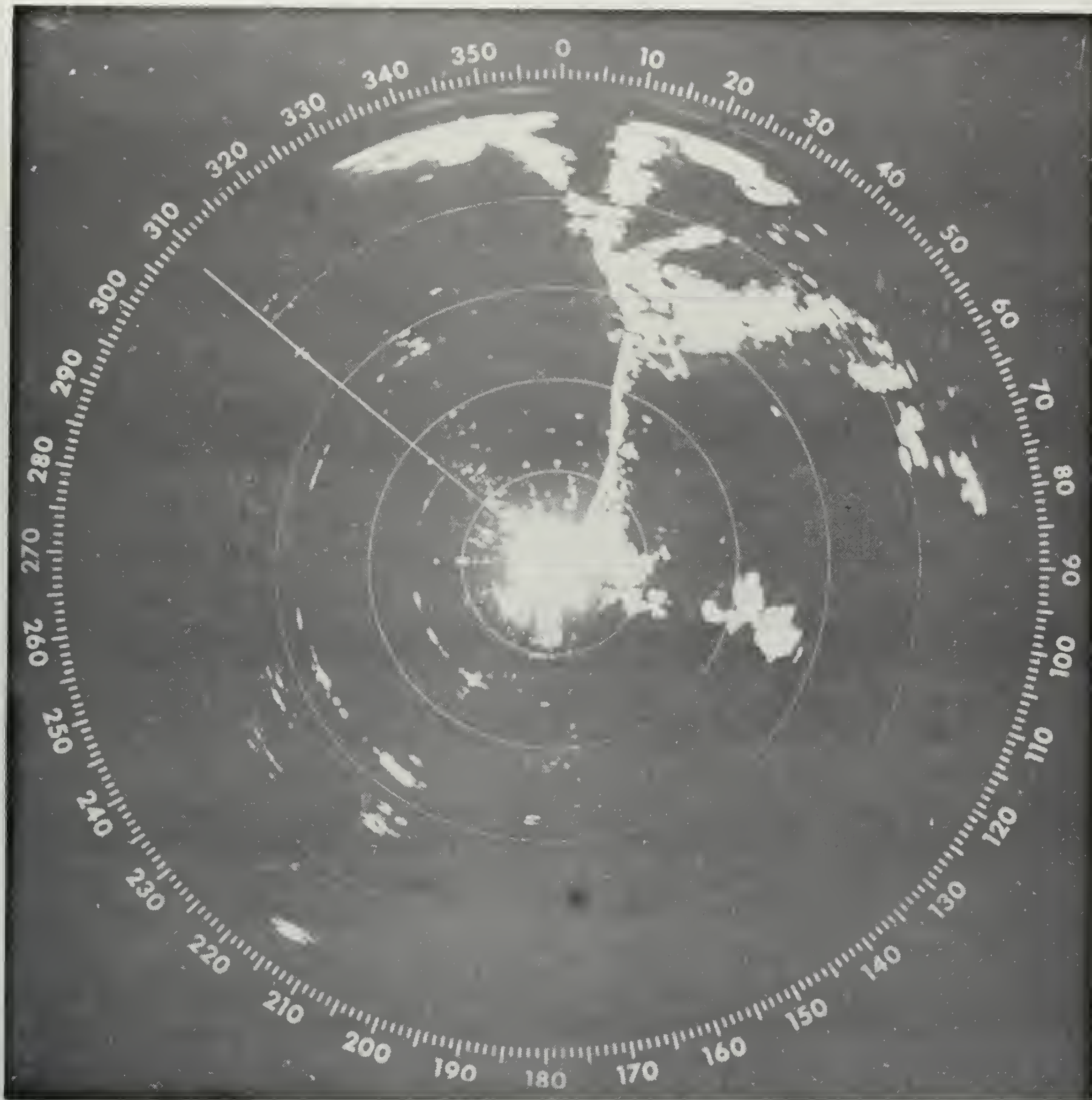

Figure 11. PPI Radar Presentation

TABLE I

SUMMARY OF AN/SPS-10 SPECIFICATIONS

FREQUENCY BAND:	5450 to 5825 MHz
TYPE OF FREQUENCY CONTROL:	Amplitude modulated
TYPE OF EMISSION:	Radar pulse (0.25 or 1.3 microseconds)
PEAK POWER OUTPUT:	190 kW to 285 kW
PULSE RATE:	Radar: 625 to 650 Hz Beacon: 312 to 325 Hz
TYPE OF RECEIVER:	Superheterodyne
BANDWIDTH:	Narrow band: 1 MHz Wide band: 5 MHz
RADAR RESOLUTION:	
Bearing:	Less than 1 degree
Range, short pulse:	45.7 m
Range, long pulse:	251.5 m

C. MK 25 MOD 3 RADAR SYSTEM

The MK 25 MOD 3 system is a conventional gunfire control radar used on naval vessels in conjunction with the Gunfire Control System MK 37 (Figure 12). It is a pulse-echo type of radar and operates in the "X" frequency band. This radar was used in the latter stages of the study because of its compatability with the AN/DPN-78, a radar transponder which had been acquired to increase the echo strength of the parachute drogue system. A disadvantage of this type of radar is that it cannot track multiple targets. It will lock on and track a single target, though, in an automatic mode. This greatly eases the tracking burden of the radar operator.

Figure 12. MK 25 Radar Antenna

D. AN/DPN-78 RADAR TRANSPONDER

Several AN/DPN-78 radar transponders were obtained for this study from the Naval Air Systems Command in order to amplify the echo strengths of the drogue buoys. This equipment is normally used in missile, satellite, target drone and aircraft applications as an enhancement device for "X" band tracking radars. Because of the availability of the MK 25 MOD 3 radar system at the Postgraduate School, it was felt that these transponders could be utilized as an aid in tracking the drogue buoys.

A radar transponder receives interrogations within its specified operation band and then transmits replies back to the radar receiver on a different frequency within the same band. As a result, the operating range of the radar system is greatly extended over that given by a passive reflector.

The AN/DPN-78 is an "X" band transponder which receives pulses in the 9100 MHz to 9600 MHz range (Figure 13). It transmits a reply pulse within the same range but offset from the radar receiver frequency by at least 50 MHz. The characteristics of the transponder are listed in Table II.

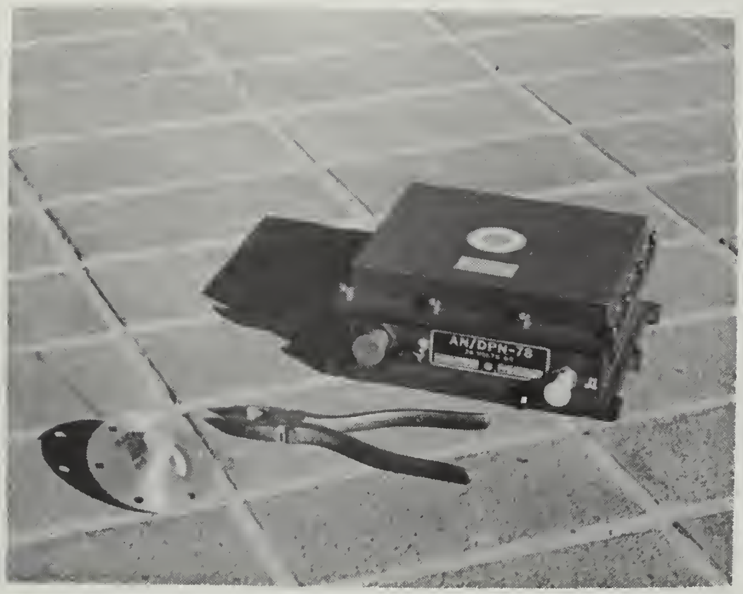

Figure 13. AN/DPN-78 Transponder and Antenna

TABLE II

AN/DPN-78 CHARACTERISTICS

RECEIVER:	
Frequency (tunable range)	9100 to 9600 MHz
Type	Superheterodyne
Sensitivity (99% reply)	-65 dBm over entire frequency range
Bandwidth (3 dB)	8 MHz minimum
Interrogation code	Single or double pulse
Pulse width	0.2 to 0.6 microseconds
TRANSMITTER:	
Frequency (tunable range)	9100 to 9600 MHz
Type	Magnetron
Peak power output	200 W
Pulse width	0.25 ± 0.1 microseconds
Pulse repetition frequency	0 to 2000 PPS
SIZE	8.53 x 7.37 x 10.06 cm
VOLUME	619.9 cu cm
POWER SOURCE	28 V
CURRENT DRAIN	2.1 A

IV. PROJECT OPERATION

In order to determine the feasibility of tracking drogues with the installed radar systems at the Naval Postgraduate School, and secondly to gather current data for circulation analysis, a tracking program was set up over a four month span from August to November 1971. During this period, 38 parachute drogues were released and tracked (Table III). The drogues were seeded by both the USNS DE STEIGUER and the School's oceanographic research vessel. The AN/SPS-10E surface search radar was utilized throughout this segment of the study in order to simultaneously track a number of drogues.

It soon became apparent that the tracking system had several limitations. Under ideal sea and weather conditions (state 1 sea, wind force 0-1, unrestricted visibility), the maximum tracking range was approximately 28,000 m. This limited the study area for normal conditions to south of the Monterey Canyon. An additional difficulty was encountered with the inexplainable sudden loss of radar contact with drogues, which, until that time, had been providing strong echoes.

The latter difficulty was determined to be the result of radar interference from several stands of tall trees on the Postgraduate School campus. These trees partially blocked radar coverage of the Bay, creating shadow zones (Figures 14-16 show a panoramic view of the Bay from the radar platform and the stands of trees in question). In order to more accurately fix these shadow zones, the School's research vessel ran a figure eight set of course legs crisscrossing the lower reaches of the Bay. The radar track provided a good indication of where the shadow

TABLE III

DROGUE TRACK DATA

DROGUE	START TIME[1]	STOP TIME[1]	TRACK DURATION	CAUSE-CEASE TRACK
1	121743 Aug.	131000 Aug.	16 hr. 17 min.	Lost contact - high sea return
2	121930 Aug.	130935 Aug.	14 hr. 5 min.	Lost contact - long range
3	-	-	-	No contact - long range
4	130100 Aug.	131045 Aug.	9 hr. 45 min.	Stopped tracking
5	130200 Aug.	130935 Aug.	7 hr. 35 min.	Lost contact - high sea return
6	182030 Aug.	191545 Aug.	19 hr. 15 min.	Stopped tracking
7	182100 Aug.	191545 Aug.	18 hr. 45 min.	Stopped tracking
8	182200 Aug.	190930 Aug.	11 hr. 30 min.	Lost contact - long range
9	182215 Aug.	182230 Aug.	- 15 min.	Lost contact - shadow zone?
10	182230 Aug.	191545 Aug.	17 hr. 15 min.	Stopped tracking
11	182300 Aug.	190230 Aug.	3 hr. 30 min.	Lost contact - shadow zone?
12	182330 Aug.	190900 Aug.	9 hr. 30 min.	Lost contact - shadow zone?
13	190000 Aug.	190730 Aug.	7 hr. 30 min.	Lost contact - shadow zone?
14	310830 Aug.	010915 Sept.	16 hr. 45 min.[2]	Lost contact - shadow zone

[1]Local times

[2]Interrupted track

DROGUE	START TIME	STOP TIME	TRACK DURATION	CAUSE-CEASE TRACK
15	310845 Aug.	312100 Aug.	12 hr. 15 min.	Lost contact - behind Pt. Pinos
16	310900 Aug.	310930 Aug.	- 30 min.	Lost contact - behind Pt. Pinos
17	310930 Aug.	010530 Sept.	20 hr. -	Lost contact - behind Pt. Pinos
18	311000 Aug.	010915 Sept.	23 hr. 15 min.	Stopped tracking
19	311045 Aug.	311330 Aug.	2 hr. 45 min.	Lost contact - unknown
20	311100 Aug.	311230 Aug.	1 hr. 30 min.[3]	Lost contact - shadow zone?
21	311130 Aug.	010300 Sept.	8 hr. - [3]	Lost contact - shadow zone?
22	311230 Aug.	010915 Sept.	20 hr. 45 min.	Stopped tracking
23	060845 Oct.	061830 Oct.	9 hr. 45 min.	Lost contact - broken mast?
24	060900 Oct.	061530 Oct.	6 hr. 30 min.	Lost contact - broken mast?
25	060915 Oct.	061530 Oct.	6 hr. 15 min.	Lost contact - broken mast?
26	061000 Oct.	061345 Oct.	3 hr. 45 min.	Lost contact - shadow zone?
27	061015 Oct.	061430 Oct.	4 hr. 15 min.	Lost contact - shadow zone?
28	061115 Nov.	080700 Nov.	43 hr. 45 min.	Lost contact - long range
29	061130 Nov.	061745 Nov.	6 hr. 15 min.	Lost contact - shadow zone
30	071800 Nov.	081700 Nov.	23 hr. -	Stopped tracking

---

[3]Interrupted track

DROGUE	START TIME	STOP TIME	TRACK DURATION	CAUSE-CEASE TRACK
31	071830 Nov.	081700 Nov.	22 hr. 30 min.	Stopped tracking
32	071900 Nov.	072030 Nov.	1 hr. 30 min.	Lost contact - shadow zone?
33	071930 Nov.	081700 Nov.	21 hr. 30 min.	Stopped tracking
34	101000 Nov.	101300 Nov.	3 hr. -	Lost contact - behind Pt. Pinos
35	130130 Nov.	130900 Nov.	7 hr. 30 min.	Stopped tracking
36	130145 Nov.	130830 Nov.	6 hr. 45 min.	Lost contact - behind Pt. Pinos
37	130200 Nov.	130830 Nov.	6 hr. 30 min.	Lost contact - behind Pt. Pinos
38	130200 Nov.	130800 Nov.	6 hr. -	Lost contact - behind Pt. Pinos
"X"	100800 Nov.	101600 Nov.	6 hr. -	Lost contact - behind Pt. Pinos
"Y"	100800 Nov.	102030 Nov.	12 hr. 30 min.	Lost contact - behind Pt. Pinos
"Z"	101000 Nov.	102000 Nov.	10 hr. -	Lost contact - behind Pt. Pinos

Figure 14. Panaromic View of Bay
(009-041 degrees true)

Figure 15. Panoramic View of Bay
(355-015 degrees true)

Figure 16. Panoramic View of Bay
(318-353 degrees true)

zones existed for the drogues (true bearing arcs of 349.5 to 353 and 000 to 007) (Figure 17). These shadow areas corresponded very well with the sudden losses of radar contact (and occasional sudden reappearances) with a number of drogues. Figures 19, 24, 31, 37, 49 and 50 display all 38 drogue tracks. The losses of contact with drogues 9, 11, 12, 13, 14, 20, 21, 26, 27, 29 and 32 can probably be attributed to these radar blackout areas.

In an attempt to obtain complete coverage of the southern half of the Bay, and also to extend the tracking range to include the northern region of the Bay, radar transponders were utilized. The transponders were AN/DPN-78 models, "X" band instruments compatible with the MK 25 MOD 3 radar system.

One of the transponders was placed on the stern of the research vessel with its antenna at a height of four meters above the waterline to approximate the masthead height of the drogue buoy. Another figure eight run was made across the southern half of the Bay with both the AN/SPS-10 and the MK 25 radars simultaneously tracking the target (While the AN/SPS-10 actually tracked the boat, the MK 25, in beacon track mode, tracked only the transponder, i.e. the scope presentation displayed only the beacon return and not other surface contacts). Radar contact was again lost through the shadow zones by the surface search radar, but solid contact was maintained throughout the track by the fire control radar (Figure 18).

The research vessel next set a course for Santa Cruz, at the north end of the Bay, to test the range capabilities of the transponder. Strong contact was maintained the entire track, which was terminated off of Soquel Point at a range of 37,000 m.

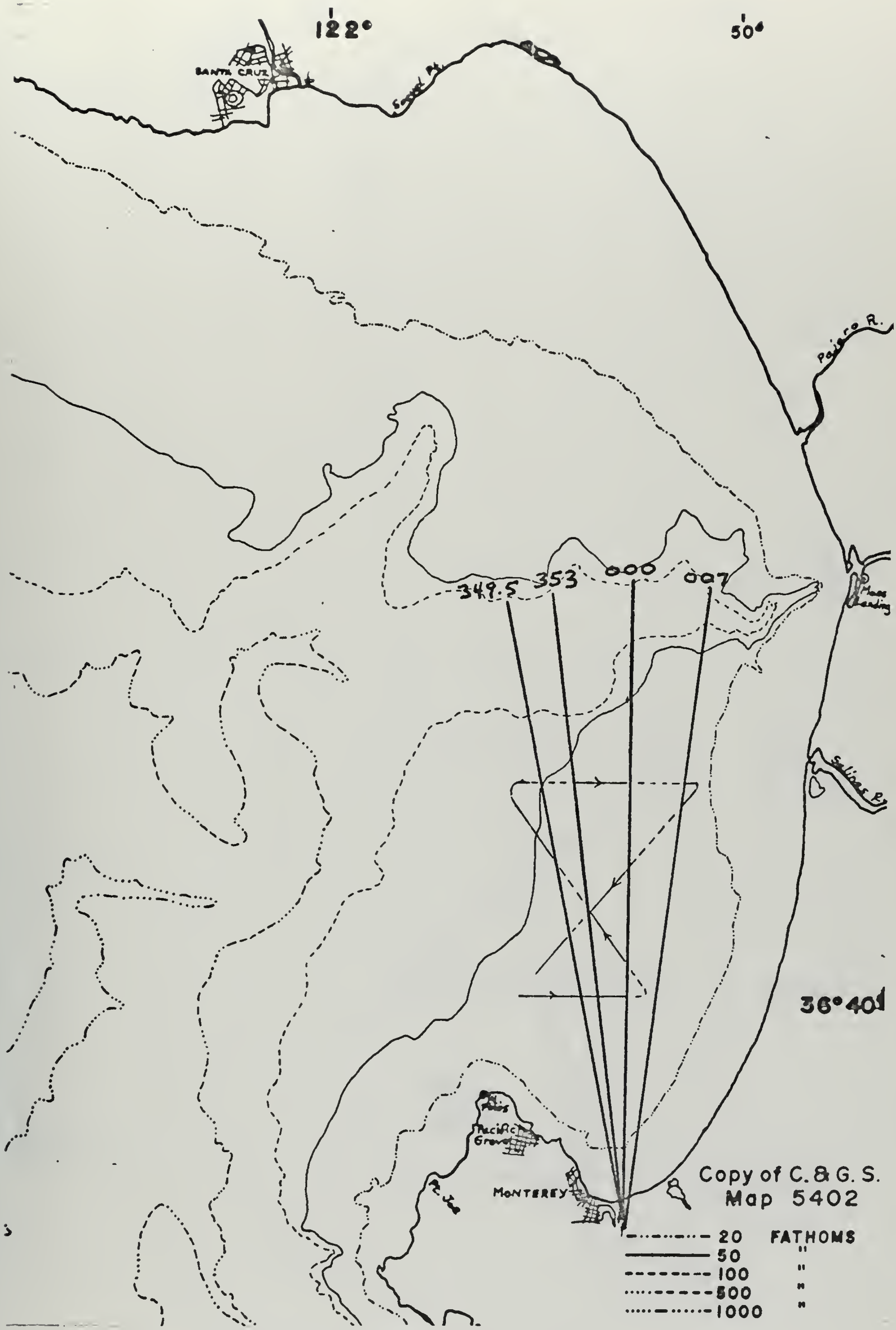

Figure 17. Radar Shadow Zones

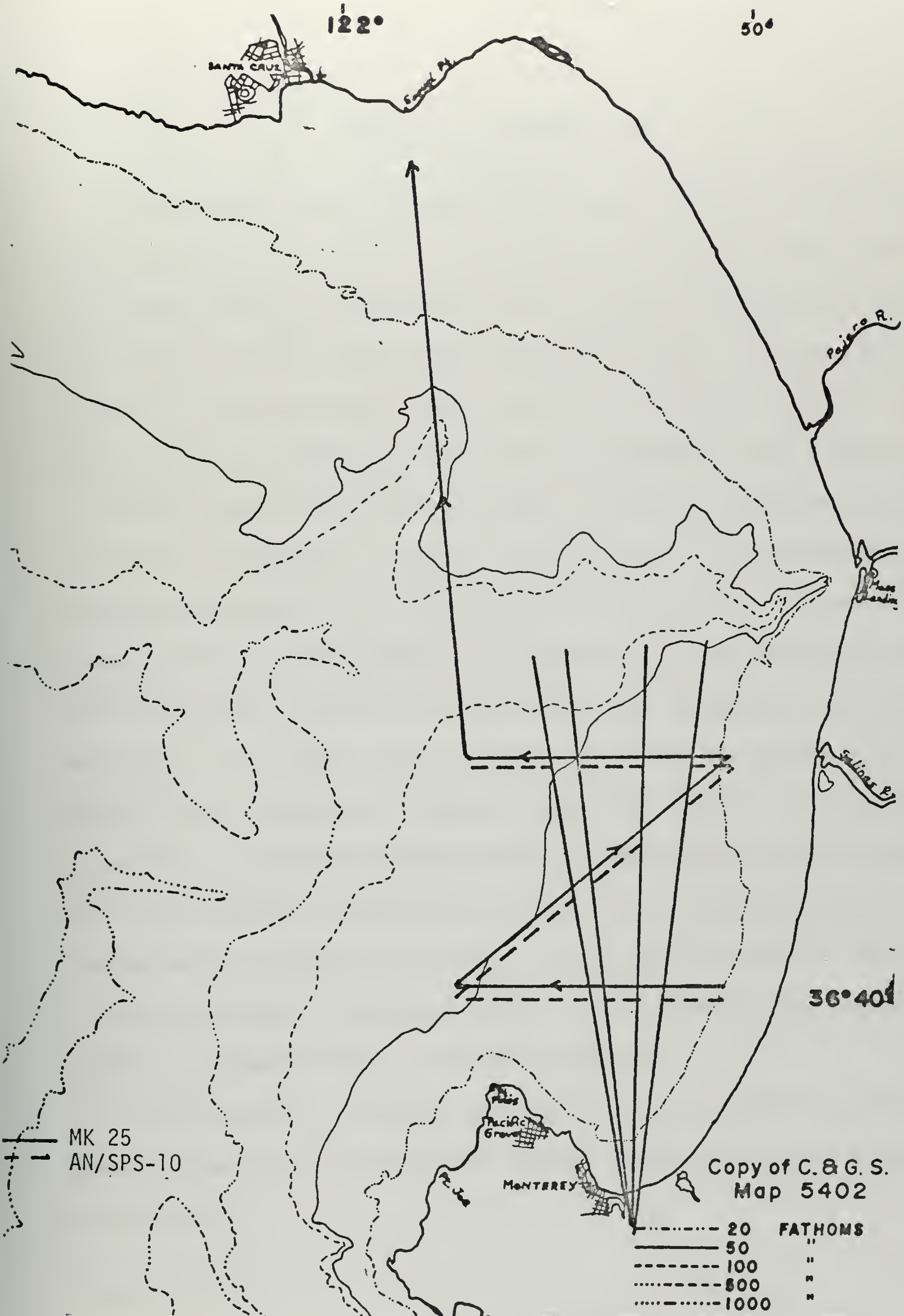

Figure 18. Transponder Track

V. ANALYSIS OF CURRENT DATA

In conjunction with the feasibility study, the drogue track data, over the four month period, was collected and analyzed. There were 38 drogues seeded and tracked during this period, resulting in a total accumulated tracking time of approximately 437 hours. The mean length of time of each individual drogue track was 11.5 hours, with the longest track being approximately 44 hours, and the shortest track 15 minutes.

Hourly drogue course and speed data, as extracted from the charts, is listed in Appendix A. To help in the analysis of the drogue data, hourly wind readings were obtained from the Pacific Gas and Electric Company's Moss Landing power plant (Appendix B). This data was not very satisfactory for accurately estimating the wind velocity at the drogue positions, as the power plant is almost 12 km from the center of the southern half of the Bay. Lacking *in situ* wind though, this data had to suffice, as these are the only hourly readings taken in the southern Bay area (excepting readings taken at the local airfields which are located well in from the coastline). Tidal data was obtained from the tidal gauge located in Monterey Harbor, supplemented by data from a similar instrument at Moss Landing (Appendix C).

