RESULTS OF A PROGRAM TO MEASURE THE TRAJECTORY OF WATER AT A DEPTH OF 100M SOUTH OF PUNTA TUNA, PUERTO RICO

DECEMBER 1980

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EXECUTIVE STATEMENT

As Puerto Rico is considered among the prime world locations for a land-connected, Ocean Thermal Energy Conversion(OTEC) electrical generating power plant, the U.S. Department of Energy is looking at the oceanographic conditions around the island. The main emphasis is being directed toward Punta Tuna, on the southeast coast of the main island.

This document is in response to a project designed to secure oceanic water trajectory data from the Punta Tuna area in answer to where potentially mixed warm and cold water effluent may go after leaving a full-scale OTEC plant. The project provides for:

---The design and construction of deep-sea current followers, or drogues, to be sensitive to water motion at 100 meters depth in the Caribbean Sea.

---A series of cruises, during a one year period, to the Punta Tuna area in order to release and follow the drogues.

---The analysis and interpretation of the results of these water following cruises.

---Recommendations for future studies of the Puerto Rico OTEC oceanographic water current program.

The final drogue design was a compromise between ease of field operation, sensitivity to the 100 meter depth, and cost. The design is composed of a surface floatation member, with radar reflector, radio beacon, light beacon, and flag, and a large two dimensional underwater panel, unfurling similiar to a windowshade, and located at a depth of 100 meters.

During the contract period, a total of eight cruises were made to the Punta Tuna area to deploy and follow these drogues:

9 November 1979
28 January to 1 February 1980
18 to 22 February 1980
24 to 25 March 1980
7 to 11 May 1980
10 to 12 June 1980
24 to 27 June 1980
16 to 23 July 1980

The cruise procedure was virtually the same for all but the first cruise. One or more drogues were deployed from a permanently moored vessel(conducting OTEC biofouling and corrosion studies) about 4 km southeast of Punta Tuna, Puerto Rico, over 1150 meters of water. The movement of the drogues was followed, relative to the moored vessel, as a function of time,from the radar aboard the vessel. At the conclusion of the cruises, the drogues were recovered using a second vessel. The first cruise differed from this procedure in that the moored vessel was not on location as yet, and the tracking vessel was always changing location.

A total of 422 hours, spread over 24 days, were devoted to collecting usable trajectory data. During that time 13 drogues were launched, and the positions were observed on these drogues on the average, every 2 hours.

In 60% of the cruises, the 100 meter deep water was moving clearly southwest, at least some of the time. During 30 % of the cruises, the 100 meter deep water was moving northeast, at least some of the time. There was little long-term motion that was not along either of these two directions. The water actually moved westerly (225-314 deg-T) about 60% of the time, and easterly (045-134 deg-T) about 15% of the time. The directionality of the 100 meter deep water correlated poorly with the surface water direction, the wind direction, and atmospheric pressure changes.

There were two cruises during which the 100 meter deep water may have come into contact with the large island slope leading up to the shallow, south-central reef area, less than 10 km west from the drogue deploy area. However, at no time during the program was any 100 meter deep water seen to move directly northward from the drop-off site toward the active reef structure, just offshore from Punta Tuna. The water did occaisionally move northward, but only after moving eastward, past the eastern edge of the island.

Inertial motion was clearly evident at 100 meters, as was an occaisional tidal cycle. Neither of these seriously altered any prevailing flow direction. There was no apparent seasonality to the 100 meter deep water flow in this area.

Although during individual time intervals the 100 meter deep water was seen to move at up to 60 cm/sec, the cruise averages ranged from 5-23 cm/sec. The overall program average speed was 13 cm/sec, based on 192 observations. Ninty percent of the time the speed was less than 24 cm/sec.

Included in the recommendations, along with the suggestions for more long-term oceanic programs to help define any cyclic behavior, and integration between plant designers, flow modelers, and field-data collectors, is the strong urging to develop usable predictive correlates to help anticipate changes in effluent flow patterns during actual plant operations.

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ACKNOWLEDGEMENTS

I wish to acknowledge the following people and organizations for their help and support to create, develop, and carry out this program.

The greatest thanks goes to Dr. Donald Sasscer of the OTEC Division of the University of Puerto Rico's Center for Energy and Environment Research (UPR/CEER) for his continuous help and support during the conception, development, and operation of this trajectory study. He continually aided the program, as well as tried to integrate this study with the other Puerto Rico OTEC programs.

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Finally, I want to thank the Puerto Rico Electrical Power Authority (PREPA) for their farsightedness and support as they originally integrated this study with their own OTEC activities so as to encourage us to gather an environmental understanding of the area in anticipation of an operational OTEC plant in the future.

1.0 INTRODUCTION

The purpose of this study was to improve the predictability of the fate of potential effluent from an Ocean Thermal Energy Conversion (OTEC) plant, if it were situated in the deep, nearshore waters, southeast of Punta Tuna, Puerto Rico.

An OTEC plant converts the thermal energy difference between the warm tropical surface water and the cold deep water into mechanical then kinetic energy, and finally into either electrical energy, or some energy-intensive by-product (Cohen, 1978). To orient the reader, this energy conversion process is accomplished by using a large, but simple heat exchanger system. The system first cools and liquifies a working fluid (such as ammonia or Freon), then heats and vaporizes the fluid. The cooling is accomplished by pumping large amounts of water (about 1600 m^3/sec for a 400 MWe plant) up from a depth as great as 1000 meters, where it may have a temperature of about 5°C. The heating of the working fluid is accomplished by passing surface water (a flow rate nearly equal to that of the deep water) past the working fluid's heat exchange area. The surface water temperature could range from 25°C to 29°C. The sea water never comes into actual contact with the working fluid, but is drawn into the large heat exchanger areas where it is separated from the working fluid by durable, high conductivity metal housings. The cooled working fluid moves from the condenser as a liquid, past a turbine (conversion from thermal to mechanical/kinetic energy) into a vaporizor where

it is heated to the gaseous state and is drawn back into the condenser area again. The turbine is the mechanism that could turn the kinetic energy of the moving fluid into either electrical energy or perform work directly.

As this process proceeds, the warmed, or cooled ($T_{final} = T_{original} \pm 2C^{o}$) water is then discarded back into the sea as effluent. The water may be either returned separatedly as slightly warmed cold water and slightly cooled warm water, or the two effluents may be combined and returned into the sea as a mid-temperature mixture, containing about equal amounts of the deep and surface water. This mixture would be released toward some mid-depth, depending on its final temperature and salinity (density) and mixed ratio.

There are numerous benefits and potential environmental hazards with this OTEC type of energy conversion. Some of the benefits include: no air pollution, not dangerous to large population centers, theoretically limitless renewable energy source, uses the earth's tropical oceans as its natural solar collector, can be either near land for direct connection into a local power grid or offshore as in the case of an energy-intensive material production. Some potential hazards that may accompany such an OTEC plant are: working fluid (ammonia) leakage, oceanic navigation and security problems, biocide and heavy metal contamination through the effluent, ocean thermal changes, destruction of surface and/or deep water organisms, and upwelling of deep ocean water with considerable nutrients.

It is this last potential hazard that produced the concern that ultimately generated this study. If the effluent of the plant contains a ratio of about equal quantities of deep and surface water, the new mixture will have a high nutrient level, compared to the usual normal tropical euphotic layers. The deep ocean waters contain 10-100 times the available dissolved phosphates, nitrates, and silicates (that may be used for primary production) compared to the tropical surface waters. These tropical surface waters are usually nutrient-limited as far as primary productivity is concerned, with the normal phytoplankton standing crop being much below that of nutrient-rich oceanic areas. The addition of large quantities of artificially upwelled nutrients, and subsequently possible increases in the phytoplankton population could cause considerable changes in the normal ecosystem by altering the standing crop of grazers and preditors, and by changing the turbidity of the water, reducing light penetration to the deeper organisms. Furthermore, this aforementioned mixed effluent would be cooler than the normal tropical euphotic waters (although possessing the same density), causing additional stress on any affected organisms.

It is not within the realm of this study to evaluate or enumerate the ecological possibilities that might occur. Rather, the purpose of the study was to make some assumptions about the physical characteristics of a potential mixed effluent from a hypothetical OTEC plant that would be located about 4 km southeast of Punta Tuna, Puerto Rico, situated in

1150 meters of water. After considering the local parameters, it was concluded that the mixed effluent might be located about 100 meters deep. The scope of this report is to discuss the results of the current measurements to determine the trajectory of this 100 meter deep water after it leaves the hypothetical OTEC site. As this site is quite near shore, and south and east of a rich, living coral reef complex, the movement of this quantity of cooled, nutrient-rich water is of deep concern to those who must decide upon the geographical placement of such a plant.