The following is a synopsis and analysis of each individual drogue track (drogue tracks and wind-tide-current correlation graphs accompany each synopsis):

August 12-13:

Drogue #1 - This drogue was placed overboard eight kilometers northwest of Pt. Pinos. Its general track was east then south toward the lee of

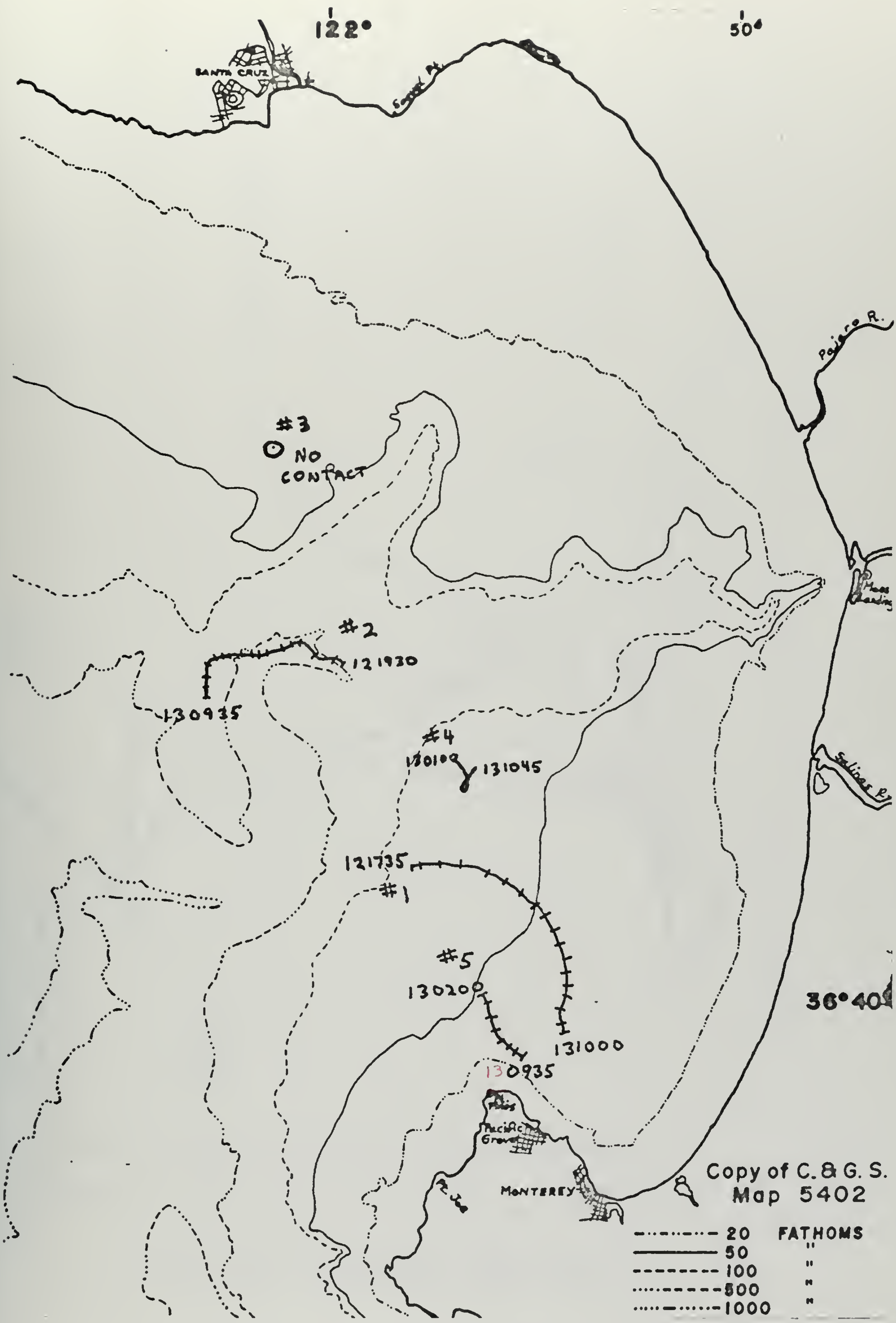

Figure 19. Drogue Tracks 1 - 5

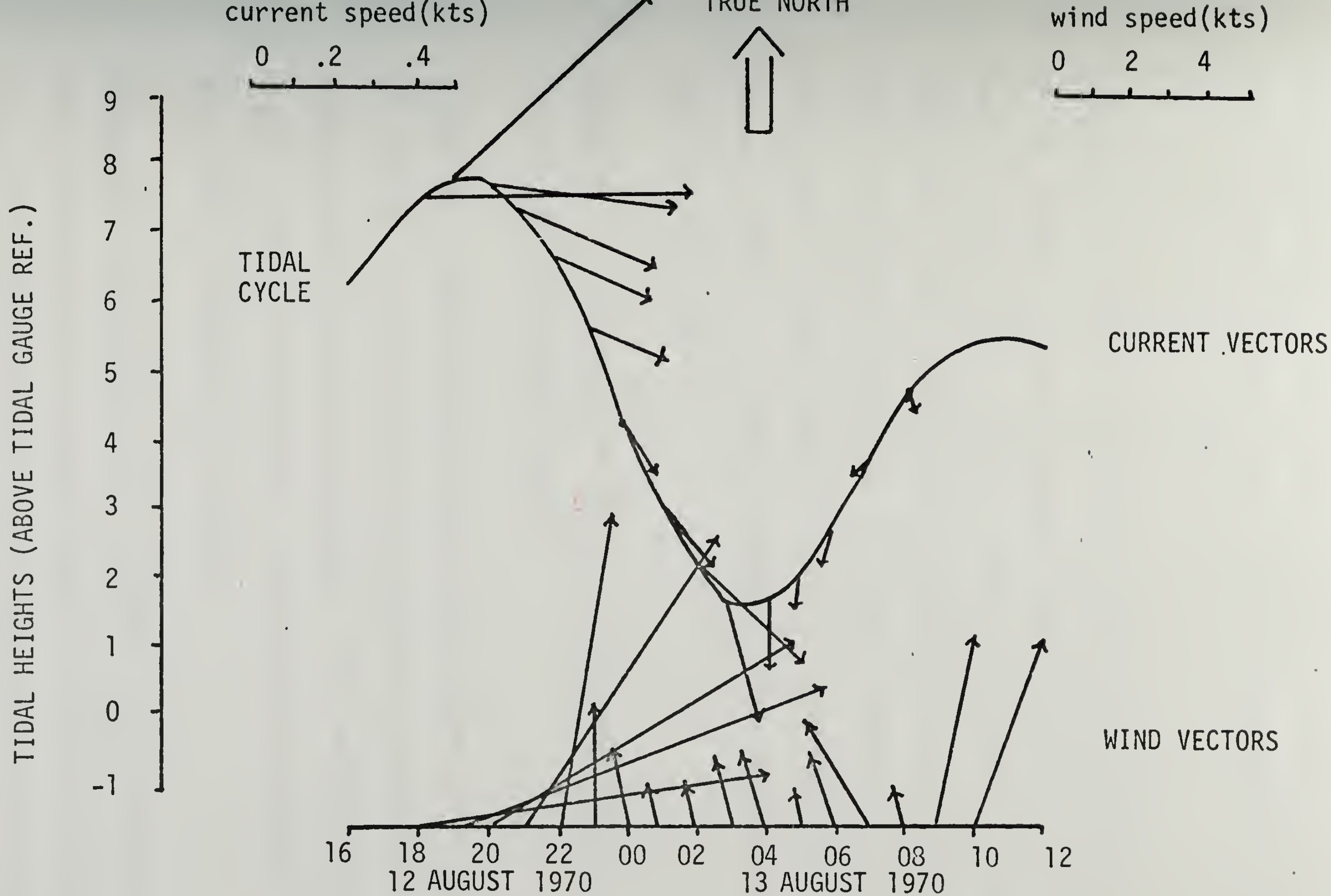

Figure 20. Drogue #1 Current-Wind-Tide Correlation

the Monterey Peninsula. Contrary to expectations, higher current speeds appear to be at the tidal extremities. At the start of the track, the wind blew briskly from the west and could account for the drogue's initially rapid movement into the Bay. Later backing of the wind could be a cause for drogue deceleration.

Drogue #2 - Drogue #2 was placed in the center of the Bay, above the axis of the Monterey Canyon, due west of Moss Landing. The drogue movement was to the west, with a turn to the south during the last few hours of the track. There appears to be alternating accelerations and decelerations during the tidal cycle, but again, seemingly out of phase. The wind, except for the middle of the track, generally was in opposition to drogue movement. The drogue's movement along the axis of the canyon might be significant.

Drogue #3 - This drogue was placed in the north central region of the Bay and was beyond radar contact.

Drogue #4 - Drogue #4 was placed in the center of the Bay just south of the Canyon. It moved quite slowly first to the southeast, and then reversed course toward the northeast. The reversal is shown to have occured during a flood period. The wind, being generally from the south, might have influenced this reversal.

Drogue #5 - Seeded about four kilometers north-northwest of Pt. Pinos, this drogue moved in the same general direction as drogue #1. Neither the wind nor the tide appeared to have forced this movement.

Discussion Drogues #1 - #5 - Possibly the movements of #1, #2, and #5 indicate a counterclockwise gyre generated by the southward flow of the

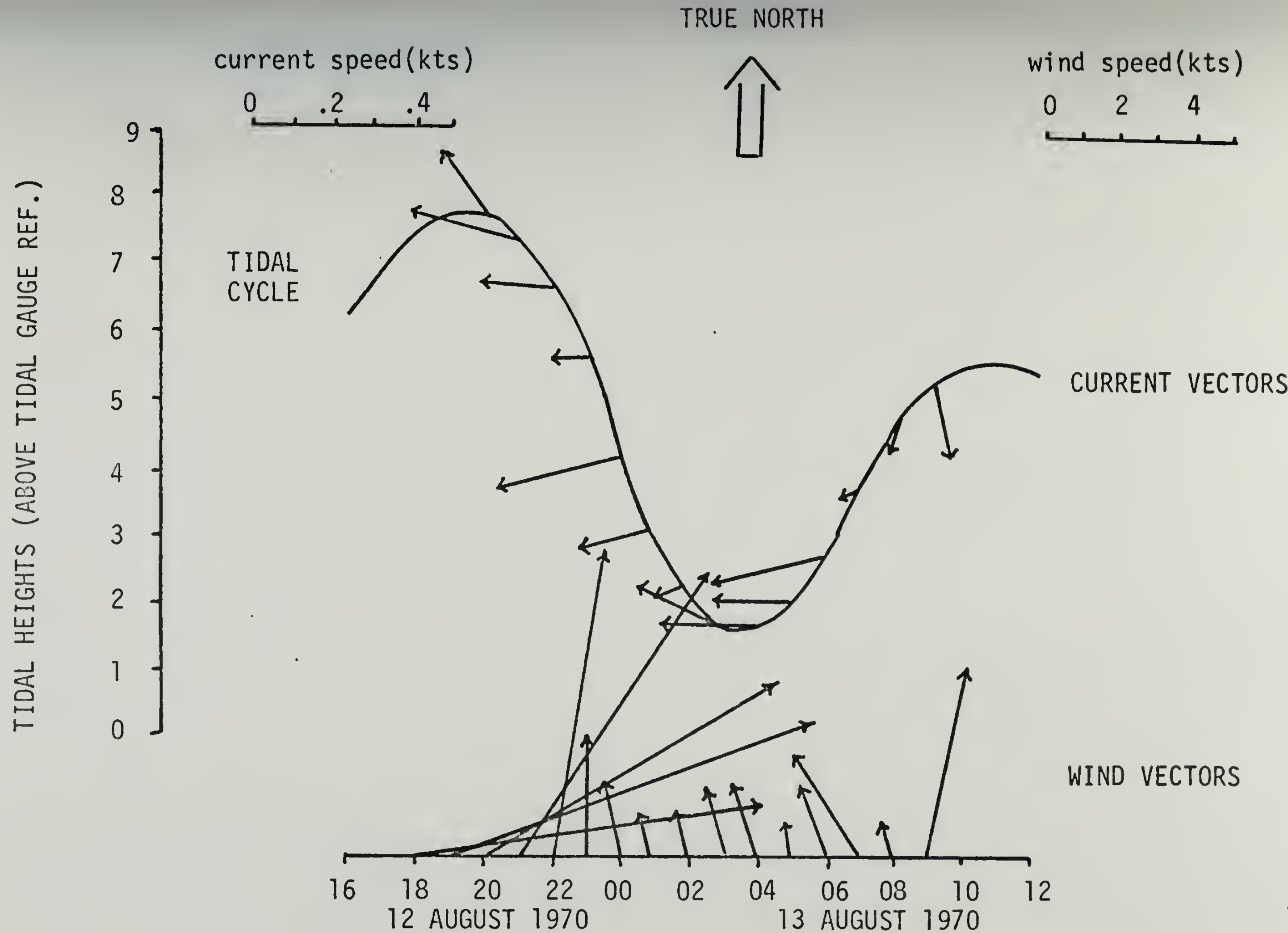

Figure 21. Drogue #2 Current-Wind-Tide Correlation

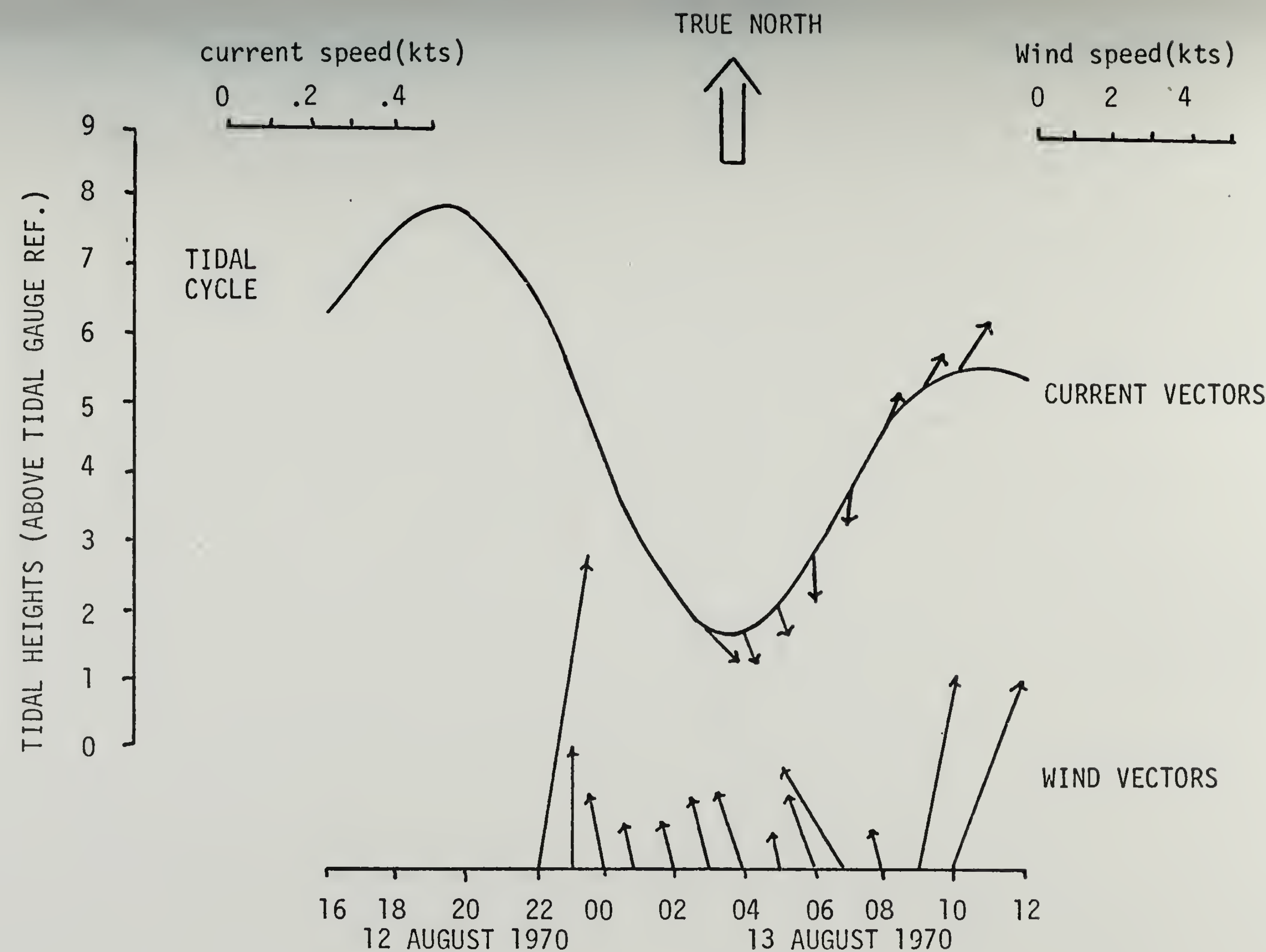

Figure 22. Drogue #4 Current-Wind-Tide Correlation

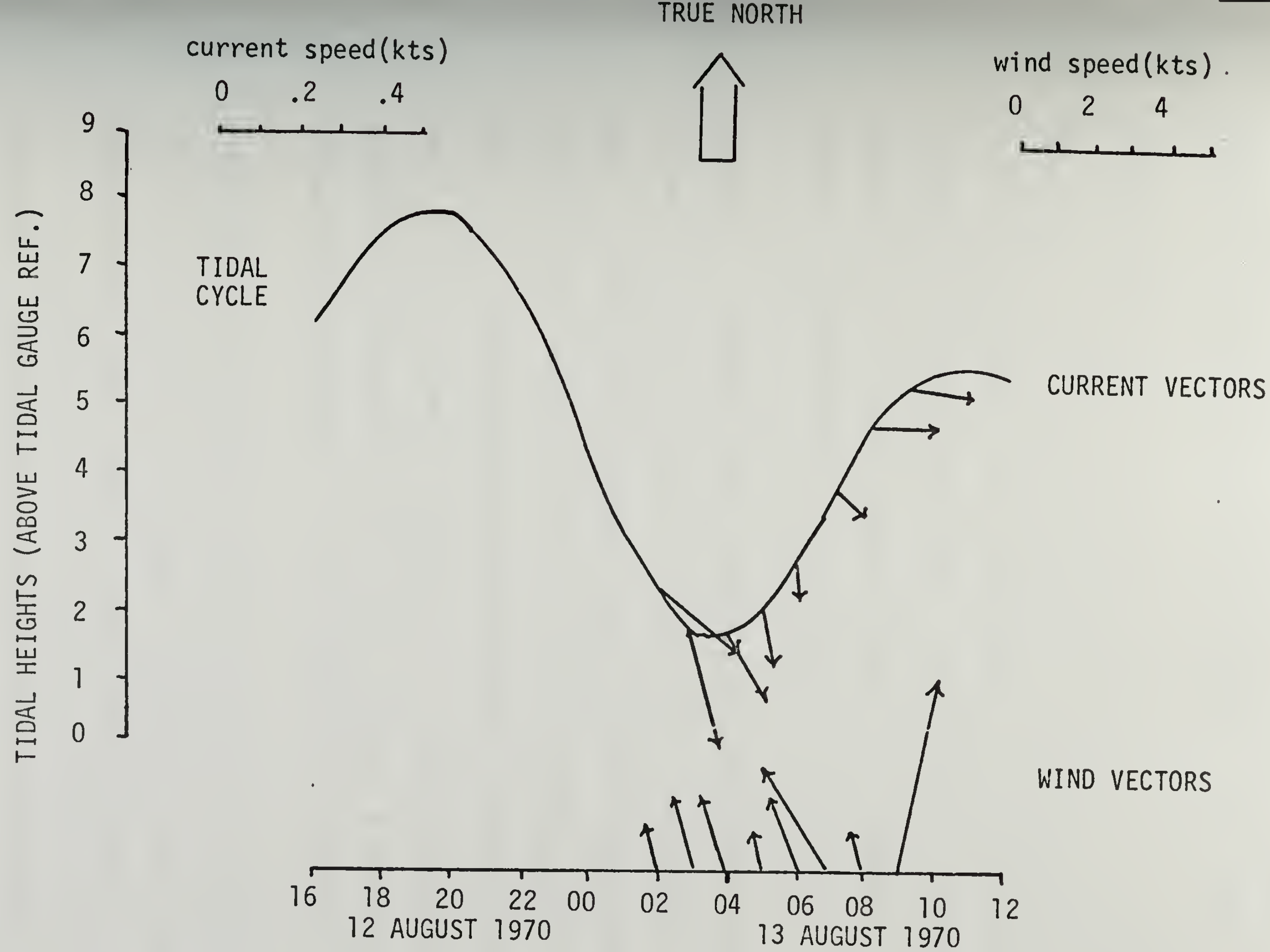

Figure 23. Drogue #5 Current-Wind-Tide Correlation

California Current. Drogue #4 could lie in the semi-stagnant center of this gyre. It is also possible that the drogue #4 parachute became fouled and did not open. This generally leads though to a strong wind dependent movement, which was not observed in this case.

August 18-19:

<u>Drogue #6</u> - This drogue was seeded in the same area as was drogue #1. The overall movement was to the southeast, but with a definite reaction to the ebb and flow of the tides. The increase in wind speed toward the northeast and east, may have attributed to the generally increasing current speed near the end of the track.

<u>Drogue #7</u> - Drogue #7 moved generally in an opposite sense than did drogue #2 the previous week. Placed at the seaward end of the canyon axis, it moved north and then to the east toward Moss Landing. The characteristic effects of the tide upon currents appeared to show up here, i.e. minimum speeds at high/low water, maximum speeds midway between the two extremes. The direction of drogue movement appeared roughly to correspond to that of the wind, but a share acceleration in the wind did not effect, at least immediately, the current speed.

<u>Drogue #8</u> - This drogue was placed in the center of the Bay just north of the Canyon axis. Its movement was generally north than east. Drogues #8 and #7 had similar tracks, and may have been part of a clockwise eddy.

<u>Drogue #9</u> - This drogue was initially held on the radar, but quickly vanished, probably in the western shadow zone (Figure 17).