1.1 BACKGROUND OF AREA

The following sections will help to describe and understand the state of knowledge of the area southeast of Puerto Rico and the potential OTEC site which encompasses the geographical area covered during this study.

1.1.1 GEOGRAPHY OF AREA

The Commonwealth of Puerto Rico consists of the main island (called Puerto Rico) and several smaller islands. These are all a part of the Antilles Chain of islands, which extend from Venezuela to Florida (see Figure 1). The Antilles Chain serves as the practical boundary between the Atlantic Ocean to the north, and the Caribbean Sea, to the south. Puerto Rico is situated near the center of the Chain, considering both geographical location and relative size. As its location of 18^{o} N. Latitude and 65^{o} W. Longitude, Puerto Rico is considered subtropical, and is affected by the east-to-west trade

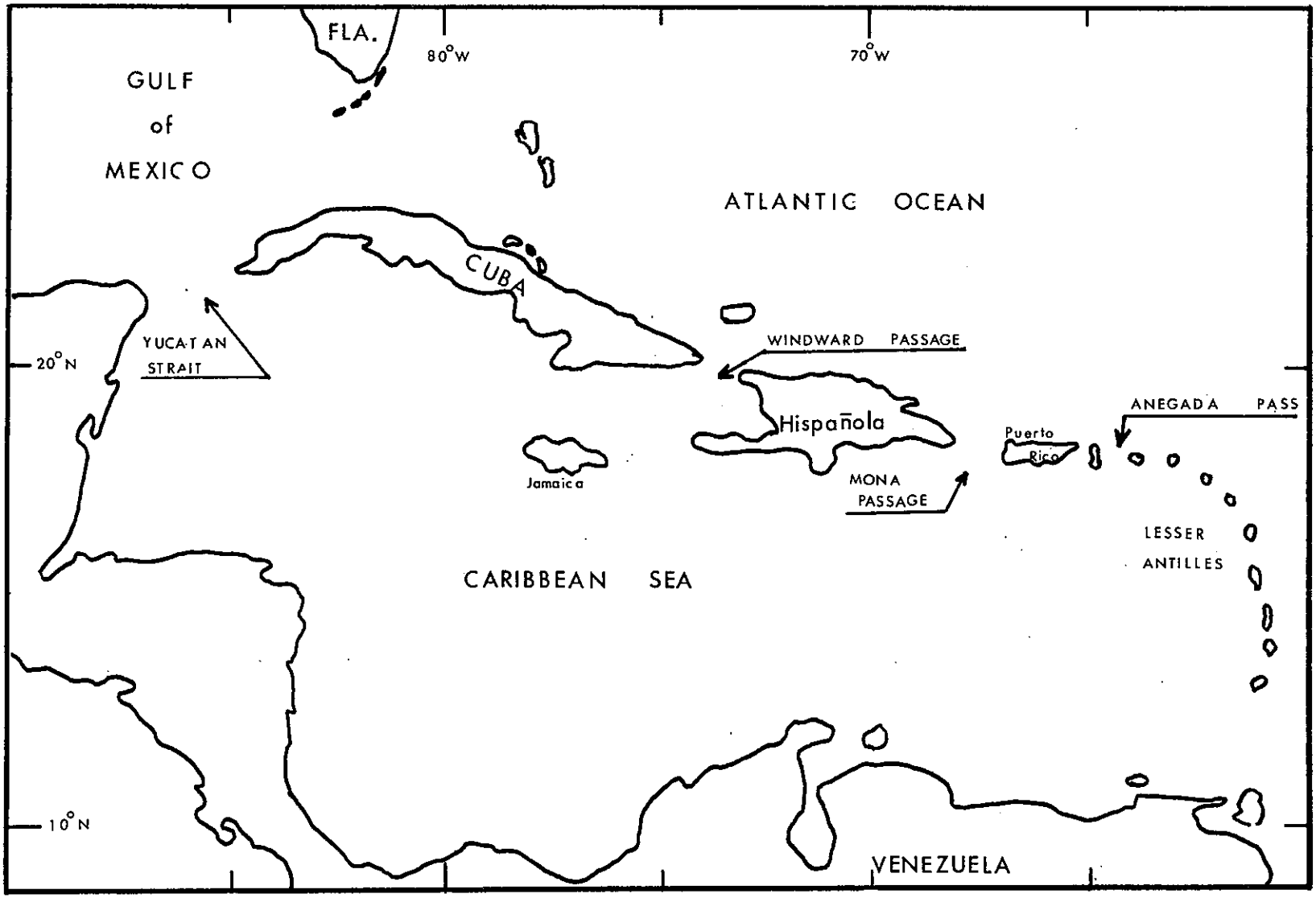

Figure 1. Map of the Caribbean Sea

wind belt. The rainfall is relatively light from early winter to late spring, and much heavier during the rest of the year.

The main island of Puerto Rico is roughly rectangular, about 180 km east-to-west, and 60 km north-to-south. The island is a mixture of mountains, rolling hills, and broad, flat plains. Where the plains meet the sea, the climate is typically tropical marine, except along the leeward, or desert-like, southwest coast.

The surface waters surrounding the island could be typified as having biseasonal characteristics also. During the summer/fall season, the surface waters are usually warmer, with lower salinities. In the winter/spring season, the opposite is usually the case. If there is any seasonality to the subsurface waters, it has not been reported as yet.

From a geological standpoint, Puerto Rico, Hispanola, and the Virgin Islands, are emergent points of a rock mass which forms the Eastern Greater Antilles Ridge. This ridge rises more than 5 km above the floor of the Caribbean Sea to the south, and 8 km above the bottom of the Puerto Rico Trench to the