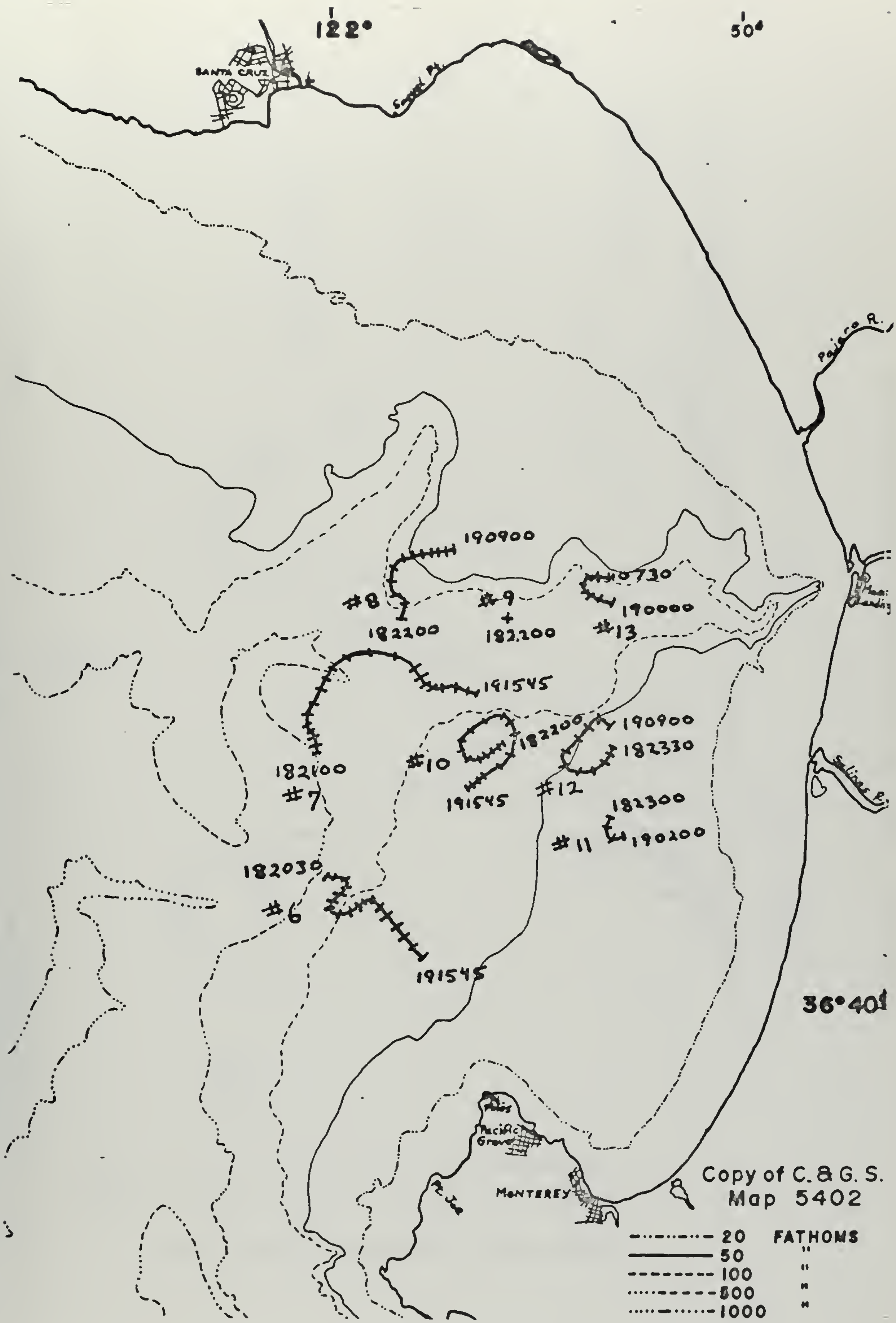

Figure 24. Drogue tracks 6 - 13

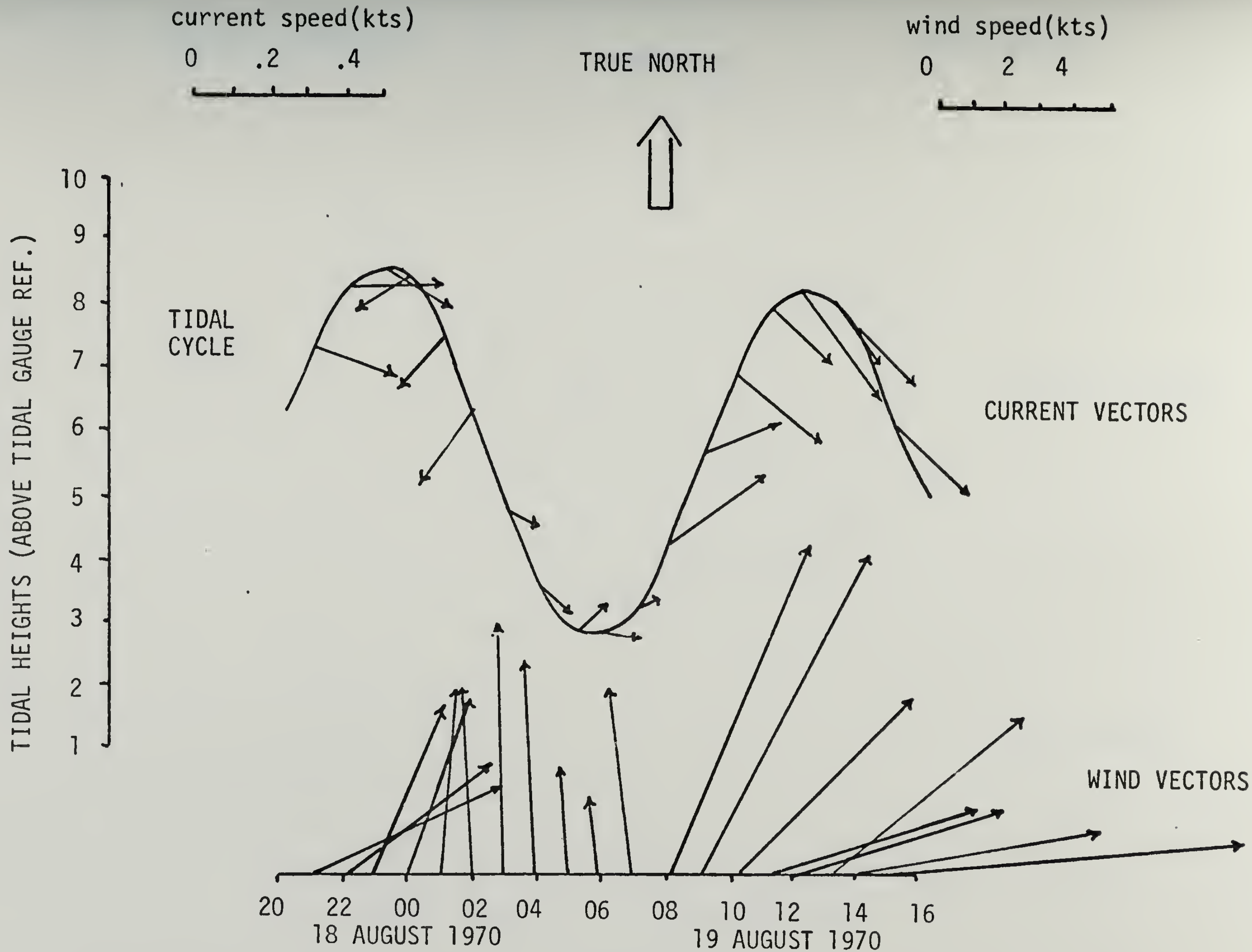

Figure 25. Drogue #6 Current-Wind-Tide Correlation

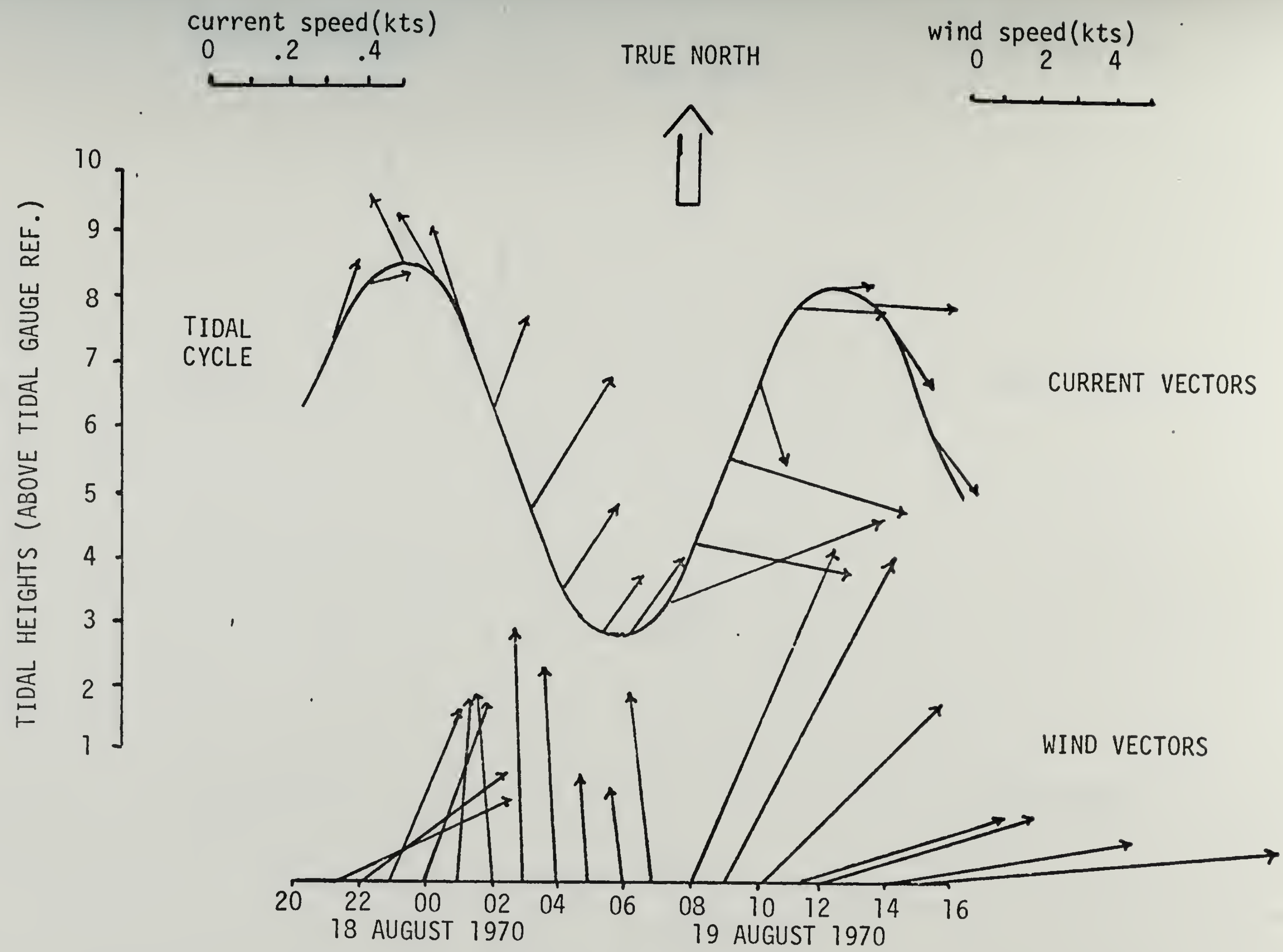

Figure 26. Drogue #7 Current-Wind-Tide Correlation

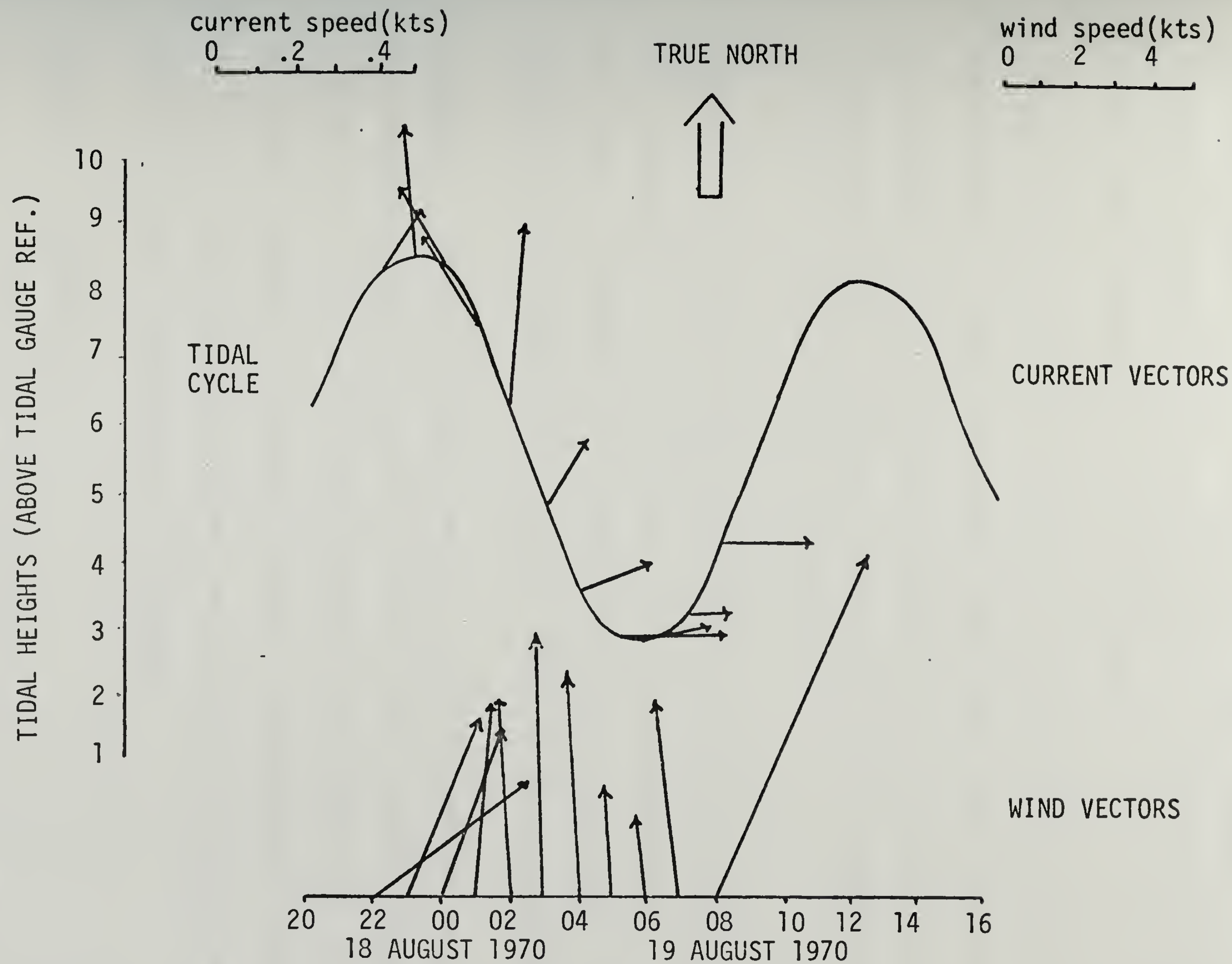

Figure 27. Drogue #8 Current-Wind-Tide Correlation

Drogue #10 - Drogue #10 was inserted close to the initial location of drogue #4. Again there was very little overall translational movement. The drogue rotated clockwise in a spiral turn greater than 360 degrees. The winds seemed to have no effect on the drogue movement. The tidal influence was shown by the drogue's movement seaward during the ebb tide and back toward shore during the flood tide.

Drogue #11 - The drogue was launched 7.3 km southwest of the Salinas River estuary. It had a very short track moving slowly to the south and southwest, and then reversing course to the northeast. This reversal corresponded roughly to the start of the flood (no graph was drawn due to a paucity of drogue course/speed data).

Drogue #12 - Drogue #12 was placed about 2.6 km east of drogue #10. Their movements were quite similar, i.e. in a clockwise spiral. The tide was again the predominating force affecting the drogue track. The southerly winds showed little apparent effect on the drogue movement.

Drogue #13 - Another clockwise movement was noted for this drogue, which was deployed about 2.5 km west of Elkhorn Slough. As with drogues #10 and #12, the drogue moved with the ebb and flow of the tide, and showed no obvious reaction to the winds. Contact with the drogue was lost as it drifted into the eastern shadow zone (Figure 17). Drogue tracks for #10 and #12 were terminated in a like manner.

August 31 - September 1:

Drogue #14 - This drogue was seeded in the southern extremity of the Bay, four kilometers northeast of Pt. Pinos. The drogue moved to the

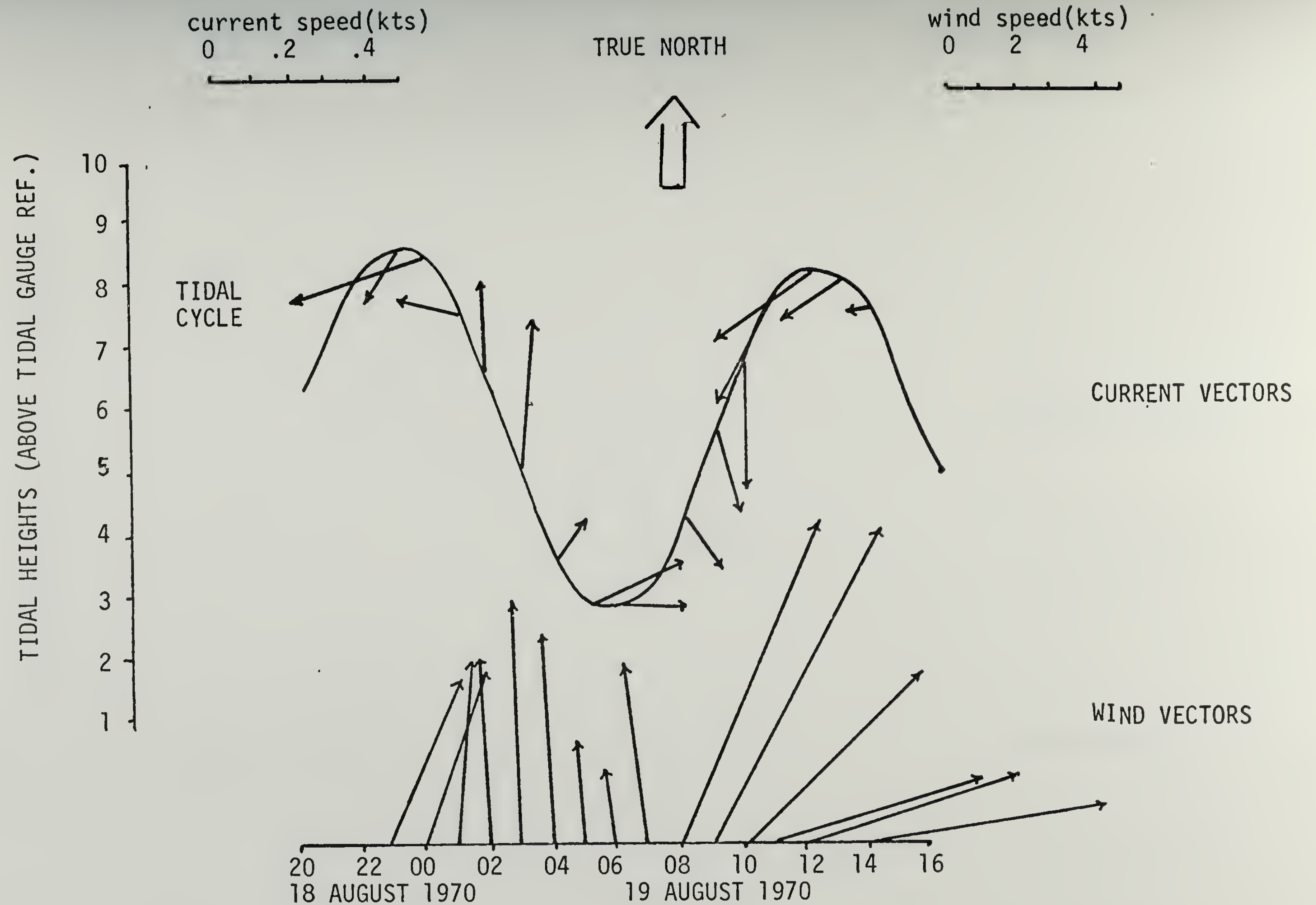

Figure 28. Drogue #10 Current-Wind-Tide Correlation

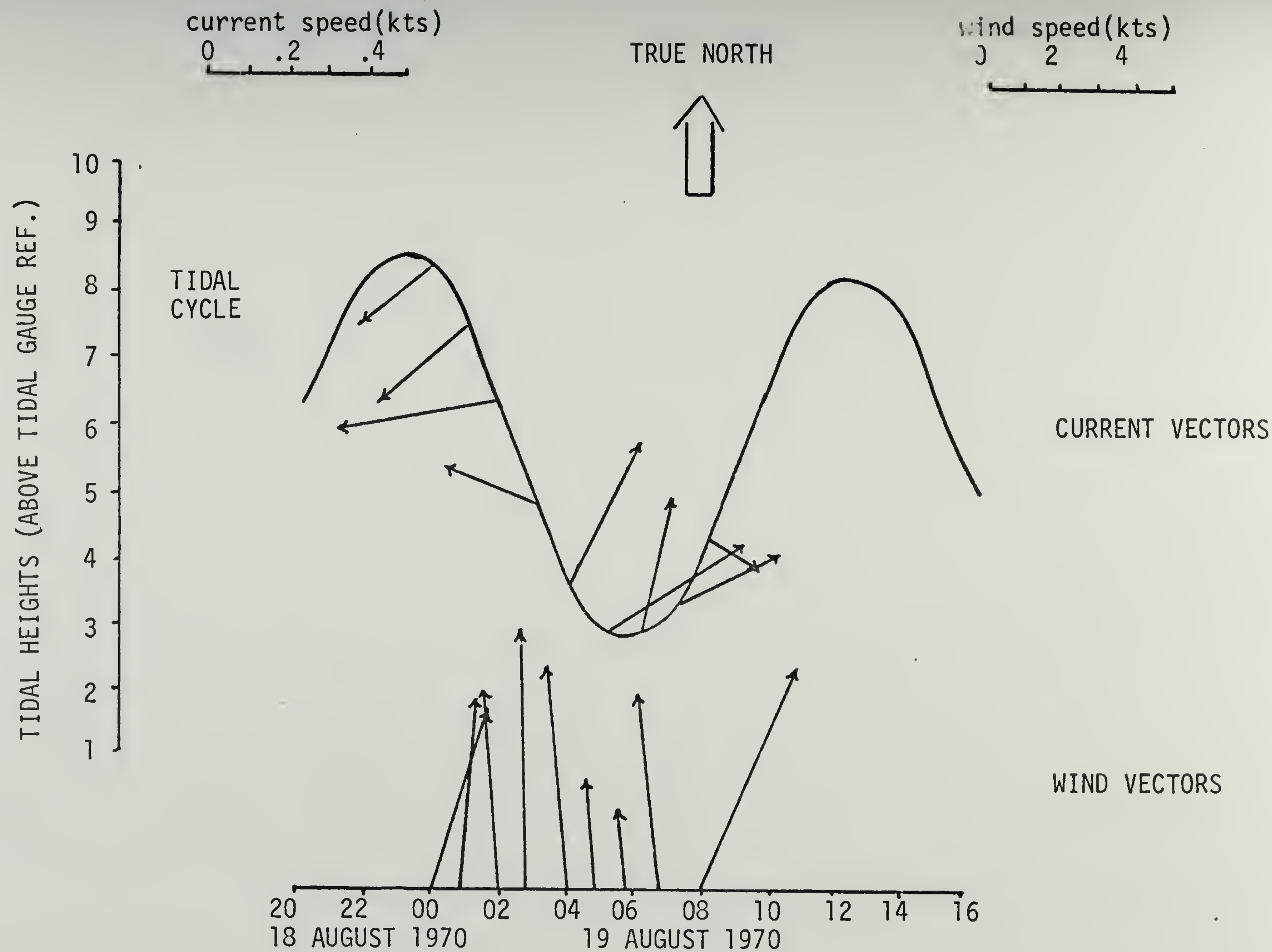

Figure 29. Drogue #12 Current-Wind-Tide Correlation

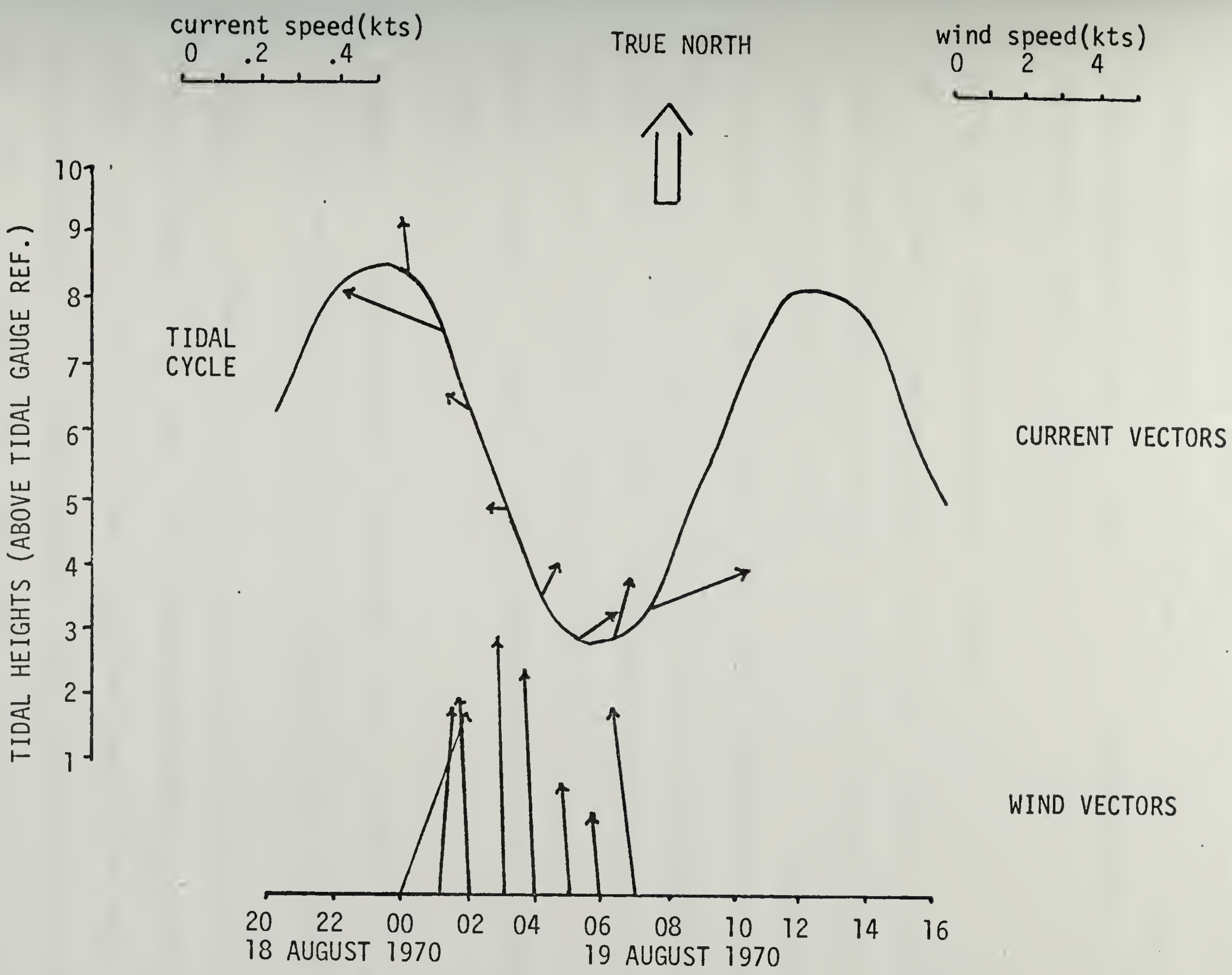

Figure 30. Drogue #13 Current-Wind-Tide Correlation

south for about five hours, at which time radar contact was lost. Contact was regained ten hours later two kilometers away to the northwest. Another southerly track followed, indicating the drogue had spiraled counterclockwise. The tide recorders for both Monterey and Moss Landing were inoperative on the first of September therefore the accompanying graph is of little use.

Drogue #15 - This one was placed in the same relative area as drogue #5, i.e. several kilometers north of Pt. Pinos. Whereas #5 moved in toward Monterey Harbor, #15 tracked to the west-southwest until radar contact was lost behind Pt. Pinos. The wind had no obvious effect upon this movement, in fact it blew in the opposite direction for much of the track. The seaward movement might be explained by the sweep down the coast of the California Current. The current might branch off of Pt. Pinos, with the main flow continuing south along the coast (carrying with it drogue #15), and the branch going east into the Bay proper creating eddies.

Drogue #16 - This drogue was planted about five kilometers northwest of Pt. Pinos and promptly tracked to the southwest behind the Point.

Drogue #17 - Southerly movement was again noted with drogue #17, emplaced 9.4 km northwest of Pt. Pinos. The track moved behind the Point after making a short jog first to the east, and then back to the west. The movement toward the Bay occured during an ebb, therefore the tide does not appear to account for it. The wind was blowing quite strongly from the west at this time, therefore it may be responsible. The general movement to the south again might be attributed to the oceanic current influence.

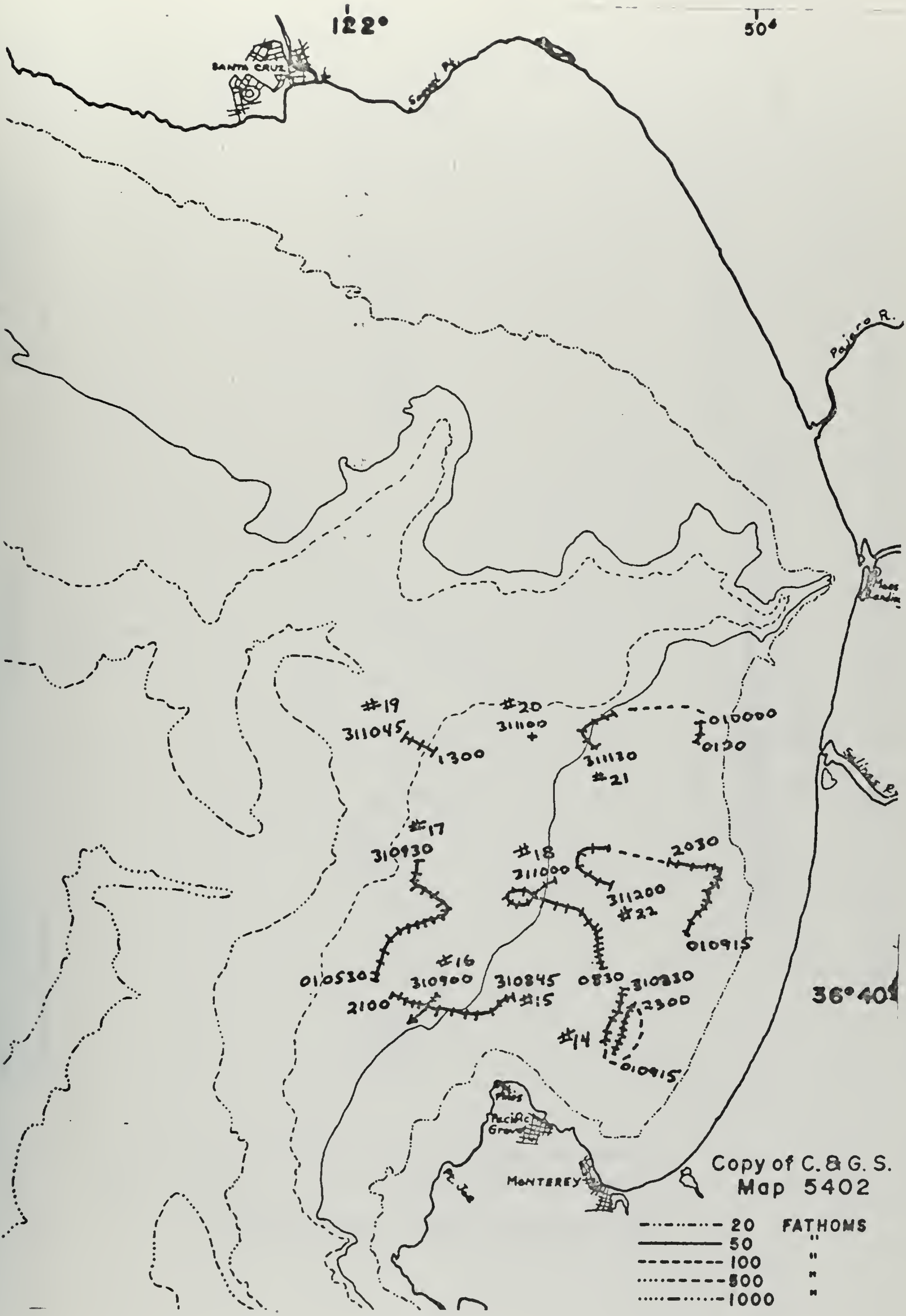

Figure 31. Drogue Tracks 14 - 22

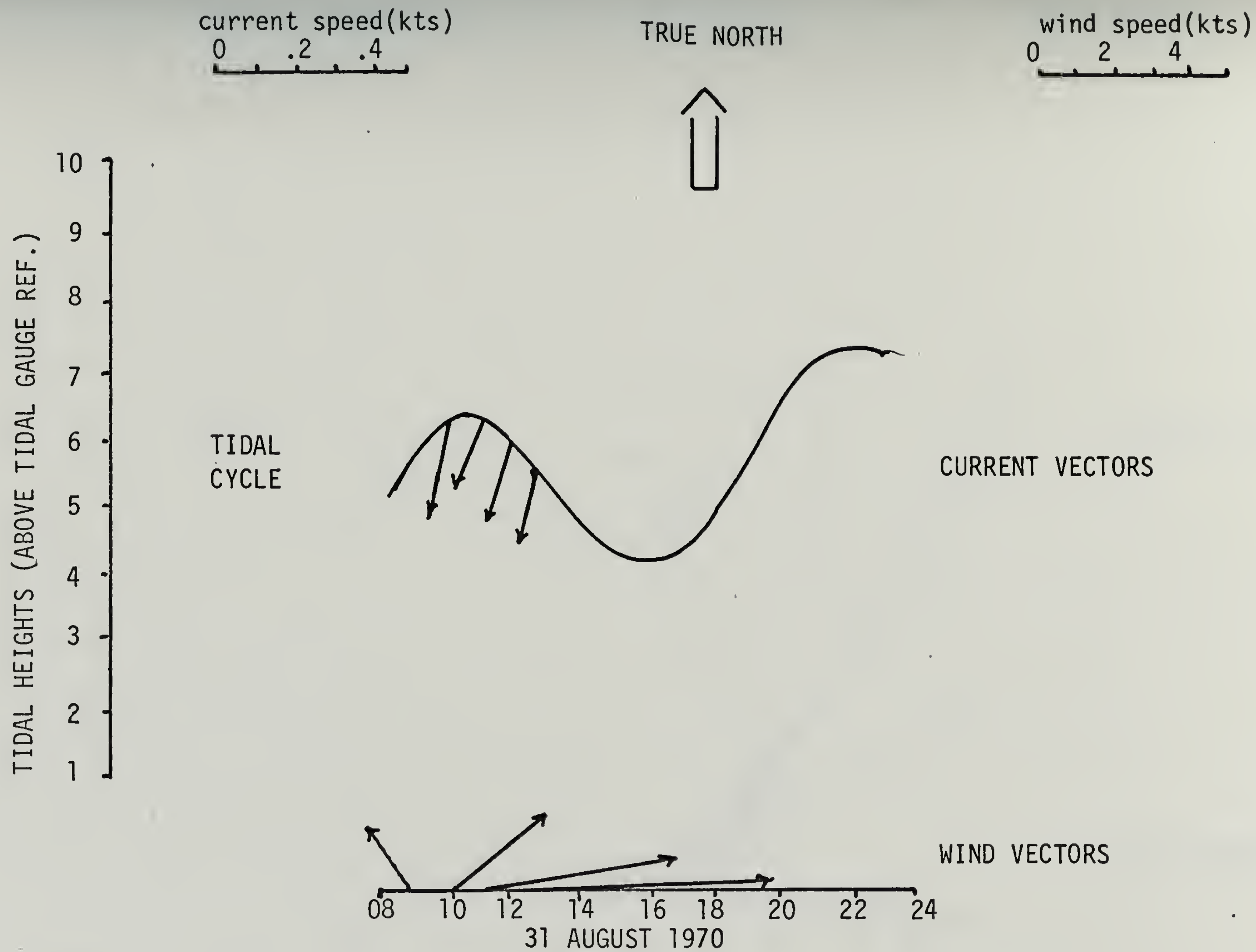

Figure 32. Drogue #14 Current-Wind-Tide Correlation

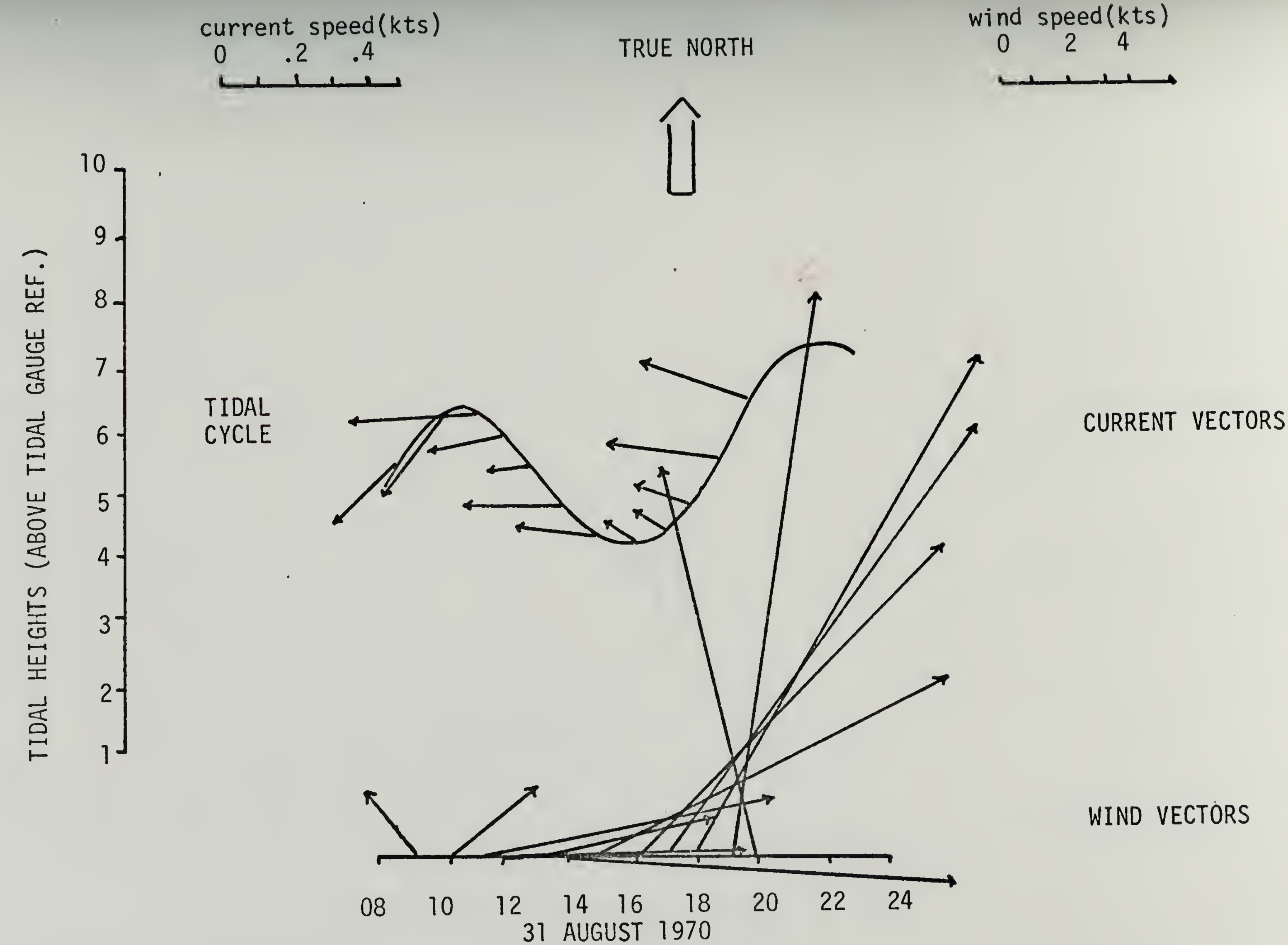

Figure 33. Drogue #15 Current-Wind-Tide Correlation

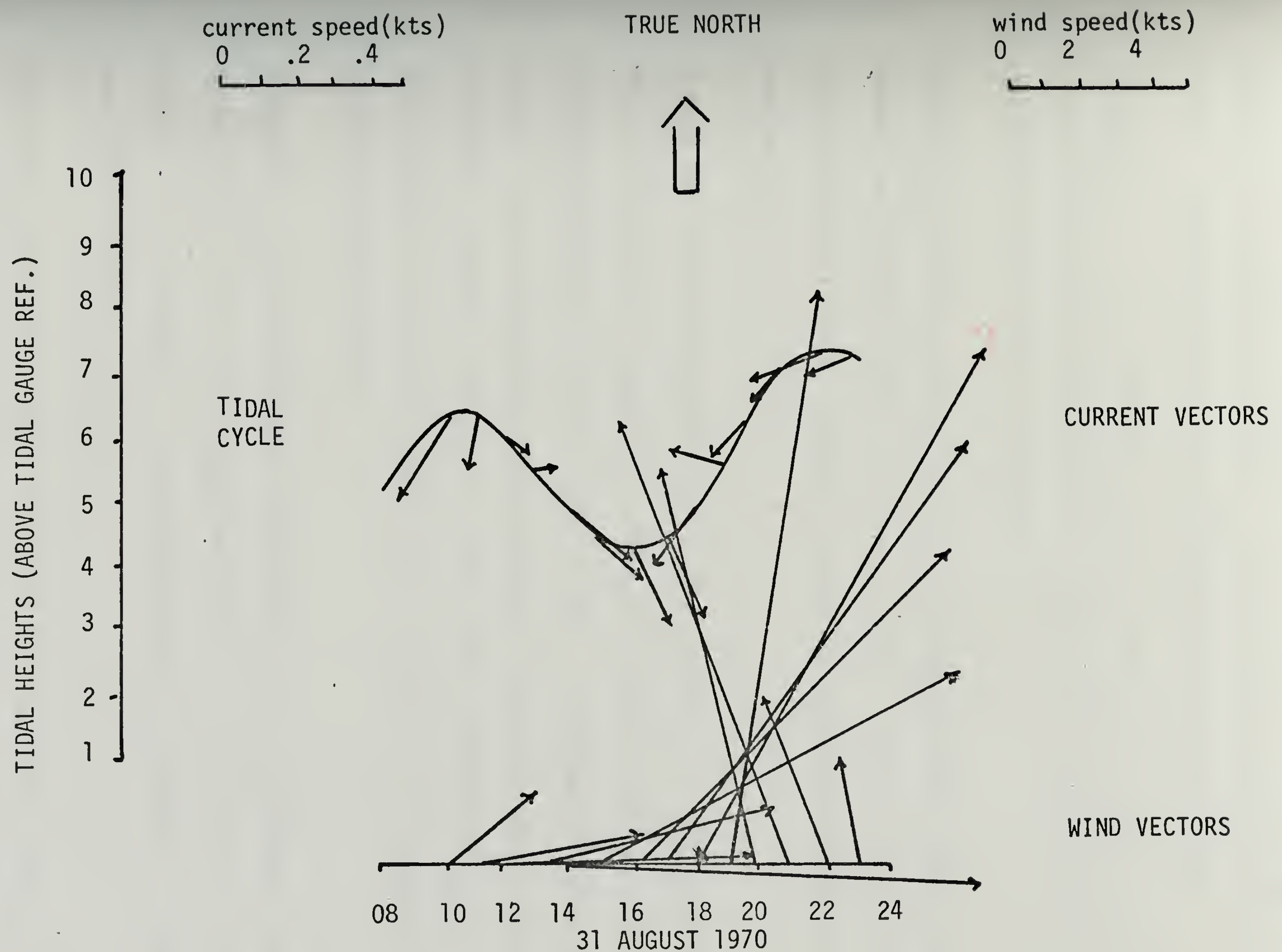

Figure 34. Drogue #17 Current-Wind-Tide Correlation

Drogue #18 - This drogue, launched in the center of the southern half of the Bay, tracked initially to the southwest and then looped clockwise around to a southeasterly head. The loop can be attributed to the tidal cycle. The winds seem to have little bearing upon the track.

Drogue #19 - It was placed in the water 17 km west of the Salinas River. Sketchy contact was maintained for several hours, during which it appeared to move toward the southeast.

Drogue #20 - Drogue #20 was initially held by the radar about four kilometers east of drogue #19's starting position. An hour and a half later radar contact was lost, probably as a result of movement into the western shadow zone.

Drogue #21 - This drogue, with its initial position in line with #19 and #20 but farther east, moved in a clockwise spiral for about four hours before disappearing from the radar screen. It reappeared nine hours later, 2.6 km to the east, and then moved to the southwest. The initial spiral was probably caused by the flood tide (although the graph shows the shoreward flow and the flood tide a few hours out of phase), and aided by westerly winds.

Drogue #22 - This was another interrupted track, with passage through the eastern shadow zone. The drogue was initially located just east of drogue #18's start point. As with #18 and #21, it moved in a tide-controlled clockwise rotation.

Discussion Drogues #14 - #20 - On top of the local tidal eddies, it appeared as if the drogues (with the exception of #14) were generally moving clockwise around the interior of the southern end of the Bay.

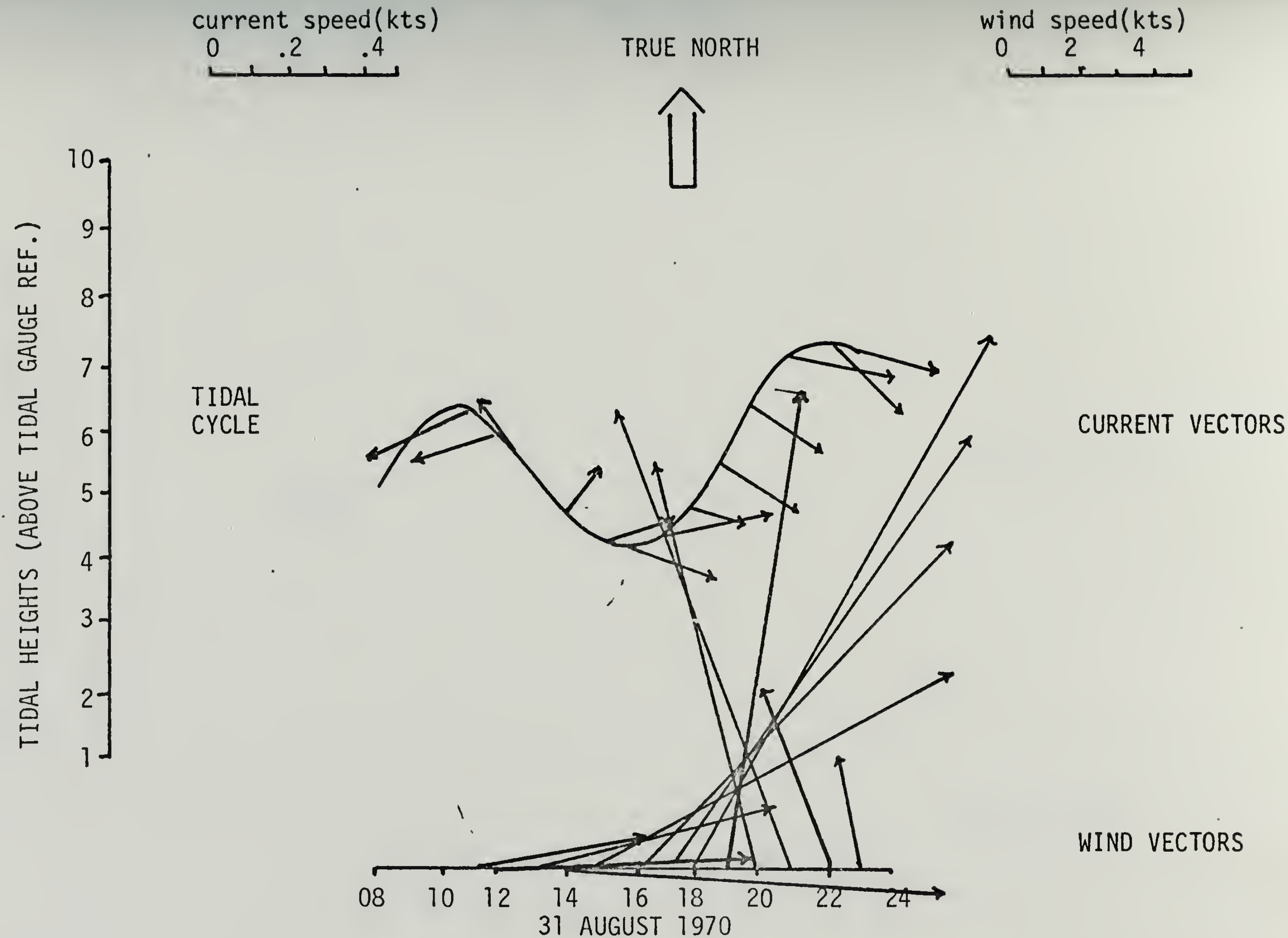

Figure 35. Drogue #18 Current-Wind-Tide Correlation

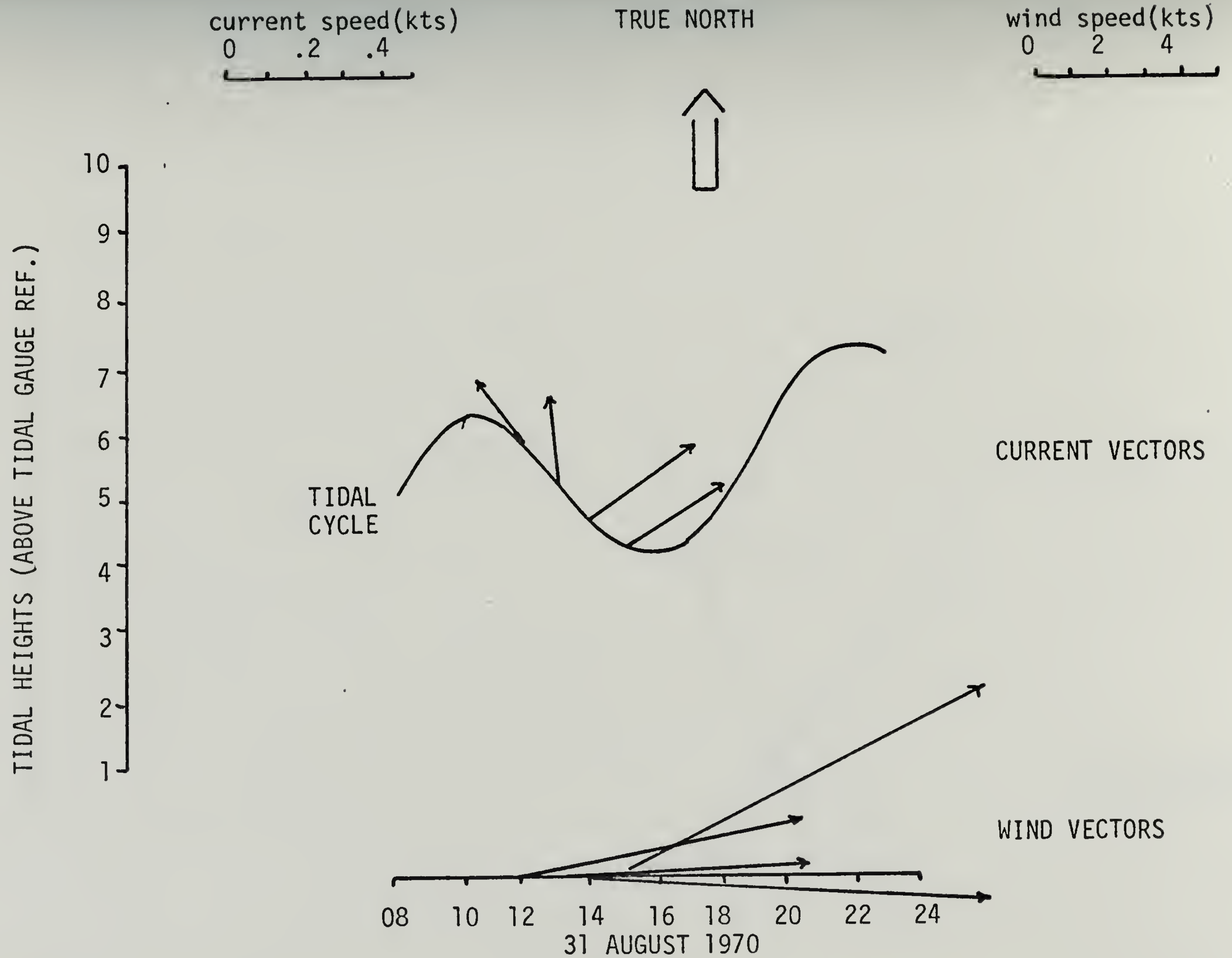

Figure 36. Drogue #21 Current-Wind-Tide Correlation

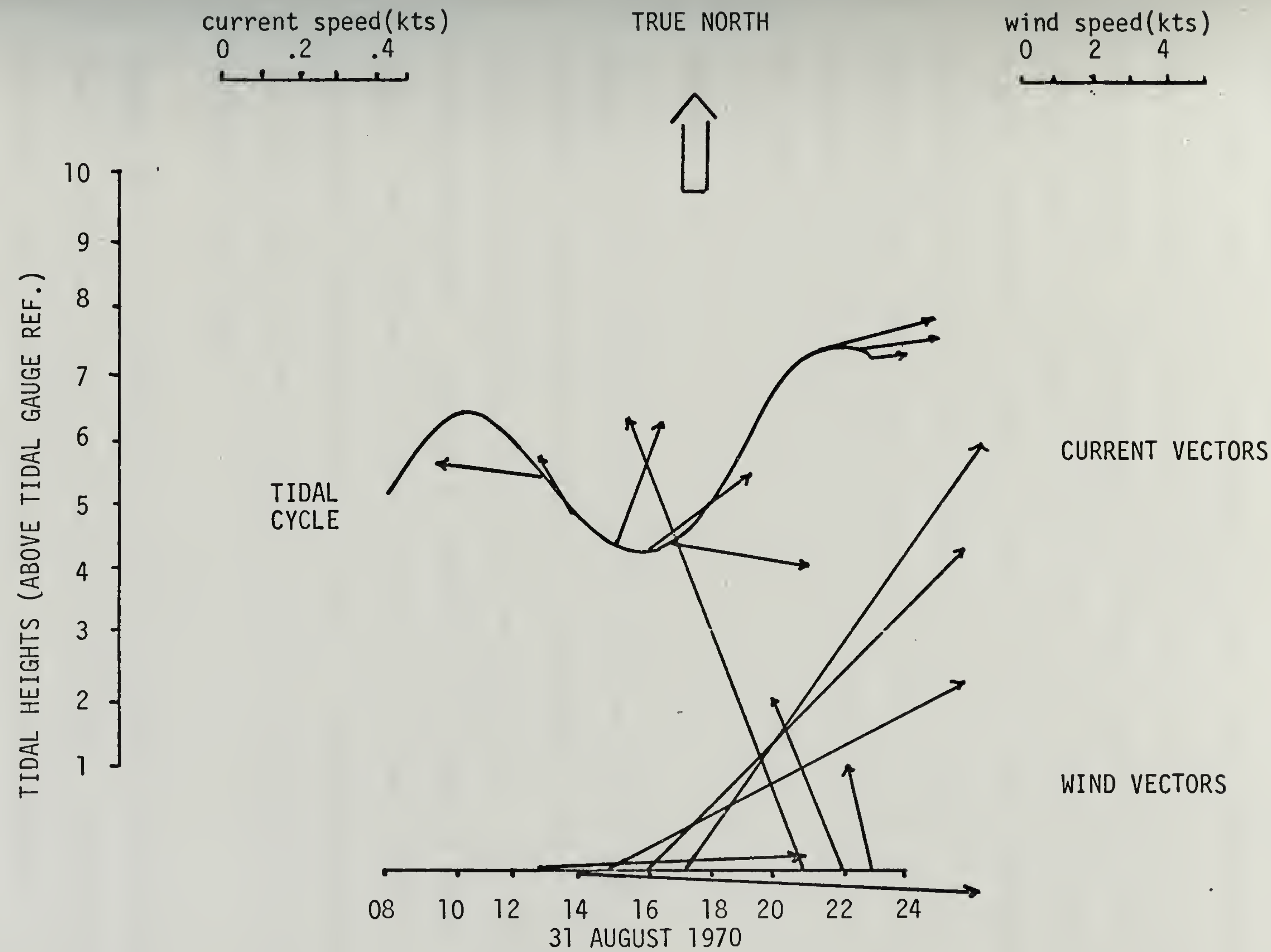

Figure 37. Drogue #22 Current-Wind-Tide Correlation

October 6:

Drogues #23 - #27 - The tracks for these drogues all roughly paralleled each other, moving east to northeast and then turning toward the south. They were planted in a relatively small cluster in the south central area of the Bay. The tracks were all abruptly terminated as the result of mast buckling failures (see Chapter VI). The movements of the drogues were probably jointly the result of the strong southwesterly winds and the flooding tide. Additionally, the northward flowing Davidson Current, which occurs during this season of the year, could have been directing flow into the Bay, and possibly setting up a clockwise gyre.

November 6-8:

Drogue #28 - The overall track of this drogue was steadily to the northwest from its initial position four kilometers north of Pt. Pinos. This tracking period was quite lengthy and exhibited a large variance in wind conditions. The winds in general did not seem to effect the track. There were no tidal loops, nor did the current speed vary directly with the ebb and flow of the tide. It would appear therefore, that the Davidson Current's northerly flow is the primary forcing mechanism in this case.

Drogue #29 - This drogue moved for about six hours to the northeast before contact was lost in the western shadow zone. Its starting position was about eight kilometers north of Pt. Pinos. The movement into the Bay was probably the combined result of the prevailing winds and the flood