north. The ridge branches to the east, forming the Anegada and Virgin Islands Troughs. The deep Windward Passage to the west, between Hispanola and Cuba, forms the western edge of the ridge. The Mona Passage lies between Puerto Rico and Hispanola, and is about 100 km wide. This passage has a maximum depth of less than 600 meters, with much of the area less than 100 meters deep. Another shelf, the Virgin Island Shelf, extends 150 km east of Puerto Rico, with all depths of this second shelf less than 50 meters.

North of Puerto Rico, the Greater Antilles Ridge is separated from the Atlantic Ocean Basin by the Puerto Rico Trench, the deepest area in the Atlantic Ocean, The trench runs east-west, and is about 150 km north of Puerto Rico.

South of Puerto Rico lies the Venezuela Basin, the middle deep basin in the Caribbean. However, between Puerto Rico and this basin of about 4000 meters depth, lies the Muertos Trough, or the Dominican Trench. The trench also runs east-west, and exceeds 5000 meters depth in some areas. This trench is less than 100 km from Puerto Rico.

On a smaller scale, the bathymetry of the area south of Puerto Rico can be seen in Figure 2. There is a 15 km wide shallow shelf south of the central part of the island. Where this shelf meets the steep drop-off, so typical in these waters, lies a healthy, living reef, running most of the distance from the east coast, along the south coast to the Mona Passage. In the area near Punta Tuna (at the southeastern "corner" of the island), the reef is about 1/2 km from shore, and in places rises to the surface. This reef and its associated shallow water organisms form the island's shallow water/deep water boundary along virtually the entire south coast. The drop-off line actually turns southward about 30-40 km west of Punta Tuna, leaving the shoreline to follow the edge of the wide shelf.

A group of shoals (one of which is the Grappler Bank) lies about 20 km south of Punta Tuna. Between this shoaling area and the reef is a rugged, 45^{o} downward slope to about