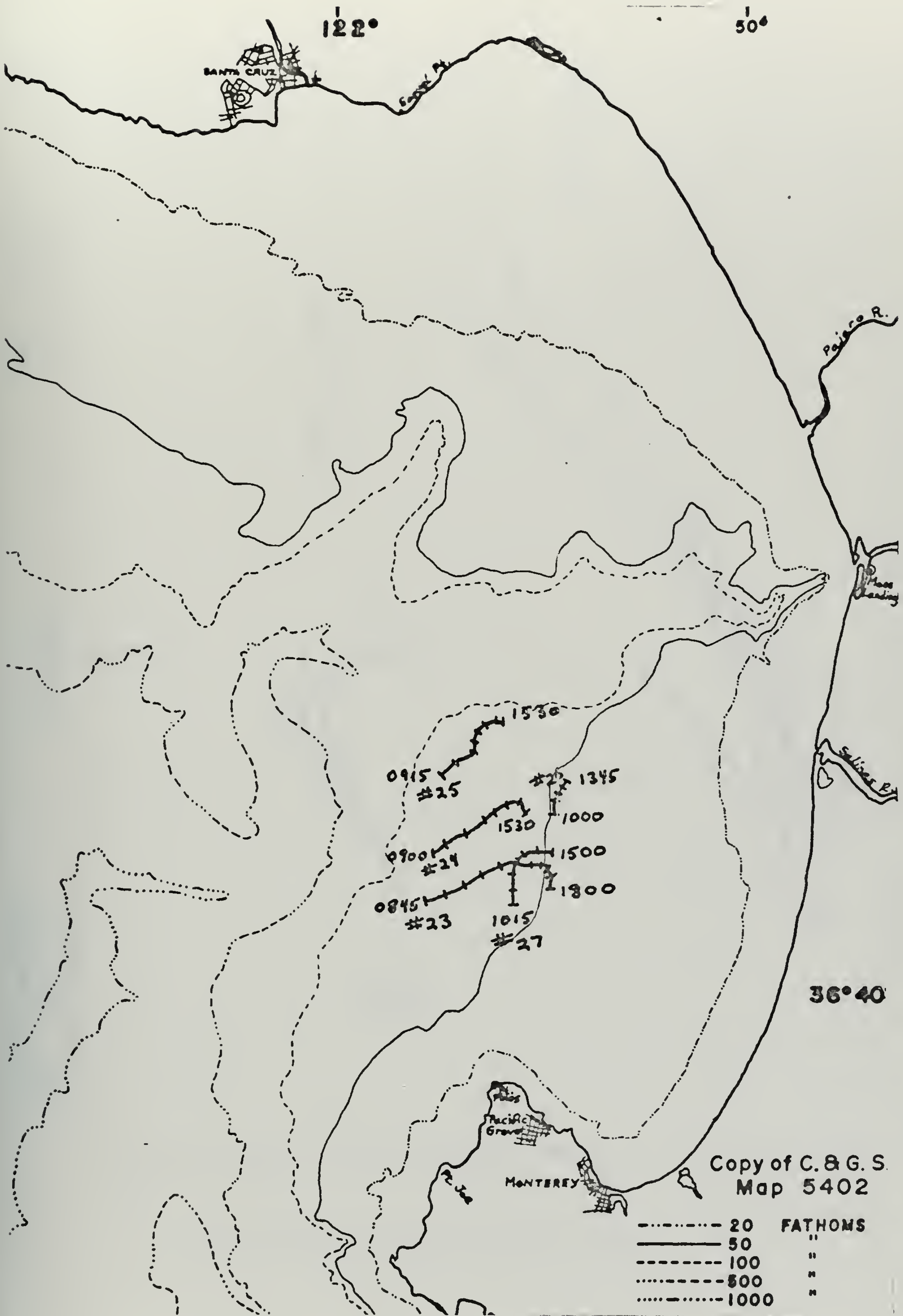

Figure 38. Drogue Tracks 23 - 27

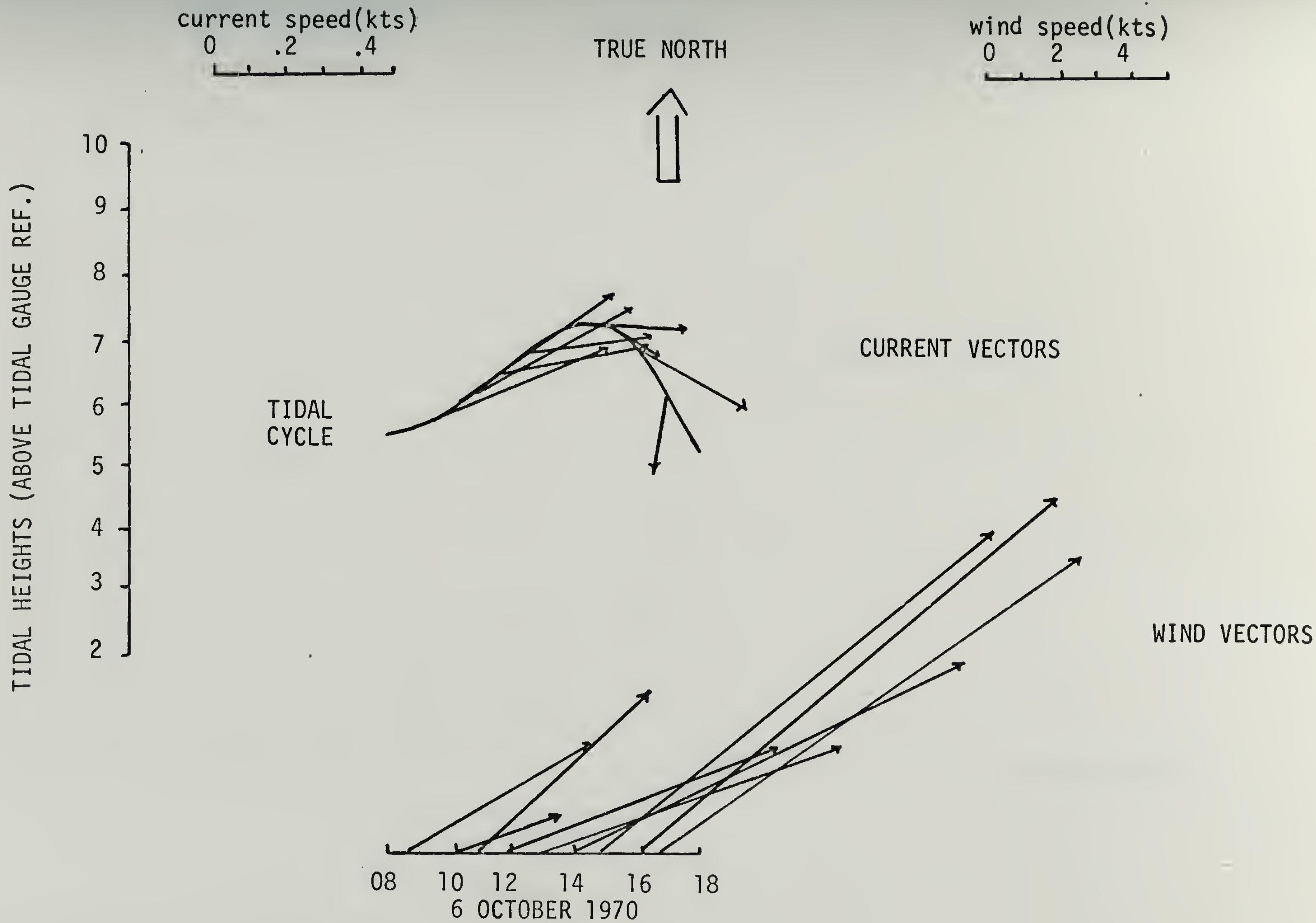

Figure 39. Drogue #23 Current-Wind-Tide Correlation

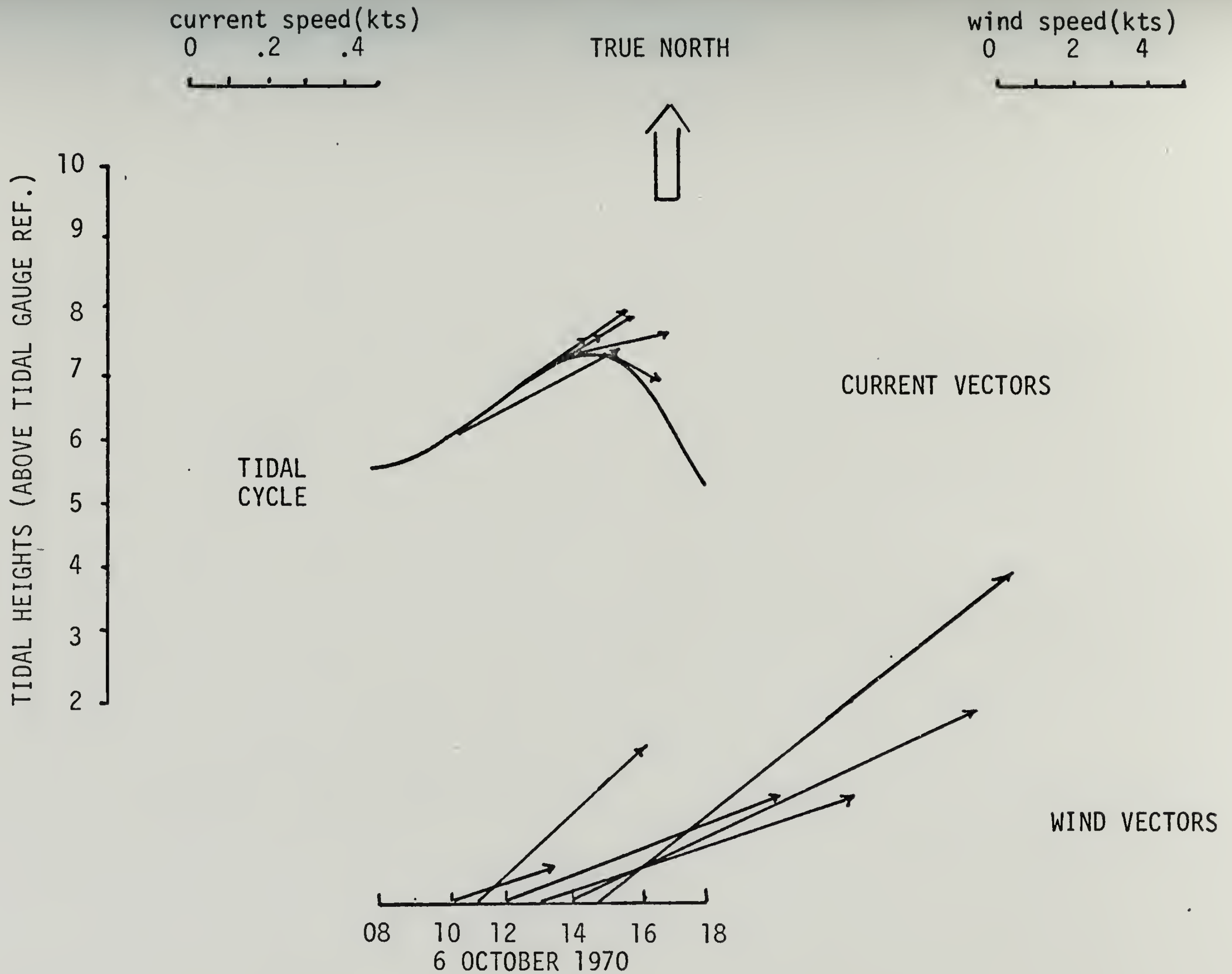

Figure 40. Drogue #24 Current-Wind-Tide Correlation

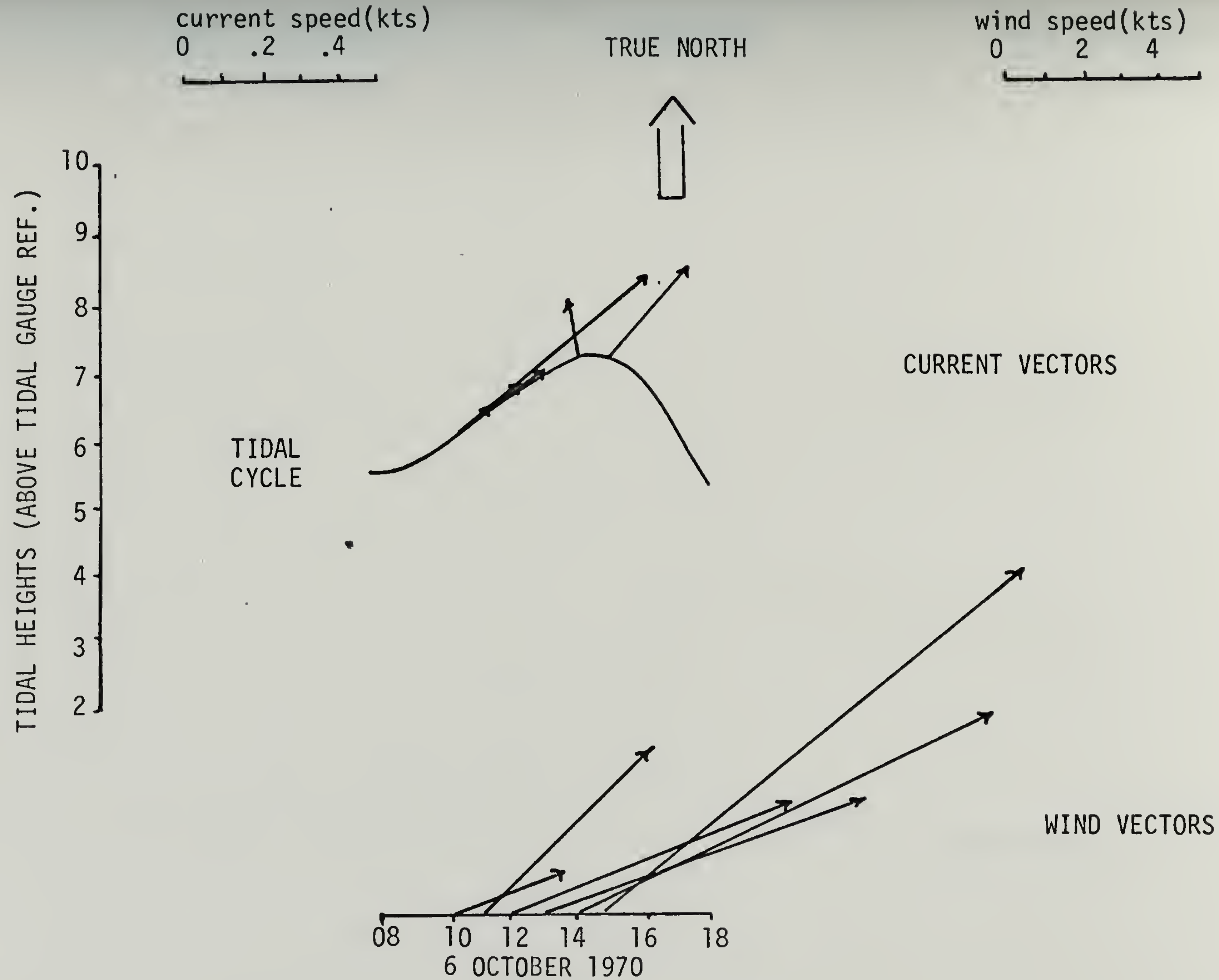

Figure 41. Drogue #25 Current-Wind-Tide Correlation

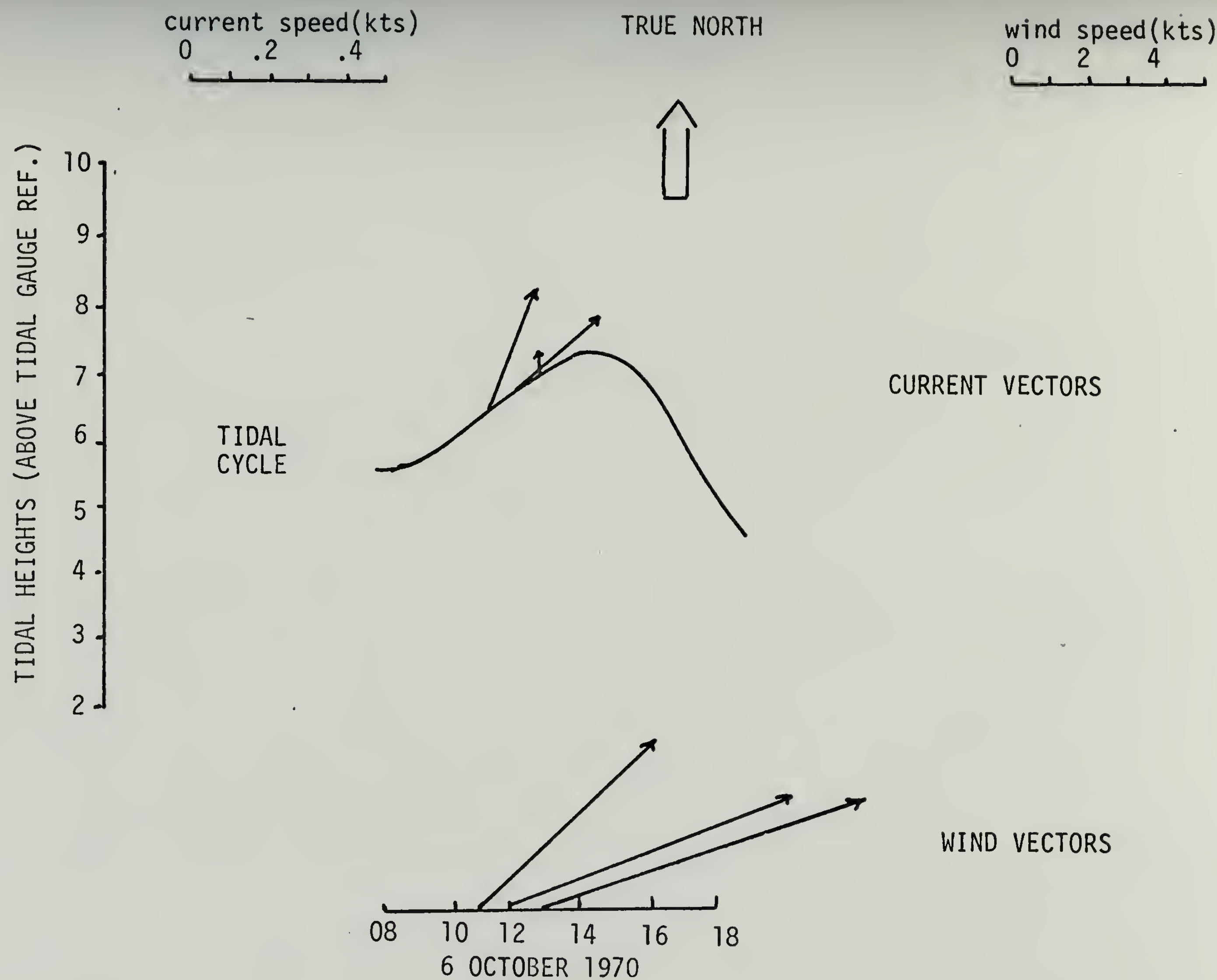

Figure 42. Drogue #26 Current-Wind-Tide Correlation

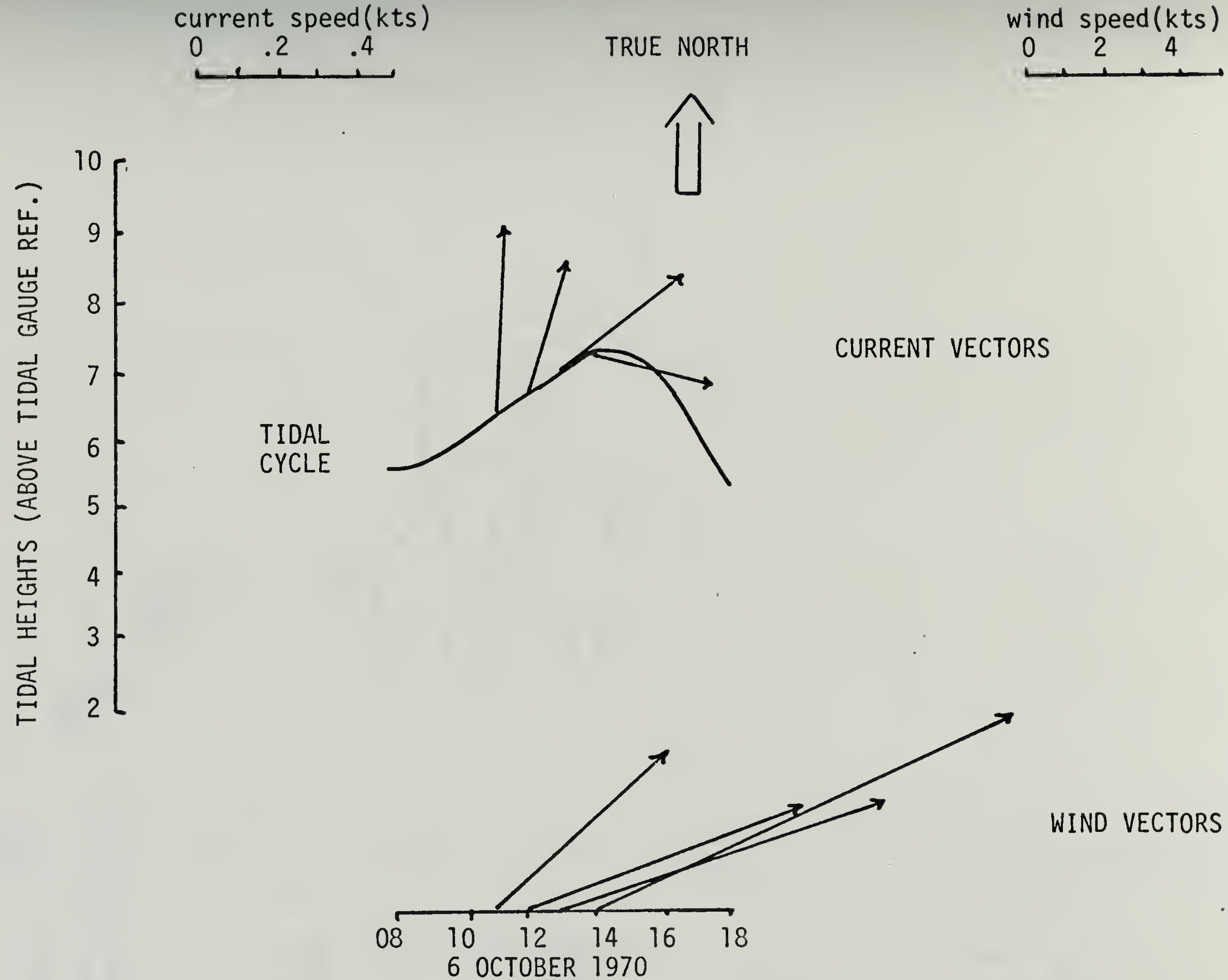

Figure 43. Drogue #27 Current-Wind-Tide Correlation

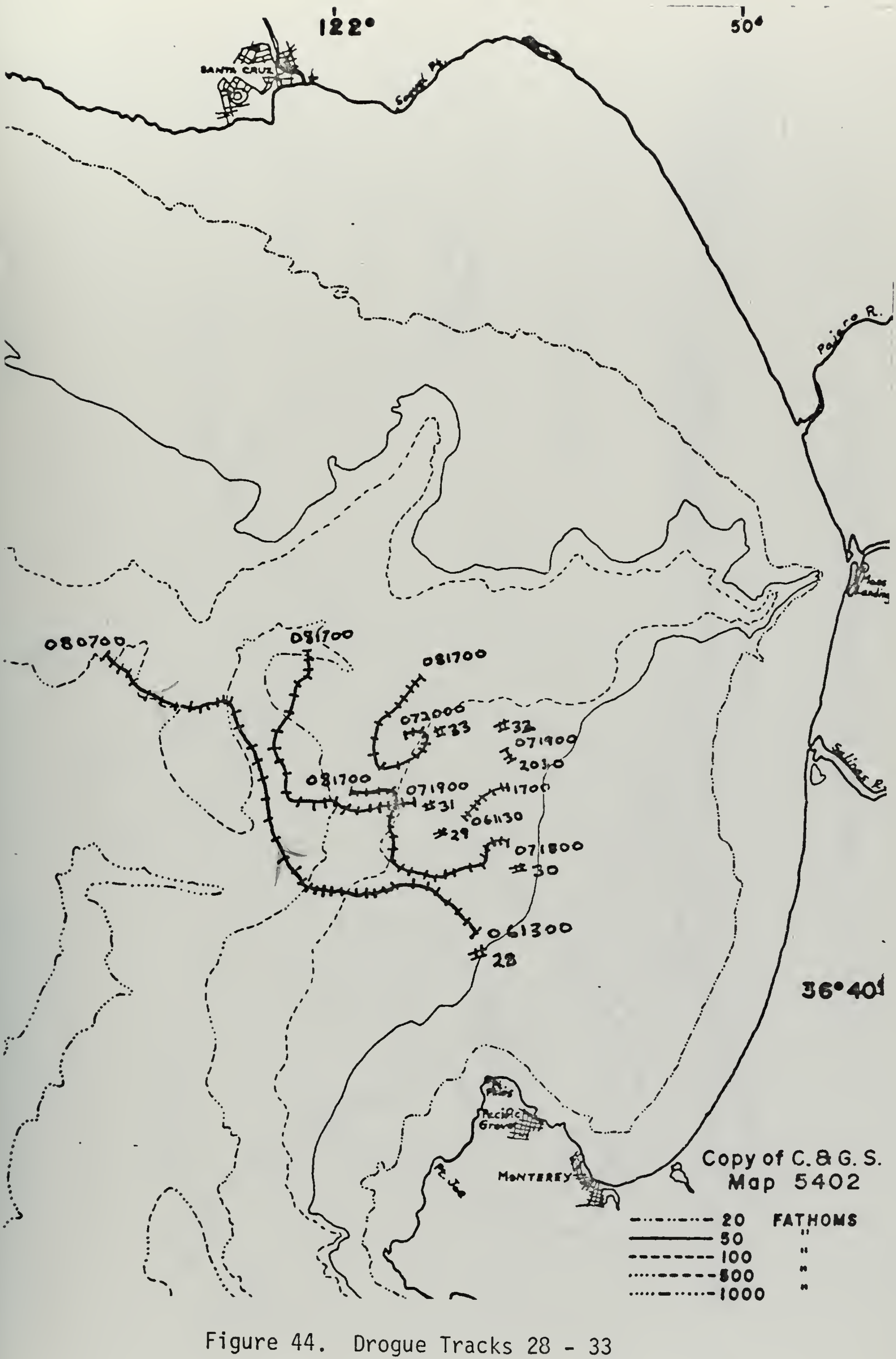

Figure 44. Drogue Tracks 28 - 33

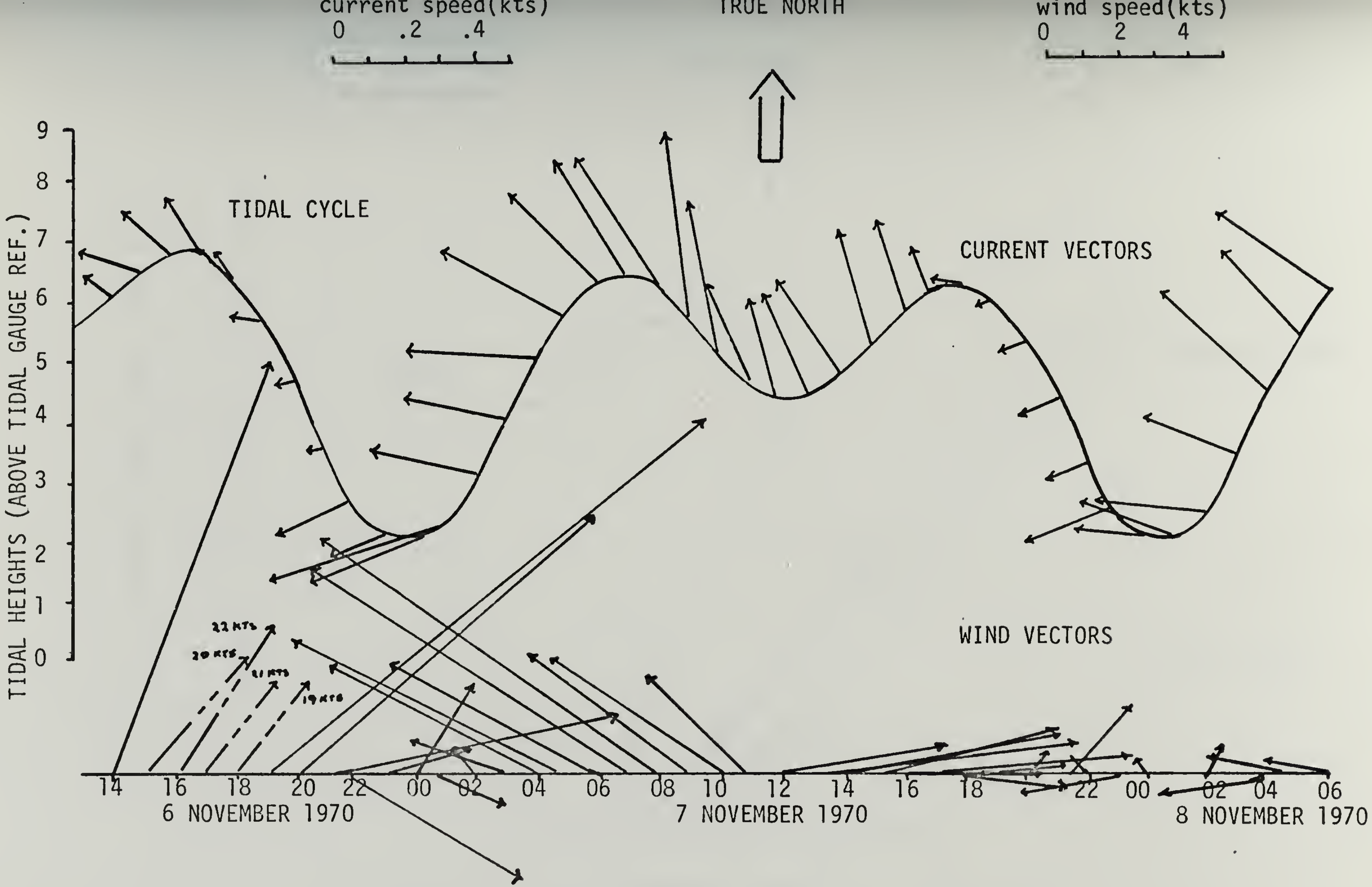

Figure 45. Drogue #28 Current-Wind-Tide Correlation

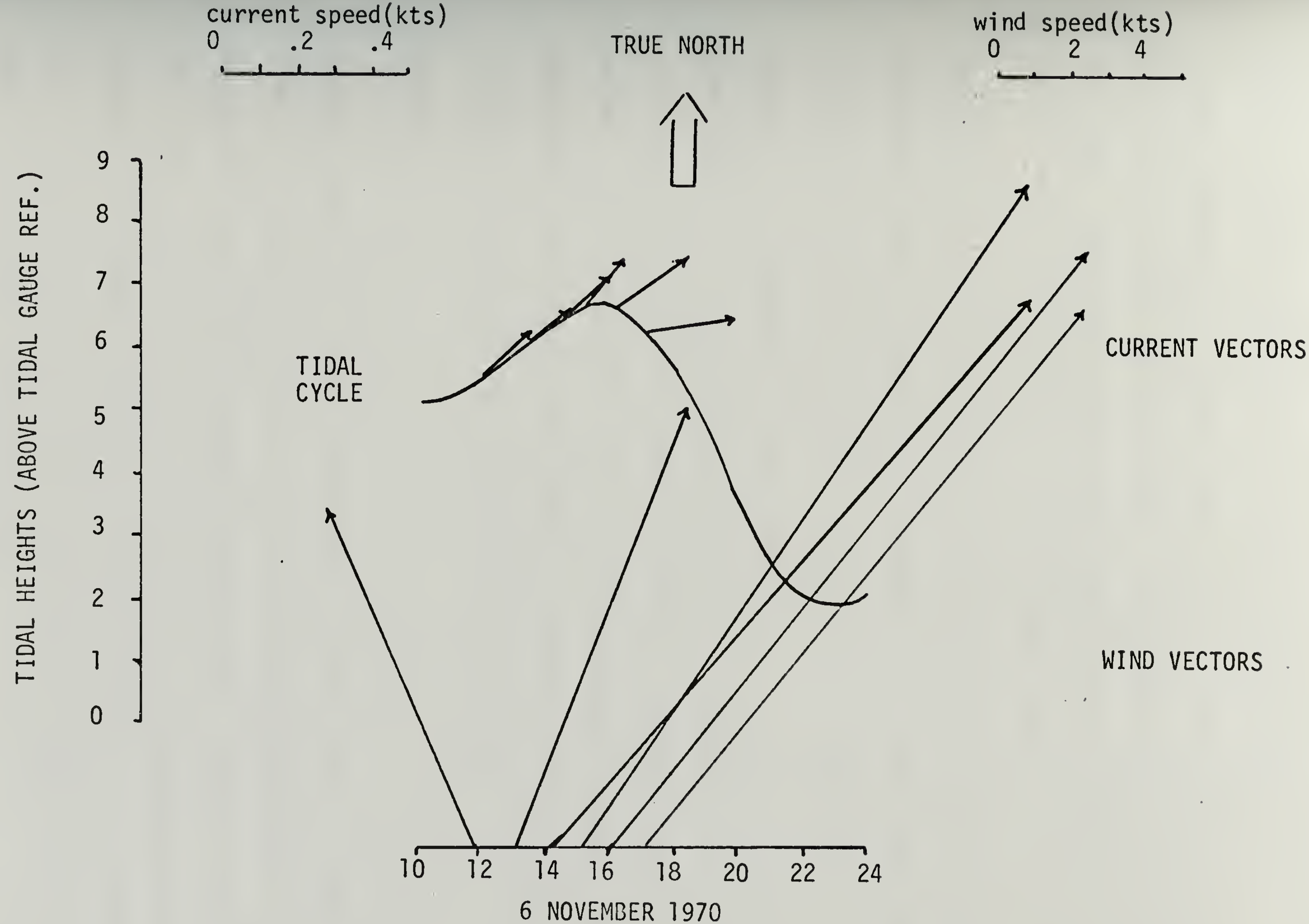

Figure 46. Drogue #29 Current-Wind-Tide Correlation

tide, with the possible additional impetus of a branch of the Davidson Current swinging into the Bay to form a clockwise gyre.