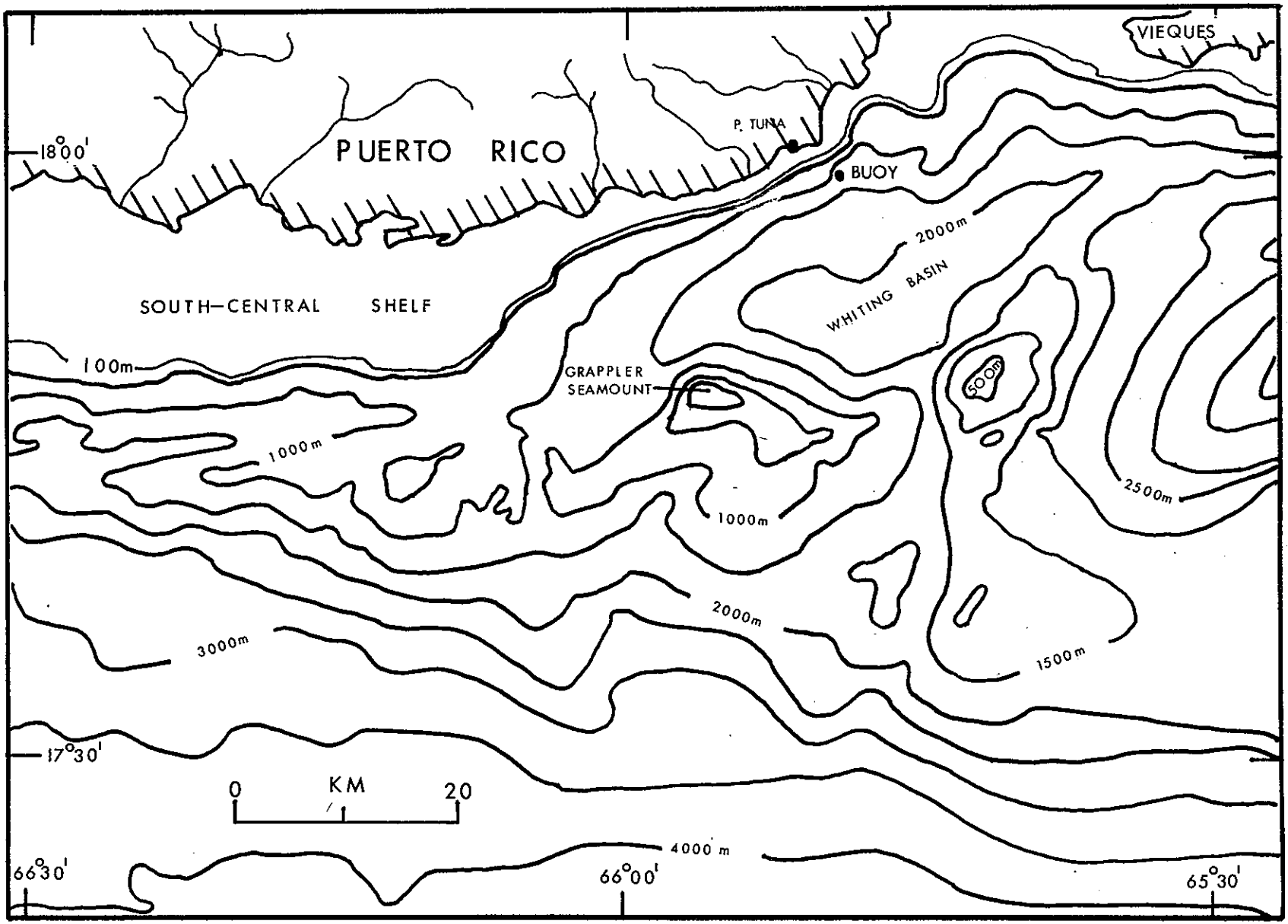

Figure 2. Bathymetry of the area southeast of Punta Tuna, Puerto Rico

2000 meters depth, and then a very flat plain. The plain connects to the Anegada Passage to the northeast and stops in a "box canyon" to the west, with a rise up to about 1500 meters depth.

1.1.2 WATER MASSES

The water masses in the Caribbean have been discussed by many authors (Wust, 1964; Parr, 1936 and 1937; Atwood et al., 1976; Craig et al., 1978; Lee et al., 1978; Hernandez Avila et al., 1979; Goldman et al., 1979), but for completeness, they shall be mentioned again as the source, depth location, movement, and characteristics of these water masses are important to the understanding of the results describes in this report.

The upper water mass is called the Tropical Surface Water (TSW) (see Figure 3). The origin of this water is under the Equatorial Atmospheric Trough (low), which is a tropical rain belt located to the northeast of Brazil in the Atlantic Ocean. The TSW is influenced both by heavy precipitation in that area and by the massive runoff from the Amazon and Orinoco Rivers. This water mass is driven by wind and coriolis into the eastern Caribbean Sea through passages in the Lesser Antilles island chain. As the water mass continues to move under the wind stress of the predominant easterly winds, the water is moved northwest toward the Yucatan. By the time it reaches Puerto Rico, the temperature and salinity of this upper water mass has been further affected by the general and local climate of the area through which it has passed. Additional