Drogues #30 and #31 - These drogues generally followed the pattern exhibited by drogue #28, but appear to be somewhat more influenced by the tides. The winds, being quite variable over the time span, do not seem to play an important role in the drogue movement.

Drogue #32 - During this drogue's very short track, it moved to the southeast from its position on the southern rim of the Canyon. Radar contact was lost when it drifted into the western shadow zone.

Drogue #33 - Drogue #33, placed in the water about ten kilometers out the Canyon axis from Moss Landing, moved in a clockwise spiral out from its initial position. The floods and ebbs of the tidal cycle were probably the cause of this spiral, but the accompanying graph shows that they were out of phase with the drogue's movements. Again, maybe an offshoot of the Davidson Current controlled this track.

November 10-13:

Drogues #34 - #38 - All of these drogues, planted north and west of Pt. Pinos, rapidly moved behind Pt. Pinos on southwesterly courses. The tides appeared to have little influence upon the tracks. The wind for tracks #35 - #38, though, was blowing strongly out of the northeast, and probably affected the drogues significantly. This possibly was in conjunction with a movement of the California Current back in toward the coast overpowering the weakened Davidson Current.

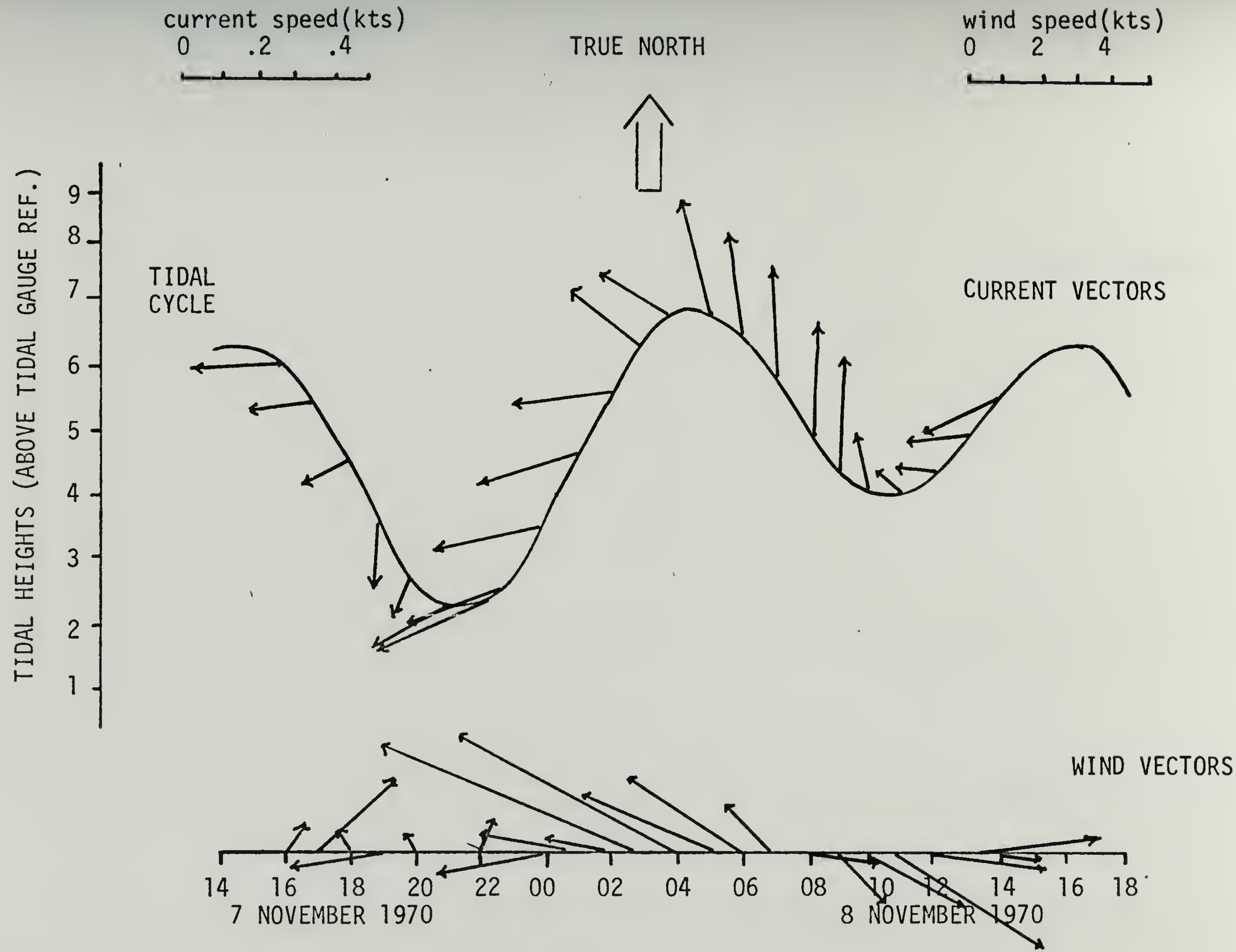

Figure 47. Drogue #30 Current-Wind-Tide Correlation

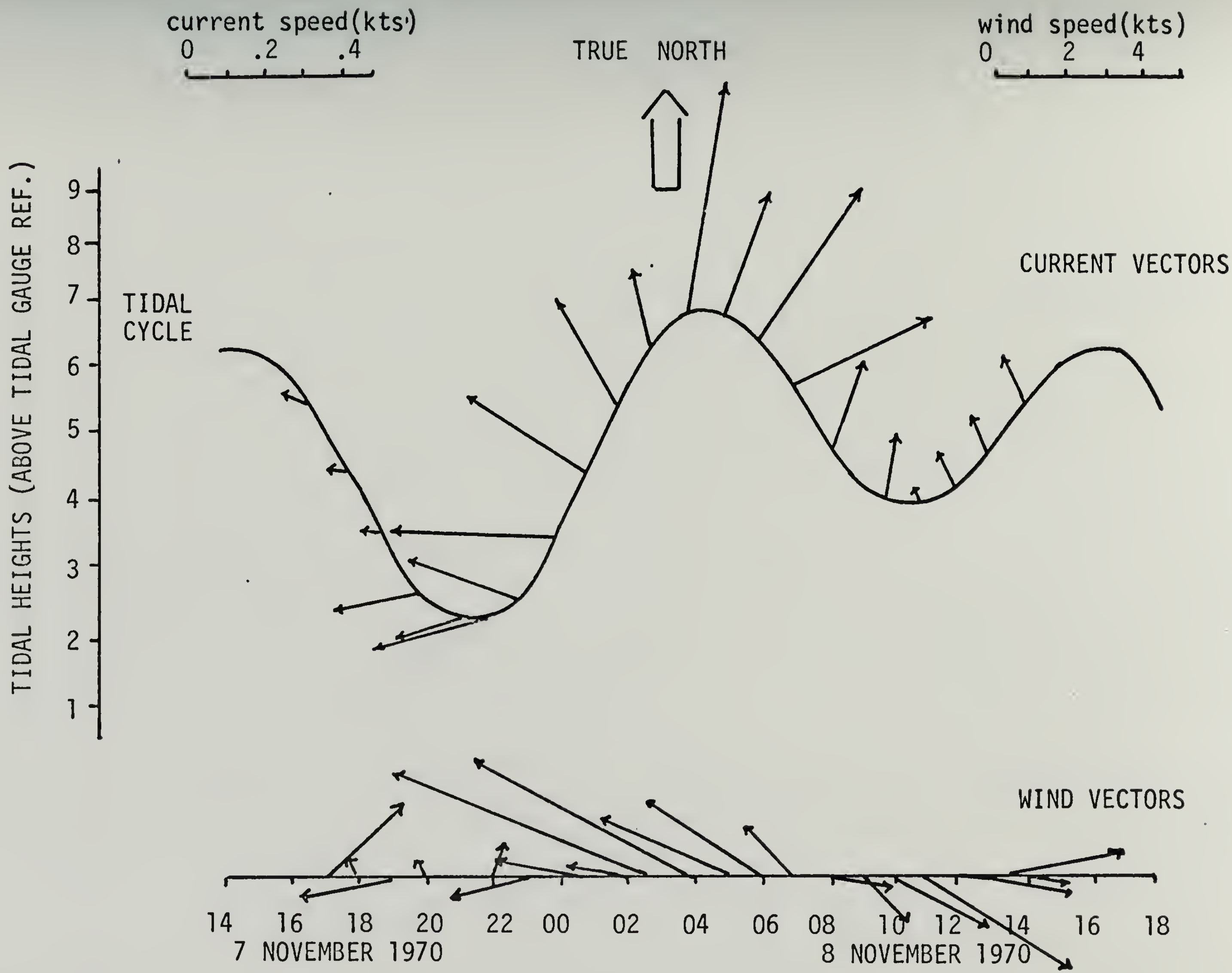

Figure 48. Drogue #31 Current-Wind-Tide Correlation

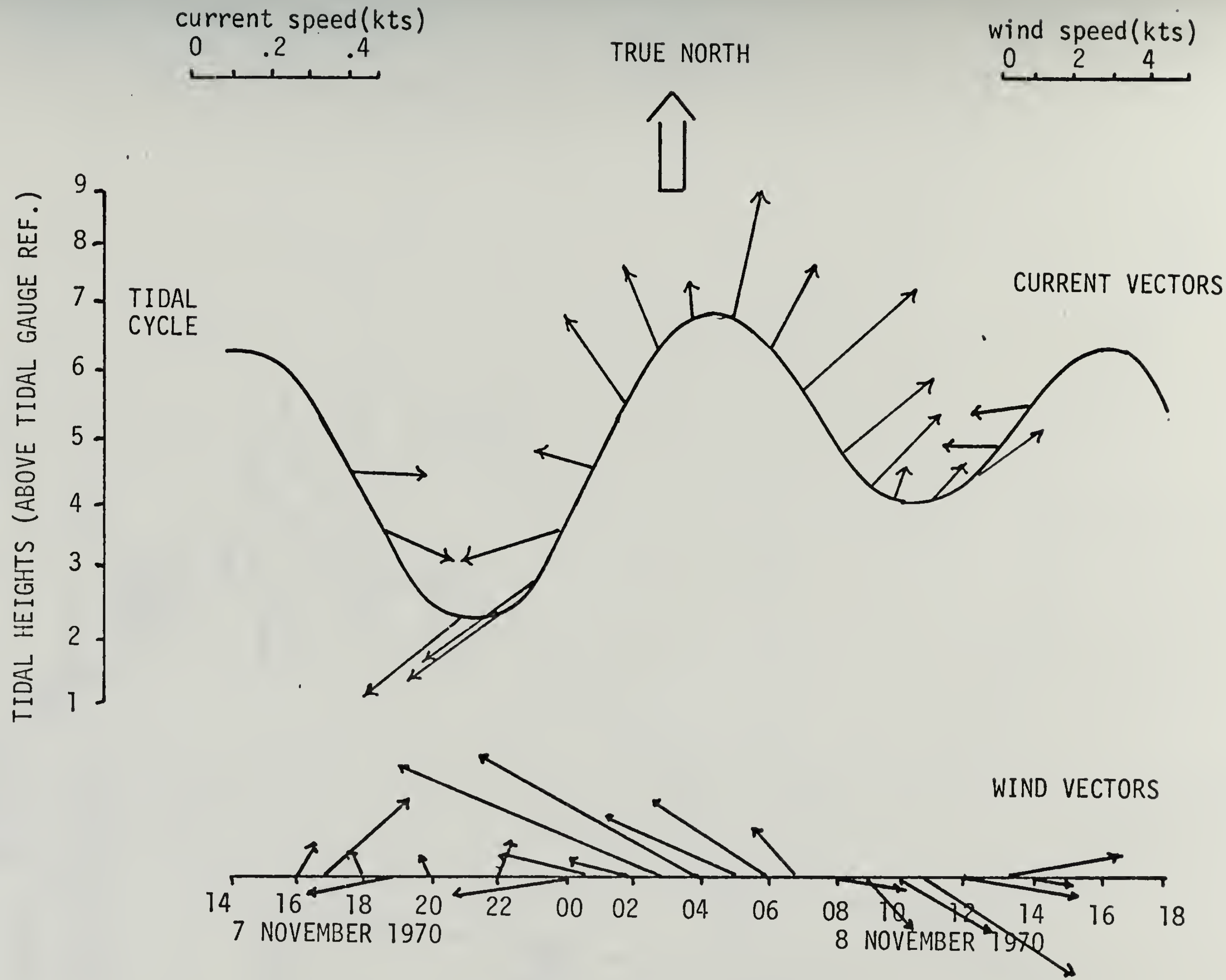

Figure 49. Drogue #33 Current-Wind-Tide Correlation

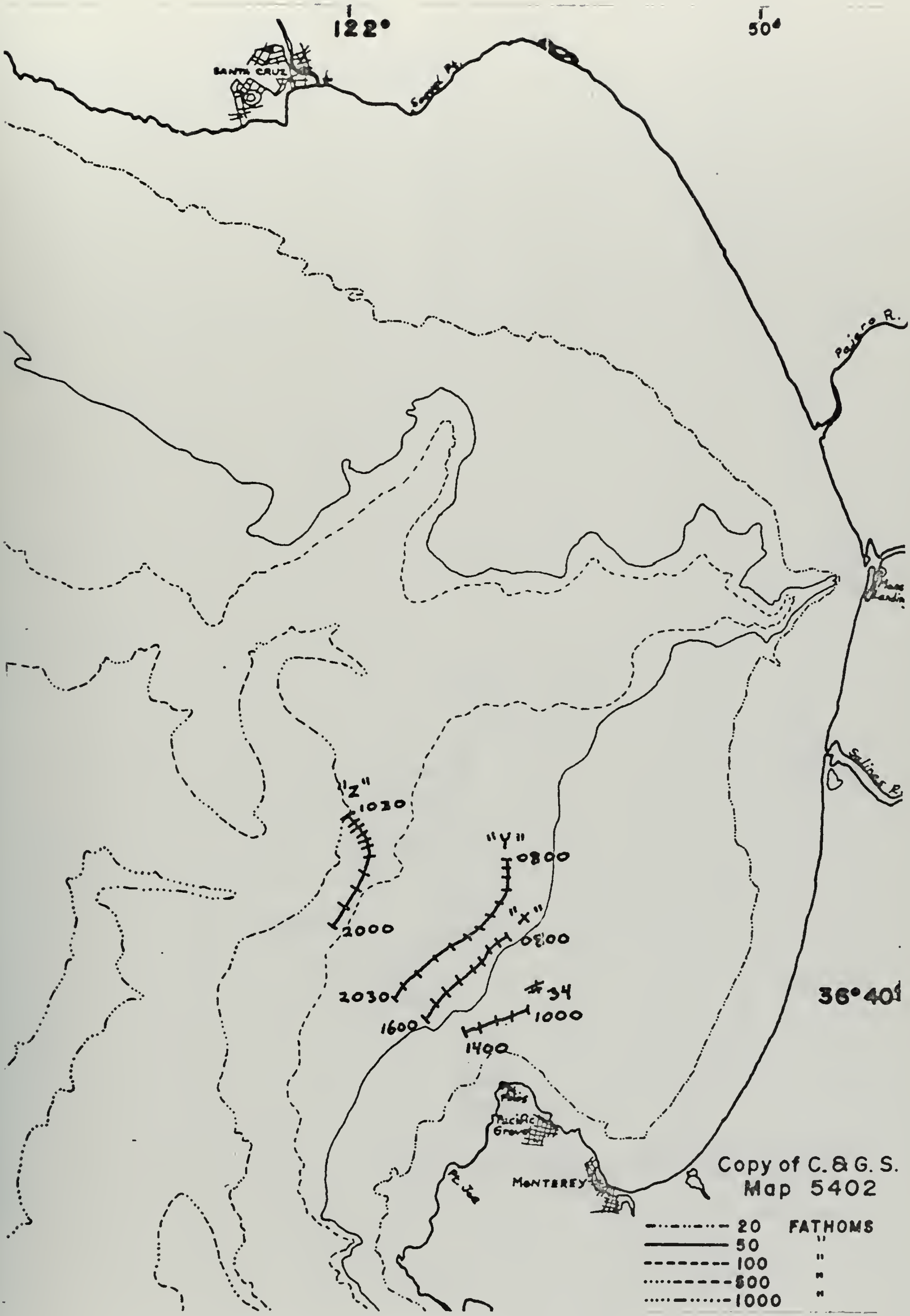

Figure 50. Drogue Tracks 34, "X", "Y", "Z"

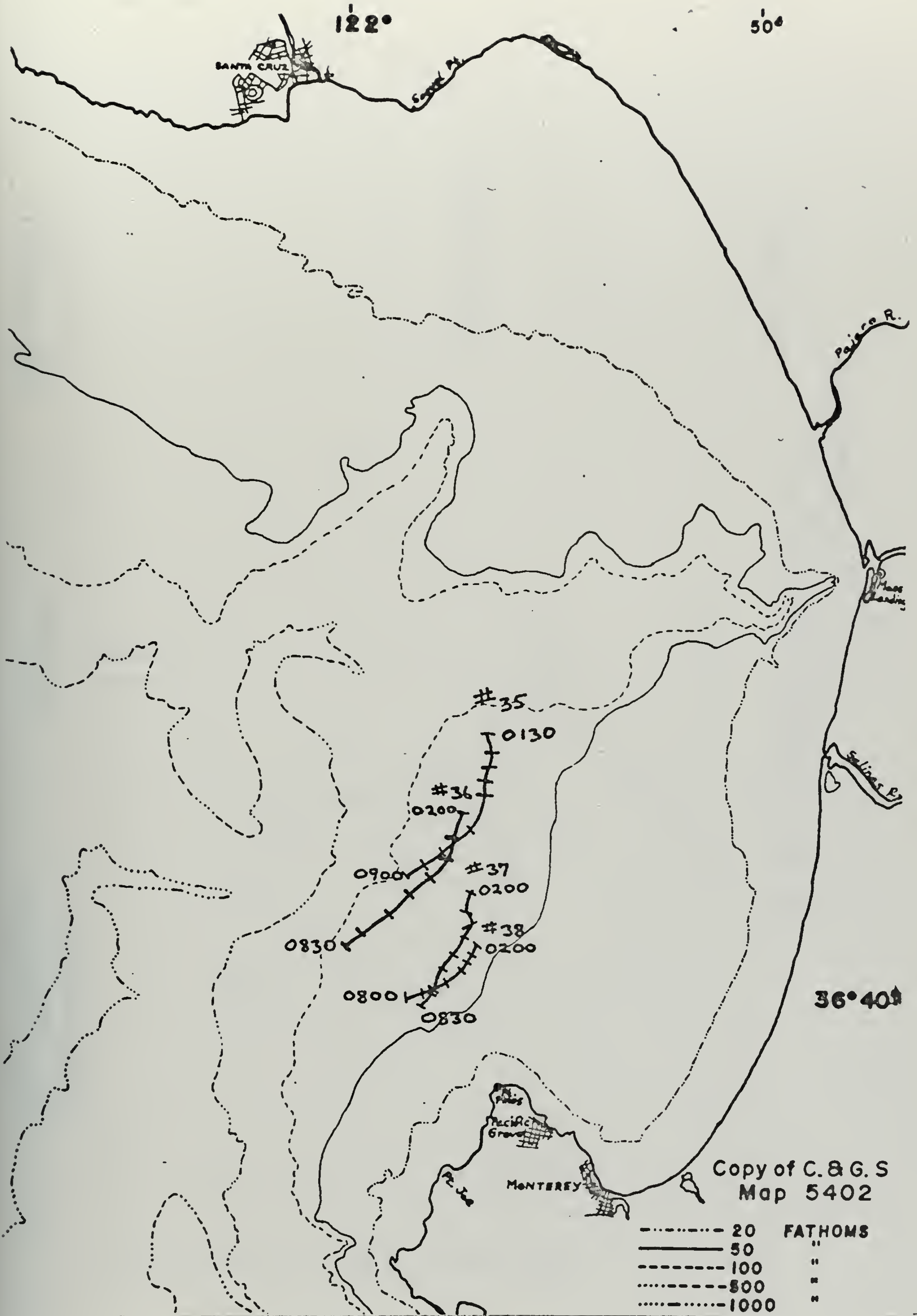

Figure 51. Drogue Tracks 35 - 38

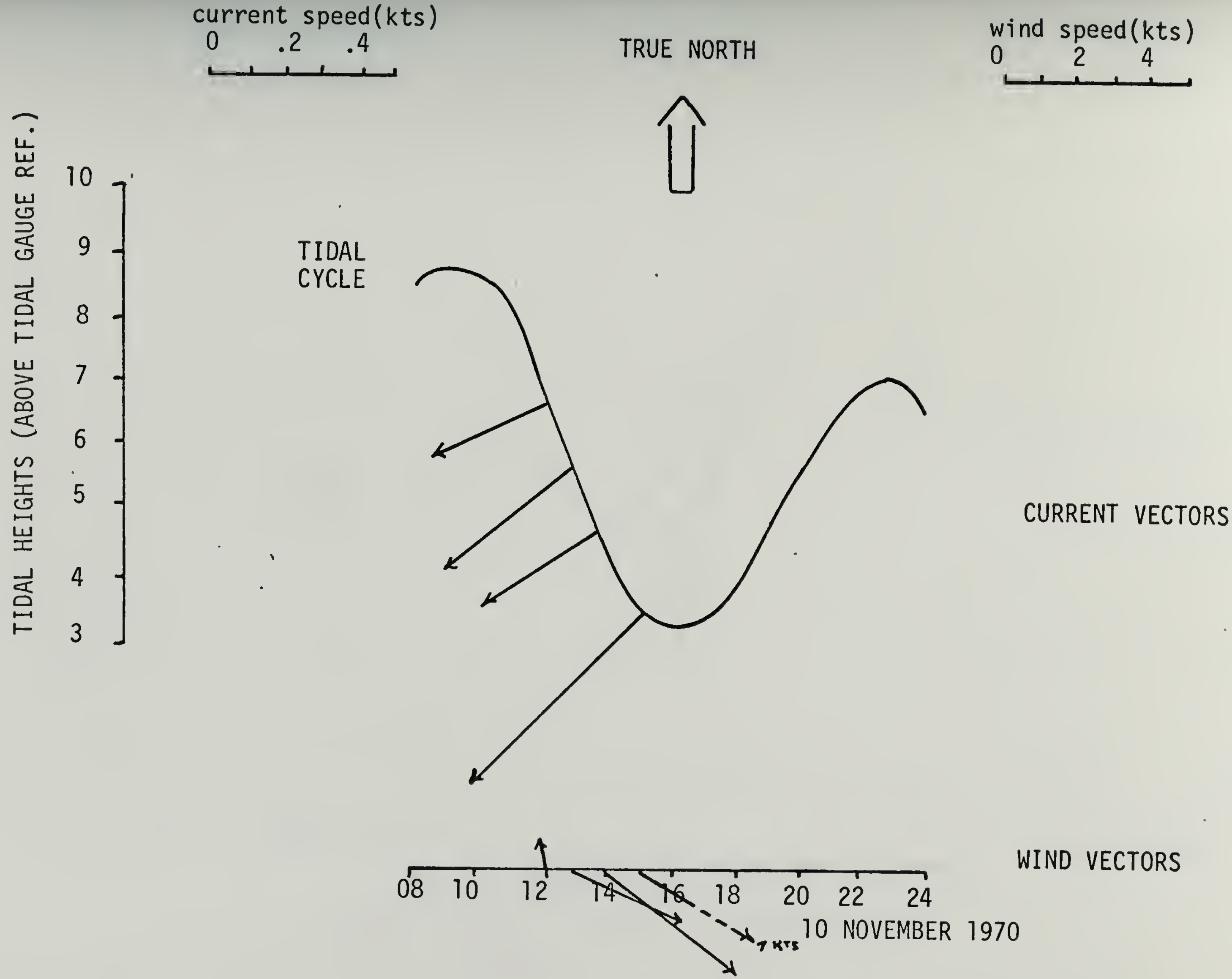

Figure 52. Drogue #34 Current-Wind-Tide Correlation

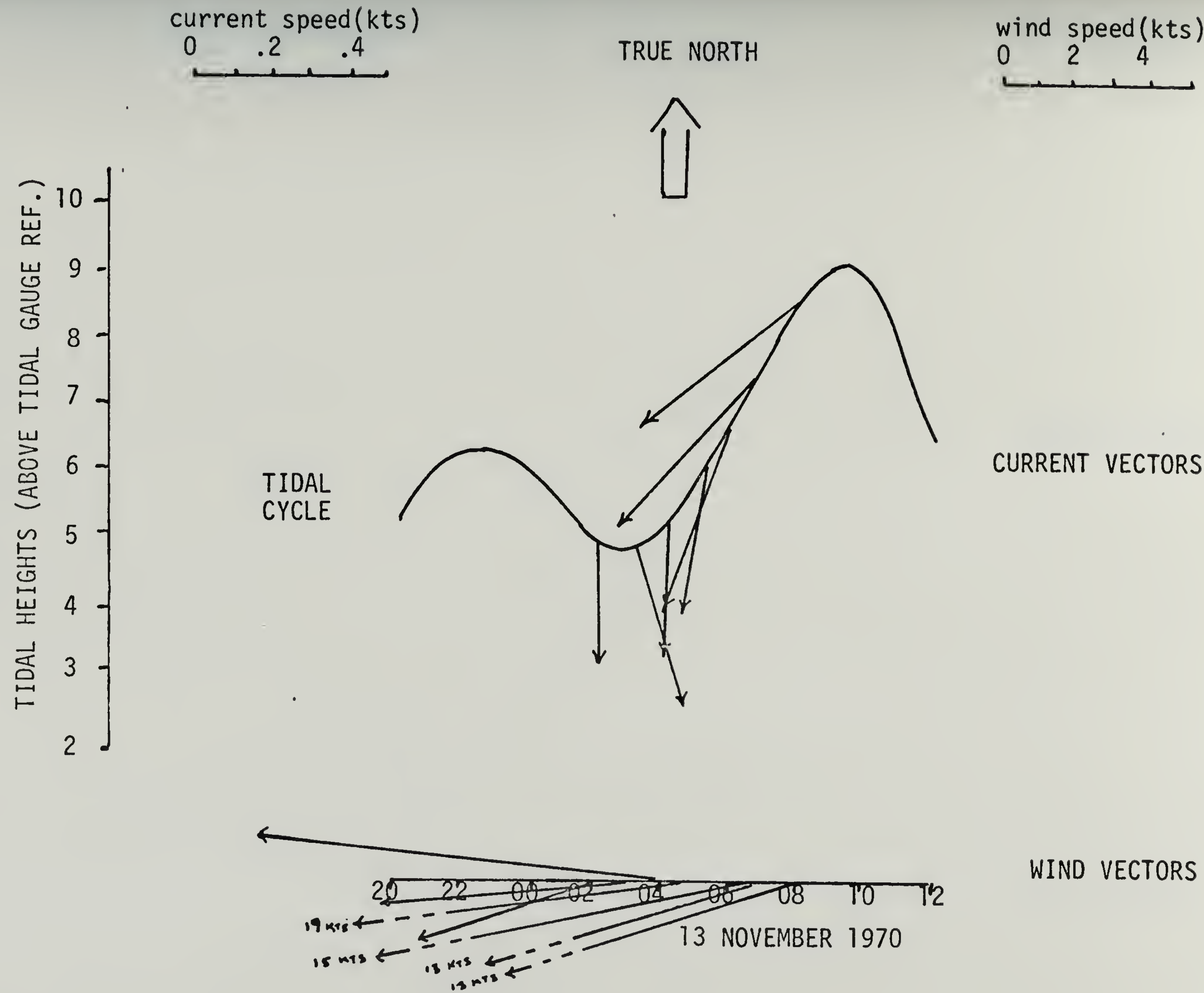

Figure 53. Drogue #35 Current-Wind-Tide Correlation

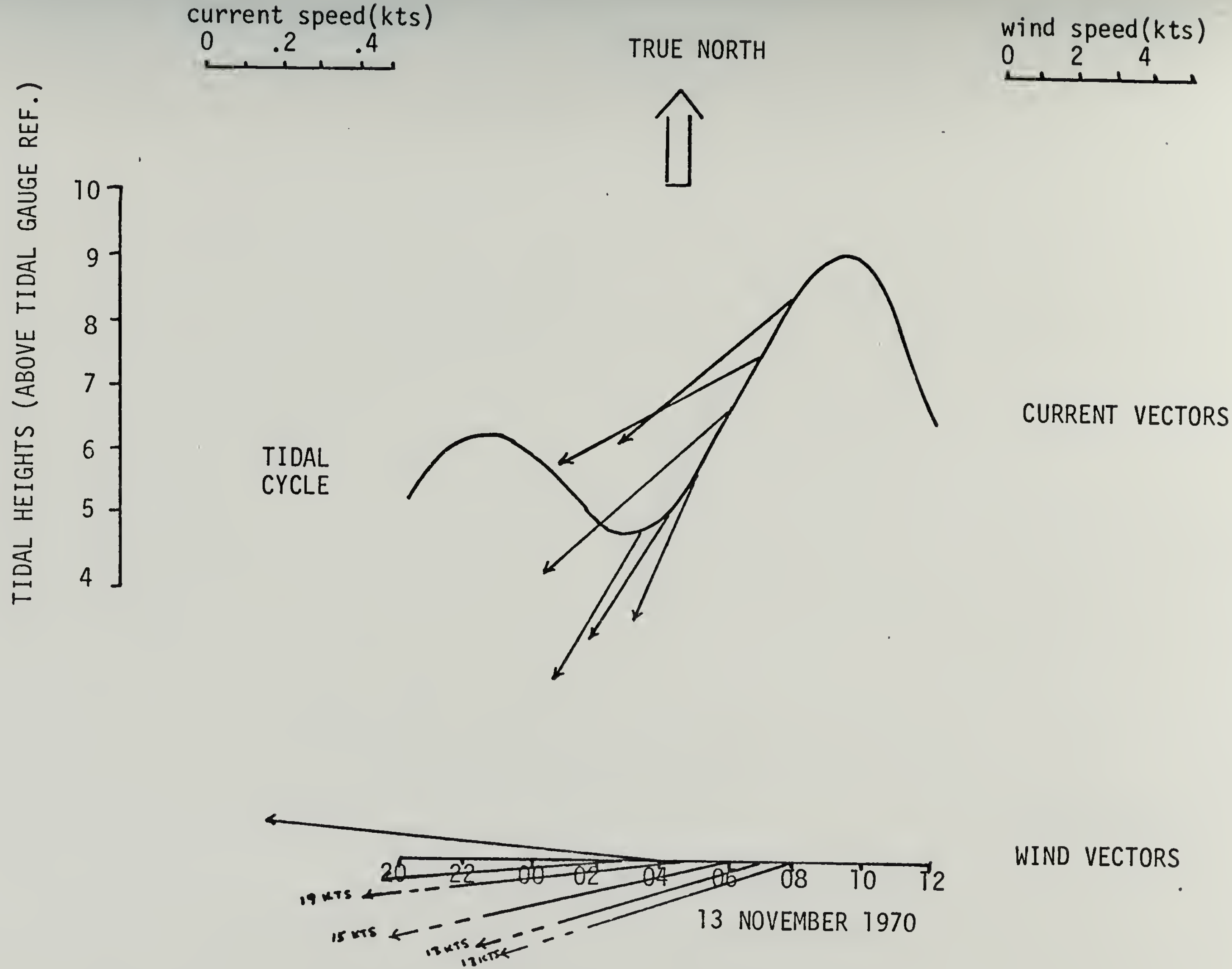

Figure 54. Drogue #36 Current-Wind-Tide Correlation

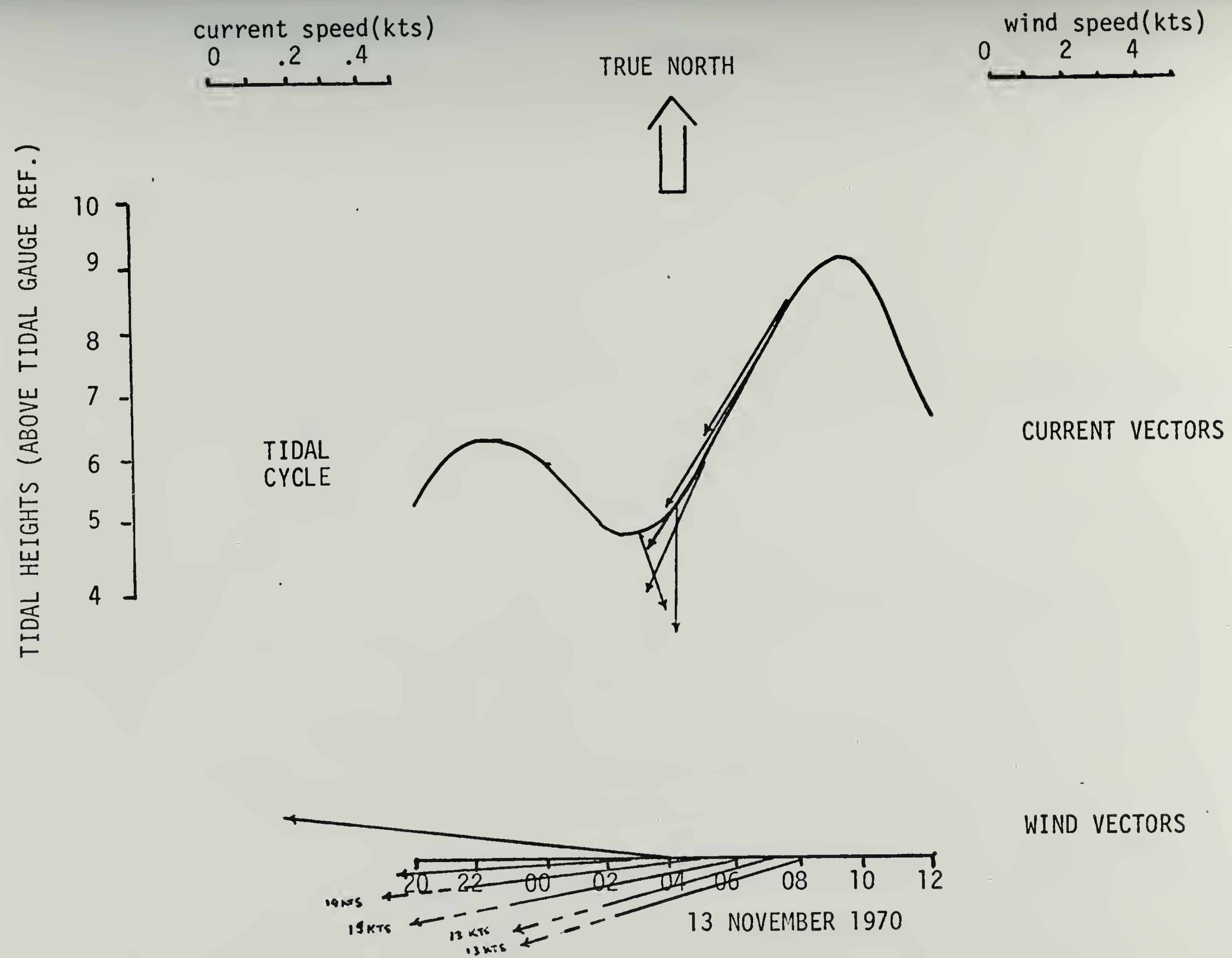

Figure 55. Drogue #37 Current-Wind-Tide Correlation

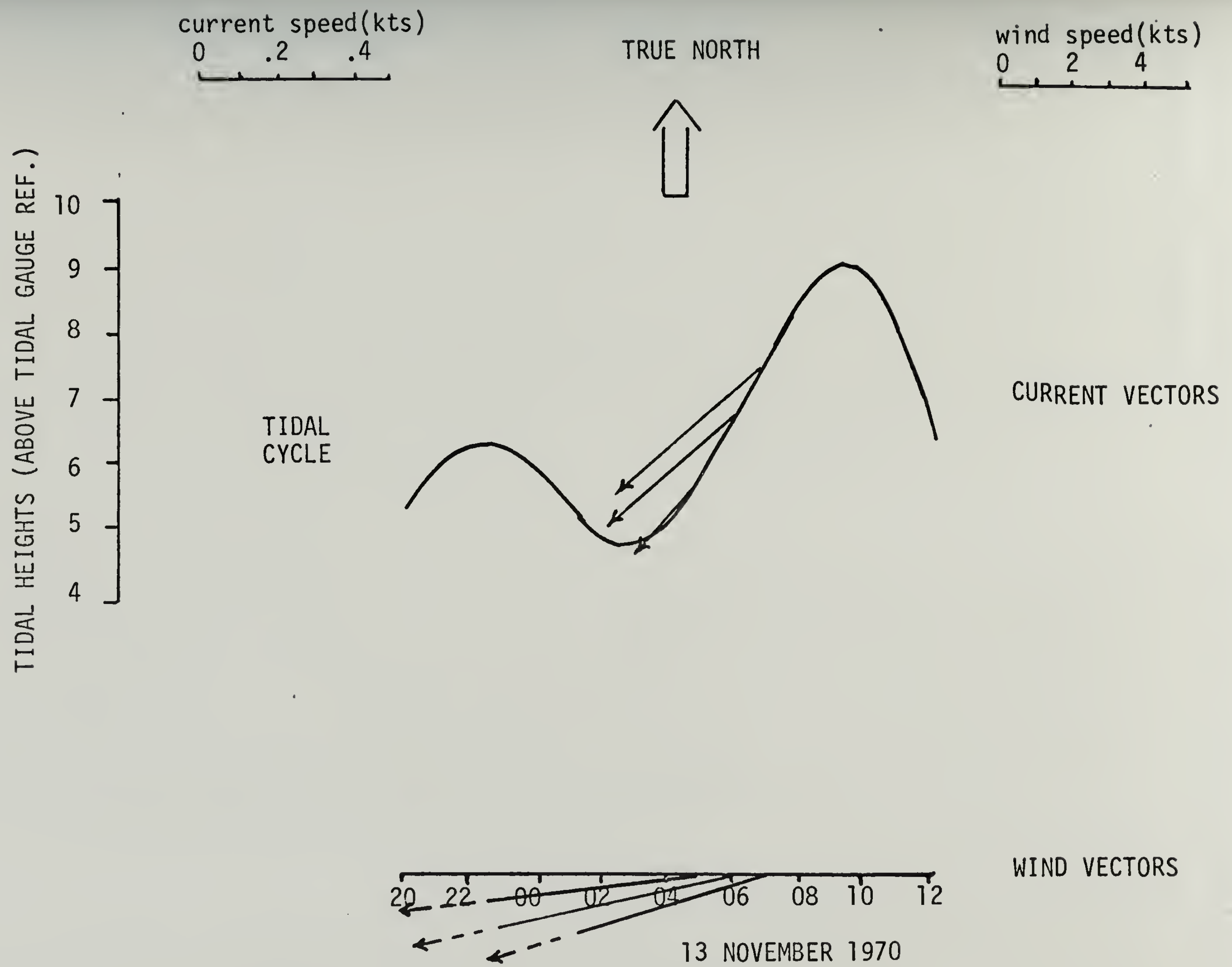

Figure 55. Drogue #38 Current-Wind-Tide Correlation

<u>Drogues "X", "Y" and "Z"</u> - These three drogues were picked up on radar on 10 November. They were three of the six drogues launched and tracked during the 6-8 November period. Their tracks closely resembled those of the #34 - #38 drogues.

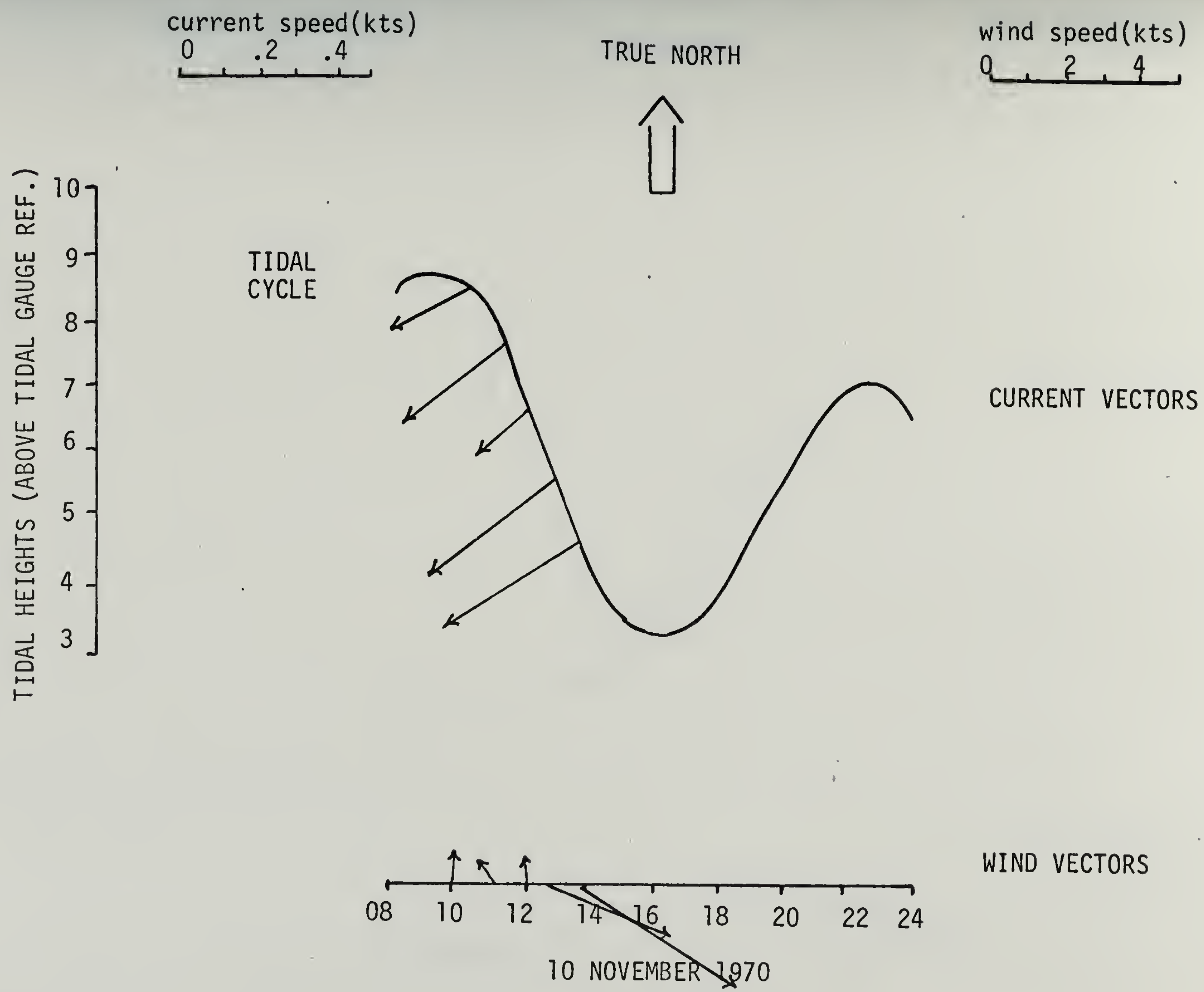

Figure 57. Drogue "X" Current-Wind-Tide Correlation

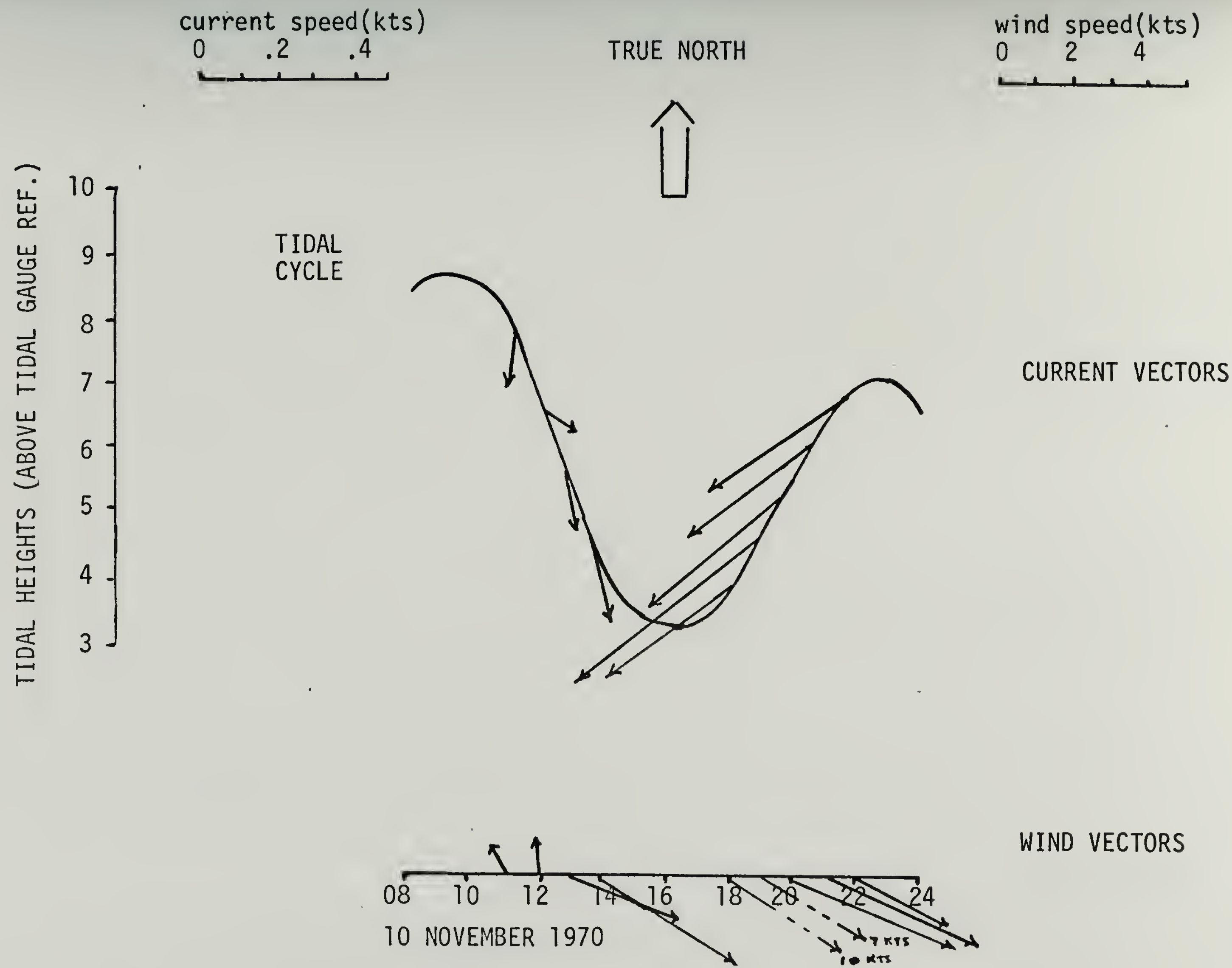

Figure 58. Drogue "Y" Current-Wind-Tide Correlation

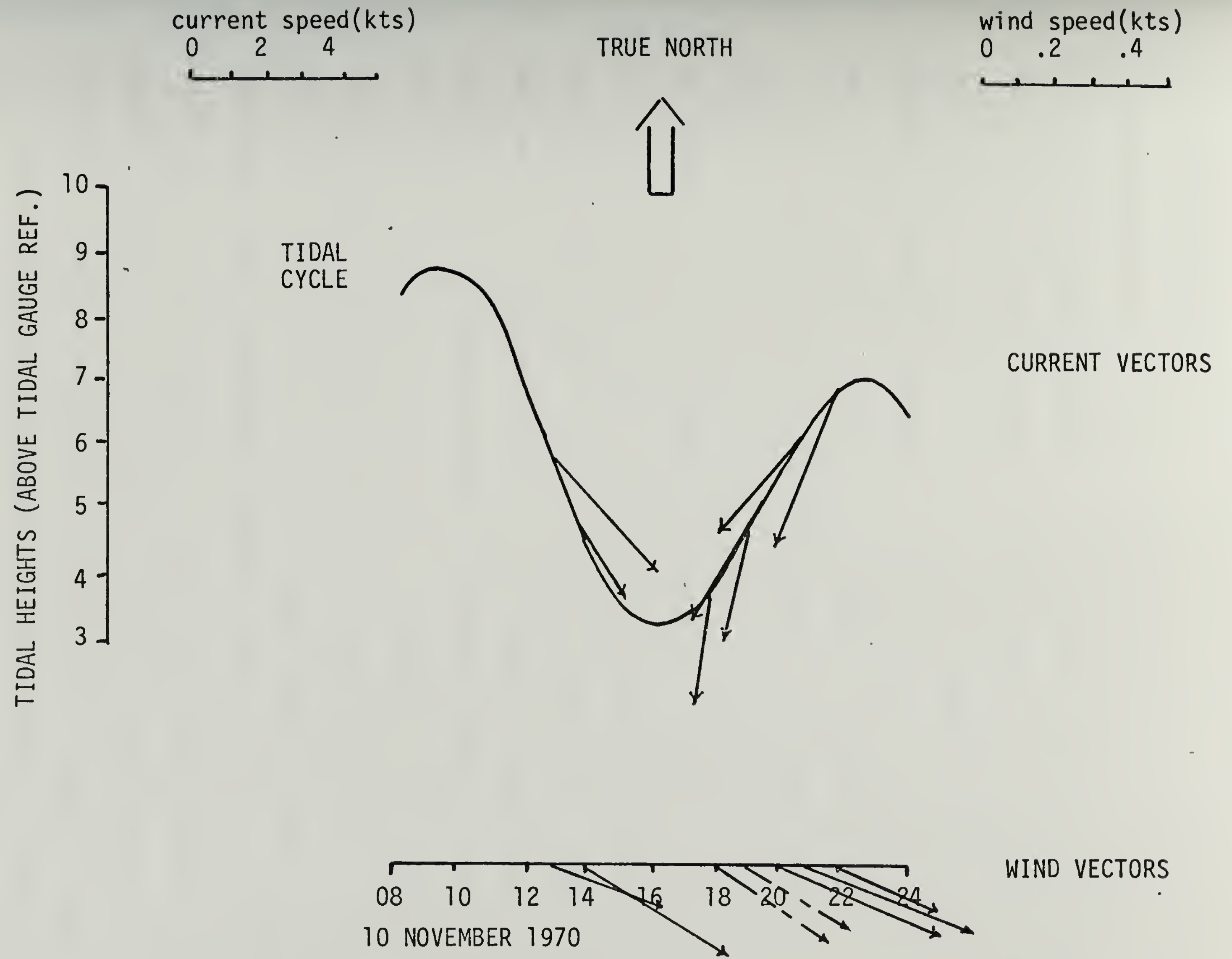

Figure 59. Drogue "Z" Current-Wind-Tide Correlation

VI. RESULTS AND CONCLUSIONS

A. SYSTEM FEASIBILITY

Although the feasibility study was not fully completed, i.e. transponder-equipped drogues were not seeded and tracked, it is felt that the success of the AN/SPS-10 radar system in tracking the drogues (equipped with corner reflectors) and the successful testing of the AN/DPN-78 transponder combined to make the system a viable method for use in the study of the surface circulation in the entire Bay.

The parachute drogue system performed satisfactorily throughout the study. It proved to be a durable system, performing well in winds up to 22 knots, and in estimated state 3-4 seas. The only buoy failures occurred during the October study period. Buoys 23, 24 and 25 had mast buckling failures under force four winds (13-16 knots). These failures were caused by a lack of internal reinforcement for the masts, which was the result of an unavailability of wooden doweling at the time. The final disposition on the 35 other drogues was: nine drogues drifted outside radar contact behind Point Pinos; radar contact was lost with four drogues due to long range; ten drogues were lost when they drifted into shadow zones; two drogues were lost when high sea return precluded maintenance of radar contact; six drogue tracks were terminated due to operator fatigue; and one drogue was lost for no known reason (It was tracking at a medium range outside of shadow zone areas when lost.).

The MK 25 MOD 3 and the AN/SPS-10E radar systems both showed the capability of tracking drogues under moderate sea and weather conditions throughout the Bay. The fire control radar, when operated with an "X"

band radar transponder, gave full coverage of the Bay (Although the transponder was not mounted on a buoy, the placement of one aboard the research vessel with its antenna at the normal buoy masthead height, indicated this capability). The surface search radar was both range-limited (approximately 28,000 m) and hindered by shadow zones when operated with the passive corner reflector, but (noting its range capabilities), if it is utilized in conjunction with a "C" band transponder, it will give full coverage of the Bay also.

The SPS-10 PPI presentation was generally excellent throughout the tracking periods, although there were sea and weather limitations. The minimum tracking range was about 2500 m. The antenna's angle of depression at close range, looking seaward from the roof of Spanagel Hall, is such that an extreme amount of sea return blanks out the target area. As the sea conditions worsen, this minimum detection range increases. Several drogues were lost during this study because of high sea return. Heavy storm clouds can also affect the presentation. On one occasion several hours of track were lost due to cloud interference.

An error study was made on the accuracy of the surface search radar. Over a twelve hour period, bearing and range to two fixed buoys were taken at half hour intervals and then compared with the charted positions. The results are shown in Appendix D. The bearing accuracy was excellent. The maximum error was one degree, and the mean error about 0.3 degree. The specifications for the radar give the bearing resolution as less than one degree. The maximum range error was 320 m with the mean range error about 295 m. The radar specifications give long pulse range resolution as 251.5 m. This accuracy is outstanding taking into effect: meandering

of buoy mooring; possible error in chart position of drogue; radar operator error; and lack of knowledge of exact charted position of the radar antenna (this was estimated).

An error study was not made of the MK 25 radar because of its classification. One definite source of error not inherent in the system is the radar mounting. Usually in a shipboard installation the radar is mounted atop a MK 37 Gun Director. At the School, the radar is mounted on a pre-WW II 36" search light pedestal (Navy Type 36-20). In the electrical system involved with this configuration, there is a certain amount of error in the bearing accuracy.

B. SURFACE CIRCULATION

Monterey Bay, being a wide embayment open to the sea, must be considered to have a very complex surface circulation system. There are multiple driving mechanisms which can effect the circulation at any one time. These factors will vary hourly, diurnally and seasonally, with one mechanism at times dominating the others.

In this study, 38 drogue tracks, compiled over a four month period, August - November 1970, were analyzed to glean the generalized current patterns at the time of the track study. The study was necessarily limited to the southern half of the Monterey Bay. The correlations of the drogue tracks to the winds, tides and oceanic currents was investigated.

In general, the drogue tracks indicated that when the California Current moved near to the coast in the late summer and early fall, this oceanic current became a dominating current driving mechanism, particularly in the outer waters of the Bay. In the late fall, when the Davidson Current prevailed off the coast, it in turn, became a dominant

current driving mechanism. These two oceanic currents appeared to set up gyres within the Bay, clockwise for the Davidson Current and counter-clockwise for the California Current.

Within the confines of the inner Bay, the effects of the tidal cycle were very apparent. Local tidal eddies often were formed. Farther out in the Bay, the effects of the tide became less and less.

In general, it appeared that the effects of the local winds were not too important in driving the currents. They did become important though, when the wind remained prevalent from a specific direction over an extended period of time.

These conclusions can not be considered hard and fast, since they were based on analysis made over a relatively short period of time. As discussed in Chapter VII, it is recommended that a thorough drogue study be initiated over the time span of a full year to corroborate or refute these conclusions, and to analyze the conditions which exist during the upwelling season as well.

VII. RECOMMENDATIONS

In that the Postgraduate School's radar installation has proven to be a useful tool, in conjunction with parachute drogues, to help study the surface circulation in the Bay, it is felt that further more detailed applications of this system should be employed. A long range study, planned over a period of a full year, should be initiated to witness the full effects of seasonal variations upon the surface current patterns. Each tracking interval should be at least 24 hours in duration in order to obtain the effects of the full tidal cycle.

To fully employ the advantages given by the use of radar transponders, it is recommended that AN/DPN-77 units be utilized for this long range study. This transponder model operates in the "C" band, and thus is compatible with the AN/SPS-10E radar system. As a result, multiple transponder-equipped drogues could be tracked simultaneously. A synoptic analysis could therefore be made of the entire Bay.

For a study of the surface circulation in a small area of the Bay, e.g. to study the current pattern in the area of a proposed sewage outfall, the MK 25 radar could be used with a single AN/DPN-78 equipped drogue. By integrating a simple X-Y plotter into the radar's tracking system, it would be possible to use the system's automatic tracking mode to alleviate the requirement for constant vigilance by a radar operator over an extended period of time.

Any study utilizing transponder-equipped drogues will require close liaison with the School's research vessel. During the study just completed,

the drogues were considered expendable after the completion of each tracking period. Future studies though will require that the expensive transponder packages be retrieved after each tracking run.

APPENDIX A

DROGUE COURSE/SPEED DATA

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue #1:	121800 Aug.	088	0.70
	1900	046	0.70
	2000	099	0.50
	2100	112	0.40
	2200	124	0.30
	2300	114	0.25
	130000	152	0.15
	0100	144	0.25
	0200	134	0.40
	0300	166	0.34
	0400	179	0.20
	0500	187	0.10
	0600	198	0.15
	0700	218	0.10
	0800	162	0.05
Drogue #2:	122000 Aug.	328	0.20
	2100	285	0.30
	2200	275	0.20
	2300	267	0.10
	130000	255	0.30
	0100	255	0.20
	0200	255	0.10
	0300	298	0.25
	0400	274	0.25
	0500	272	0.20
	0600	258	0.34
	0700	237	0.05
	0800	201	0.10
	0900	167	0.20
Drogue #3:	No track (never gained contact)		
Drogue #4:	130200 Aug.	143	0.15
	0300	130	0.15
	0400	156	0.10
	0500	160	0.10
	0600	182	0.15
	0700	191	0.10
	0800	026	0.10
	0900	028	0.10
	1000	030	0.15

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue #5:	130200 Aug.	132	0.40
	0300	169	0.40
	0400	150	0.34
	0500	168	0.20
	0600	175	0.15
	0700	135	0.15
	0800	094	0.20
	0900	097	0.20
Drogue #6:	182100 Aug.	112	0.25
	2200	090	0.25
	2300	124	0.20
	190000	238	0.175
	0100	221	0.20
	0200	215	0.25
	0300	120	0.075
	0400	132	0.125
	0500	043	0.10
	0600	097	0.075
	0700	065	0.025
	0800	056	0.30
	0900	069	0.225
	1000	130	0.30
	1100	134	0.25
	1200	144	0.375
	1300	143	0.20
	1400	132	0.225
	1500	133	0.275
Drogue #7:	182100 Aug.	017	0.225
	2200	074	0.125
	2300	334	0.20
	190000	327	0.20
	0100	342	0.30
	0200	019	0.275
	0300	031	0.40
	0400	034	0.275
	0500	034	0.20
	0600	034	0.425
	0700	069	0.50
	0800	101	0.425
	0900	107	0.50
	1000	163	0.25
	1100	200	0.225
	1200	096	0.225
	1300	081	0.15
	1400	084	0.275
	1500	143	0.20

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue #8:	182200 Aug.	034	0.20
	2300	353	0.325
	190000	328	0.225
	0100	328	0.275
	0200	003	0.45
	0300	030	0.20
	0400	071	0.20
	0500	089	0.275
	0600	080	0.15
	0700	087	0.125
	0800	090	0.25
Drogue #9:	182215 Aug. No track (lost contact after 15 min.)		
Drogue #10:	182300 Aug.	214	0.175
	190000	252	0.40
	0100	285	0.175
	0200	356	0.30
	0300	003	0.45
	0400	037	0.15
	0500	065	0.275
	0600	093	0.175
	0700	087	0.175
	0800	146	0.20
	0900	165	0.25
	1000	180	0.375
	1100	207	0.40
	1200	235	0.325
	1300	237	0.225
	1400	263	0.05
Drogue #11:	182300 Aug. Very short track. Moved due south 250 yds., 2300-2400. Shifted to approximate head 250 for 30 min. covering 200 yds. Reversed track to about 070 for 2 hrs. covering 400 yds. Lost contact at 190230 (shadow zone?).		
Drogue #12:	190000 Aug.	230	0.275
	0100	229	0.325
	0200	261	0.425
	0300	293	0.275
	0400	026	0.40
	0500	056	0.425
	0600	012	0.375
	0700	064	0.30
	0800	117	0.175

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue #13:	190000 Aug.	355	0.125
	0100	292	0.30
	0200	305	0.075
	0300	272	0.05
	0400	028	0.075
	0500	055	0.125
	0600	016	0.175
	0700	068	0.325
Drogue #14:	310900 Aug.	209	0.10
	1000	193	0.275
	1100	204	0.20
	1200	197	0.20
	1300	193	0.175 [4]
	----	---	-----
	010100 Sept.	193	0.075
	0200	184	0.10
	0300	195	0.10
	0400	207	0.10
	0500	207	0.075
	0600	192	0.075
	0700	162	0.05
	0800	132	0.225
	0900	184	0.25
Drogue #15:	310900 Aug.	225	0.325
	1000	219	0.30
	1100	266	0.375
	1200	258	0.225
	1300	264	0.15
	1400	273	0.30
	1500	277	0.25
	1600	305	0.125
	1700	302	0.125
	1800	298	0.175
	1900	277	0.34
	2000	290	0.10

Drogue #16: Tracked to the southwest for 30 min. Lost contact behind Pt. Pinos.

[4] Interrupted track

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue #17:	311000 Aug.	211	0.275
	1100	193	0.125
	1200	130	0.075
	1300	085	0.075
	1400	130	0.25
	1500	134	0.20
	1600	151	0.225
	1700	155	0.25
	1800	216	0.20
	1900	287	0.175
	2000	222	0.20
	2100	219	0.15
	2200	248	0.225
	2300	251	0.15
	010000 Sept.	235	0.10
	0100	222	0.10
	0200	199	0.125
	0300	209	0.20
	0400	196	0.25
	0500	201	0.275
Drogue #18:	311100 Aug.	246	0.325
	1200	252	0.275
	1300	323	0.175
	1400	041	0.125
	1500	072	0.225
	1600	116	0.225
	1700	078	0.30
	1800	109	0.15
	1900	120	0.25
	2000	125	0.25
	2100	103	0.30
	2200	133	0.275
	2300	106	0.225
	010000 Sept.	152	0.15
	0100	188	0.05
	0200	188	0.05
	0300	165	Negligible
	0400	165	Negligible
	0500	165	Negligible
	0600	165	Negligible
	0700	135	0.05
	0800	132	0.10

Drogue #19: Tracked to the southeast for several hours. Lost contact (reason unknown).

Drogue #20: No track (lost contact after 1 1/2 hours — minimal movement).

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue #21:	311200 Aug.	323	0.2
	1300	357	0.2
	1400	056	0.34
	1500	058	0.3 [5]
	----	---	---
	010000 Sept.	207	0.125
	0100	220	0.125
	0200	213	0.15
Drogue #22:	311300 Aug.	278	0.275
	1400	322	0.25
	1500	020	0.375
	1600	060	0.34
	1700	101	0.375 [5]
	----	---	----
	2100	080	0.375
	2200	082	0.25
	2300	083	0.10
	010000 Sept.	206	0.15
	0100	202	0.175
	0200	170	0.15
	0300	183	0.15
	0400	195	0.125
	0500	195	0.10
	0600	195	0.125
	0700	218	0.225
	0800	219	0.175
Drogue #23:	060900 Oct.	068	0.60
	1000	057	0.50
	1100	061	0.45
	1200	081	0.375
	1300	084	0.40
	1400	093	0.30
	1500	121	0.225
	1600	118	0.325
	1700	193	0.20
Drogue #24:	061000 Oct.	060	0.525
	1100	055	0.50
	1200	055	0.30
	1300	055	0.25
	1400	077	0.225
	1500	114	0.175

[5] Interrupted track

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue #25:	061000 Oct.	052	0.65
	1100	055	0.25
	1200	055	0.075
	1300	055	0.075
	1400	350	0.15
	1500	043	0.30
Drogue #26:	061100 Oct.	025	0.375
	1200	050	0.325
	1300	003	0.05
Drogue #27:	061100 Oct.	001	0.50
	1200	019	0.40
	1300	052	0.425
	1400	106	0.30
Drogue #28:	061300 Nov.	310	0.275
	1400	310	0.125
	1500	290	0.20
	1600	311	0.20
	1700	327	0.20
	1800	327	0.10
	1900	281	0.10
	2000	257	0.05
	2100	257	0.05
	2200	244	0.25
	2300	246	0.175
	070000	248	0.325
	0100	253	0.425
	0200	283	0.333
	0300	280	0.325
	0400	273	0.375
	0500	298	0.40
	0600	315	0.375
	0700	327	0.40
	0800	330	0.475
	0900	352	0.55
	1000	348	0.45
	1100	338	0.325
	1200	342	0.30
	1300	336	0.325
	1400	327	0.325
	1500	342	0.34
	1600	342	0.275
	1700	336	0.125
	1800	277	0.10
	1900	250	0.05
	2000	248	0.10
	2100	247	0.15
	2200	247	0.15
	2300	247	0.275

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue #28 (cont'd)	080000	276	0.225
	0100	290	0.30
	0200	275	0.325
	0300	292	0.30
	0400	314	0.425
	0500	316	0.34
	0600	304	0.40
Drogue #29:	061200 Nov.	048	0.175
	1300	048	0.175
	1400	051	0.20
	1500	040	0.15
	1600	056	0.25
	1700	082	0.25
Drogue #30:	071800 Nov.	268	0.25
	1900	263	0.175
	2000	244	0.15
	2100	183	0.20
	2200	207	0.125
	2300	241	0.225
	080000	249	0.30
	0100	248	0.275
	0200	258	0.325
	0300	253	0.30
	0400	263	0.275
	0500	311	0.25
	0600	302	0.225
	0700	345	0.325
	0800	352	0.30
	0900	358	0.325
	1000	002	0.325
	1100	002	0.325
	1200	348	0.175
	1300	310	0.10
	1400	276	0.10
	1500	264	0.15
	1600	244	0.275
Drogue #31:	071900 Nov.	293	0.10
	2000	278	0.05
	2100	278	0.05
	2200	259	0.225
	2300	251	0.175
	080000	260	0.40
	0100	290	0.30
	0200	272	0.45
	0300	303	0.375
	0400	294	0.325

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue #31 (cont'd)	080500	319	0.225
	0600	339	0.65
	0700	002	0.325
	0800	010	0.34
	0900	021	0.475
	1000	046	0.40
	1100	031	0.25
	1200	009	0.175
	1300	333	0.05
	1400	333	0.10
	1500	338	0.10
	1600	338	0.125
Drogue #32:	Very short track. Moved for 1 1/2 hours on approximate heading 170 covering 550 yds. Lost contact (shadow zone?).		
Drogue #33:	072000 Nov.	095	0.175
	2100	117	0.20
	2200	152	0.15
	2300	229	0.325
	080000	234	0.275
	0100	237	0.34
	0200	253	0.30
	0300	284	0.175
	0400	325	0.275
	0500	344	0.225
	0600	359	0.10
	0700	012	0.375
	0800	030	0.225
	0900	048	0.40
	1000	051	0.325
	1100	043	0.275
	1200	021	0.10
	1300	041	0.125
	1400	054	0.275
	1500	267	0.15
Drogue #34:	101000 Nov.	246	0.34
	1100	233	0.45
	1200	238	0.375
	1300	226	0.40
Drogue "X":	100800 Nov.	240	0.25
	0900	234	0.34
	1000	231	0.20
	1100	232	0.375
	1200	236	0.45
	1300	224	0.34

	TIME	APPROX. COURSE	APPROX. SPEED(kts)
Drogue "Y":	100900 Nov.	190	0.15
	1000	164	0.20
	1100	118	0.125
	1200	166	0.25[6]
	----	---	---
	1600	236	0.40
	1700	232	0.425
	1800	229	0.475
	1900	232	0.425
	2000	236	0.475
Drogue "Z":	101100 Nov.	137	0.40
	1200	151	0.25[6]
	----	---	---
	1600	192	0.34
	1700	195	0.325
	1800	210	0.45
	1900	219	0.375
	2000	203	0.45
Drogue #35:	130200 Nov.	180	0.325
	0300	164	0.425
	0400	182	0.34
	0500	191	0.375
	0600	201	0.575
	0700	223	0.575
	0800	231	0.575
Drogue #36:	130300 Nov.	210	0.45
	0400	213	0.45
	0500	205	0.475
	0600	229	0.70
	0700	241	0.65
	0800	230	0.675
Drogue #37:	130300 Nov.	162	0.225
	0400	180	0.325
	0500	205	0.375
	0600	214	0.45
	0700	212	0.50
	0800	214	0.475
Drogue #38:	130500 Nov.	219	0.275
	0600	225	0.45
	0700	228	0.525

[6] Interrupted track

APPENDIX B

WIND DATA

Pacific Gas & Electric Co., Moss Landing

August:

121700	- 260/10kts
1800	- 262/09
1900	- 250/10
2000	- 239/09
2100	- 214/09
2200	- 189/08
2300	- 166/03
130000	- 167/02
0100	- 165/01
0200	- 164/01
0300	- 158/02
0400	- 161/02
0500	- 167/01
0600	- 159/02
0700	- 148/03
0800	- 164/01
0900	- 187/05
1000	- 199/05
1100	- 249/03
182100	- 246/06
2200	- 233/05
2300	- 210/05
190000	- 200/05
0100	- 188/06
0200	- 176/05
0300	- 177/08
0400	- 177/07
0500	- 176/03
0600	- 172/02
0700	- 172/05
0800	- 204/11
0900	- 208/11
1000	- 225/08
1100	- 252/07
1200	- 253/07
1300	- 233/08
1400	- 261/09
1500	- 265/11
1600	- 261/12
310800	- 169/03
0900	- 149/02
1000	- 228/03
311100	- 262/05
1200	- 269/07
1300	- 256/07
1400	- 271/11
1500	- 241/11
1600	- 224/12
1700	- 219/14
1800	- 208/16
1900	- 191/16
2000	- 168/11
2100	- 161/13
2200	- 159/05
2300	- 171/03

September:

010000	- 129/03
0100	- 146/03
0200	- 281/02
0300	- 158/02
0400	- 203/02
0500	- 155/02
0600	- 131/03
0700	- 142/02
0800	- 133/02
0900	- 137/04
1000	- 187/05

October:

060800	- 271/06
0900	- 236/06
1000	- 249/03
1100	- 228/06
1200	- 248/09
1300	- 254/10
1400	- 245/12
1500	- 232/14
1600	- 231/15
1700	- 235/14
1800	- 232/16
1900	- 250/05

November:

061100	-	144/13
1200	-	156/10
1300	-	201/13
1400	-	221/20
1500	-	214/22
1600	-	219/21
1700	-	220/19
1800	-	234/16
1900	-	231/17
2000	-	229/15
2100	-	259/09
2200	-	301/06
2300	-	251/05
070000	-	212/03
0100	-	295/02
0200	-	130/01
0300	-	109/04
0400	-	118/07
0500	-	115/09
0600	-	118/07
0700	-	124/11
0800	-	123/12
0900	-	126/06
1000	-	124/06
1100	-	132/04
1200	-	256/05
1300	-	263/08
1400	-	261/06
1500	-	263/06
1600	-	269/08
1700	-	270/07
1800	-	274/03
1900	-	266/02
2000	-	224/01
2100	-	225/04
2200	-	134/01
2300	-	087/03
080000	-	138/01
0100	-	Calm
0200	-	203/01
0300	-	Calm
0400	-	089/03
0500	-	108/02
0600	-	122/04
0700	-	117/08
0800	-	118/07
0900	-	114/04
081000	-	132/04
1100	-	133/02
1200	-	274/02
1300	-	314/02
1400	-	298/03
1500	-	302/05
1600	-	271/03
1700	-	265/04
1800	-	273/01
100800	-	182/01
0900	-	148/01
1000	-	173/01
1100	-	295/03
1200	-	305/05
1300	-	302/07
1400	-	301/08
1500	-	296/12
1600	-	304/10
1700	-	304/07
1800	-	292/05
1900	-	293/05
2000	-	282/03
2100	-	Calm
130100	-	074/04
0200	-	089/05
0300	-	094/07
0400	-	082/11
0500	-	083/19
0600	-	079/15
0700	-	074/15
0800	-	082/13
0900	-	076/14

APPENDIX C

MONTEREY HARBOR TIDE READINGS

TIME	HT. ABOVE TIDAL GAUGE REF.
121700 Aug.	8.5
1800	8.8
1900	8.9
2000	8.5
2100	7.9
2200	7.85
2300	5.6
130000	4.45
0100	3.5
0200	3.0
0300	2.9
0400	3.3
0500	3.95
0600	4.8
0700	5.6
0800	6.3
0900	6.7
1000	6.8
1100	6.6
182000-190800 Aug.	Tide gauge inoperable
190900 Aug.	6.0
1000	7.2
1100	8.2
1200	8.5
1300	8.2
1400	7.4
1500	6.5
1600	5.3
310800 Aug.	6.0
0900	6.7
1000	7.2
1100	7.4
1200	7.0
1300	6.4
1400	5.7
1500	5.3
1600	5.1
1700	5.3
1800	5.8
1900	6.6
2000	7.5

TIME	HT. ABOVE TIDAL GAUGE REF.
312100 Aug.	8.0
2200	8.2
2300	7.9
010000-0700 Sept.	No reading
0800	5.72
0900	6.69
1000	7.25
060800 Oct.	6.56
0900	6.68
1000	6.94
1100	7.25
1200	7.62
1300	7.75
1400	8.25
1500	8.2
1600	7.88
1700	7.2
1800	6.3
1900	5.38
061100-081400 Nov.	Tide gauge inoperable
081500 Nov.	5.9
1600	6.68
1700	7.3
100800 Nov.	8.6
0900	7.5
1000	6.3
1100	4.7
1200	3.55
1300	3.2
1400	3.3
1500	4.0
1600	4.9
1700	6.3
1800	7.2
1900	7.5
2000	7.5
2100	6.9
130100	6.2
1200	5.0

TIME	HT. ABOVE TIDAL GAUGE REF.
130300 Nov.	5.05
0400	5.9
0500	6.55
0600	7.3
0700	8.5
0800	9.2
0900	9.5

APPENDIX D

Bearing/Range Accuracy Data
(12 Hour Study-6 Oct)

	SPS-10 Radar Position		Charted Position	
Time	Buoy "D"	Buoy "A"	Buoy "D"	Buoy "A"
0730	009/16000	012/6160	009/15700	012.5/5850
0800	008.8/15990	012.3/6200		
0830	008.8/15950	012.1/6170		
0900	009/15970	012.5/6180		
0930	008.8/15980	012.5/6190		
1000	008.8/15990	012.3/6180		
1030	008.9/15950	012.5/6150		
1100	009/15980	012.7/6190		
1130	008.8/15980	012.5/6190		
1200	009/15940	012.5/6170		
1230	009/15920	012.8/6160		
1300	009/15960	012.5/6180		
1330	009/15970	012.5/6190		
1400	009/15970	012.5/6200		
1430	009/15950	012.5/6200		
1500	009/15940	012.7/6200		
1530	009/15950	012.5/6200		
1600	009/15970	012.5/6200		
1630	008.9/15980	012.5/6200		
1700	008.5/15950	012.5/6160		
1730	009/15940	012.5/6200		
1800	009/15960	013.5/6200		
1830	008.7/15960	012.5/6200		
1900	009/16000	012.5/6200		

BIBLIOGRAPHY

Bureau of Ships, Technical Manual for Radar Set AN/SPS-10, 4 May 1953.

Bureau of Weapons, Ordnance Pamphlet 1845, Vol. 1, Description, Installation and Operation of Radar Equipment MK 25, MOD 3, 6 January 1960.

Bureau of Yards and Docks Final Report on Contract No. 13116, Determination of Wave, Surge, and Ship Motion,, U.S. Naval Station Long Beach, California, by R. T. Knapp, 36p., May 1951.

Caster, W. A., Near Bottom Currents in Monterey Submarine Canyon, Unpublished Master's Thesis, Naval Postgraduate School, 1969.

Coast and Geodetic Survey, Tide Tables for West Coast of North and South America, 1970.

Cromwell, T., Montgomery, R. and Stroup, E., "Equatorial Undercurrent in the Pacific Ocean Revealed by New Methods," Science, v. 119, p. 648-649, 1954.

Jennings, F. D. and Schwartlose, R. A., "Measurements of the California Current in March 1968," Deep Sea Research, v. 7, p. 42-47, 1960.

Naval Air Systems Command, Preliminary Technical Manual for Radar Transponder AN/DPN-77 and AN/DPN-78 (NAVAIR 16-30 DPN77-1), 15 June 1969.

Neumann, G. and Williams, R. E., "Observations of the Equatorial Undercurrent in the Atlantic Ocean at 15 W During Equilant I," Journal of Geophysical Research, v. 70, p. 297-304, 1965.

Reid, J., "Measurements of the California Countercurrent at a Depth of 250 Meters," Journal of Marine Research, v. 20, p. 134-137, 1962.

Robson, R., "Radar Method in Ocean Current Detection," Commonwealth Engineer, v. 42, p. 219-225, January 1955.

Skogsberg, T., "Hydrography of Monterey Bay, California. Thermal Conditions, 1929-1933," Transactions of the American Philosophical Society, v. 29, 1936.

Stalcup, M. C. and Parker, C. E., "Drogue Measurements of Shallow Currents on the Equator in the Western Atlantic Ocean," Deep Sea Research, v. 12, p. 535-536, 1965.

Stevenson, C. D., A Study of Currents in Southern Monterey Bay, Unpublished Master's Thesis, Naval Postgraduate School, 1964.

Stommel, H., "Serial Observations of Drift Currents in the Central North Atlantic Ocean," Tellus, v. 6, p. 203-214, 1954.

Thomson, C. W. and Murray, J., "Report on the Scientific Results of the Voyage of HMS Challenger," Narrative, 1885.

Volkmann, G., Knauss, J. and Vine, A., "The Use of Parachute Drogues in the Measurement of Subsurface Ocean Currents," Transactions of the American Geophysical Union, v. 37, p. 573-577, 1956.

Wooster, W. S. and Gilmartin, M., "The Peru-Chile Undercurrent," Journal of Marine Research, v. 19, p. 97-122, 1961.

Wylie, F. J. (ed.), The Use of Radar at Sea, 4th ed., American Elsevier, 1968.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor Warren W. Denner Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
4.	Professor Edward B. Thornton Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
5.	LCDR Howard Sanford Stoddard 175 Ridge Road Nutley, New Jersey 07110	1
6.	Department of Oceanography Naval Postgraduate School Monterey, California 93940	3
7.	Mr. M. J. Dole, Jr. Department of Engineering Research Pacific Gas and Electric Company 4245 Hollies Street Emeryville, California 94608	1

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3 REPORT TITLE

Feasibility Study on the Utilization of Parachute Drogues and Shore-based Radar to Investigate Surface Circulation in Monterey Bay

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Master's Thesis; March 1971

5. AUTHOR(S) (First name, middle initial, last name)

Howard Sanford Stoddard

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
March 1971	115	19

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

An intensive study is presently being made of the current patterns in Monterey Bay. Up to this time, no means has been available to examine the flow over the entire Bay. The feasibility of utilizing radar systems installed at the Naval Postgraduate School to track free-floating parachute drogues was investigated. Radar transponders extended the tracking range of the radars to include the north end of the Bay, and eliminated shadow zones which had been present when tracking passive reflectors. An analysis of the drogue tracks indicated the importance of the oceanic currents as primary current driving mechanisms. Tides strongly influenced flow in the Bay's interior. Winds generally were a relatively unimportant driving mechanism, except when winds prevailed from one direction over an extended period of time.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Parachute Drogues						
Circulation in Monterey Bay						
Monterey Bay						

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

A-31409

Feasibility study on the utilization of parachute drogues and shore-based radar to investigate surface circulation in Monterey Bay.

Thesis 126613
S734 Stoddard
c.1
Feasibility study on the utilization of parachute drogues and shore-based radar to investigate surface circulation in Monterey Bay.