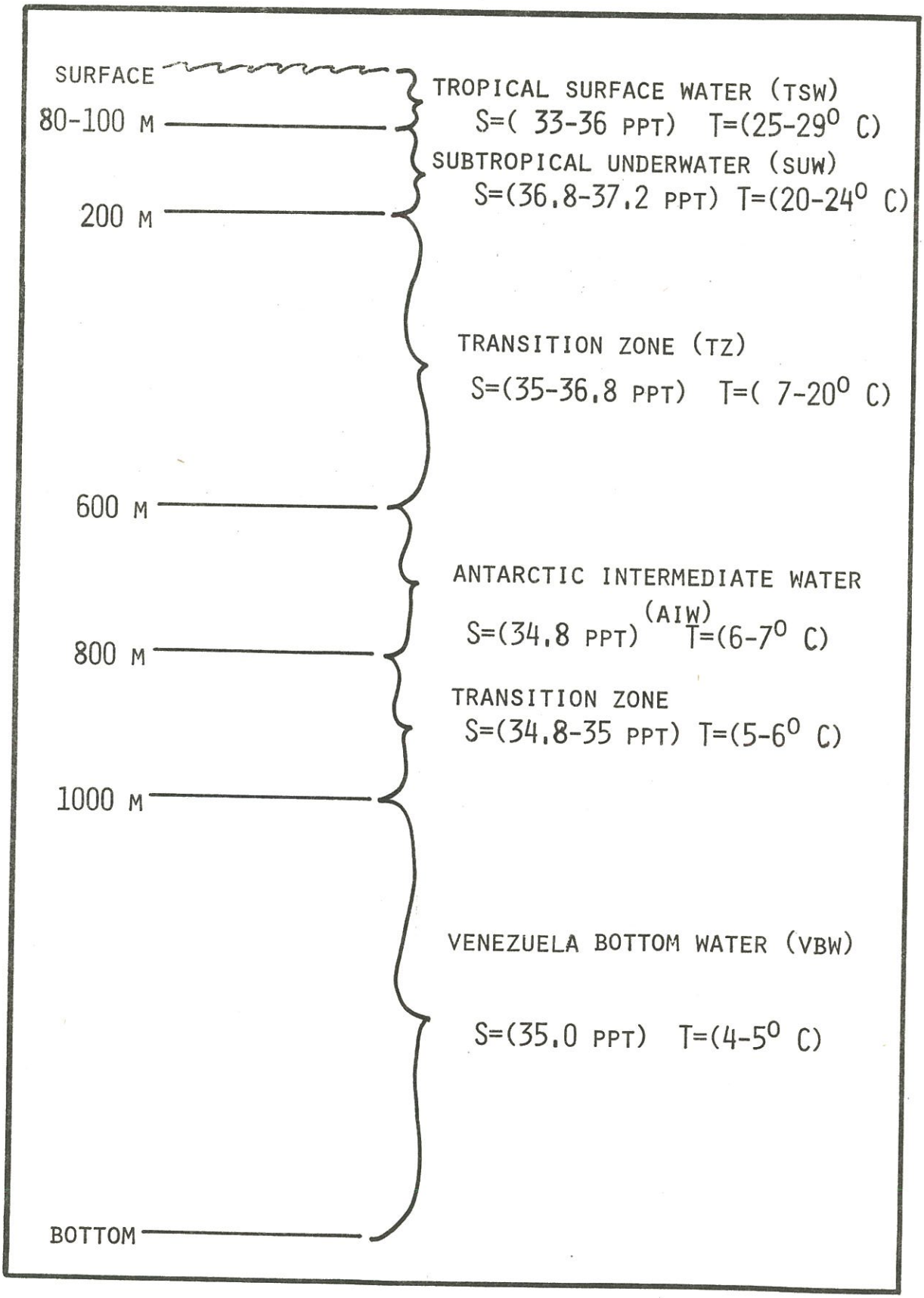

Figure 3. Caribbean Sea water column structure south of Puerto Rico

precipitation and runoff (although slight), evaporation from wind and insulation could further influence both the temperature and salinity. In the TWS the salinity generally ranges from 33-36 ppt, and the temperature generally ranges from 25°C to 29°C. This water mass appears to be wedge-shaped, attaining its maximum depth along the northern Caribbean, due to the geostrophic subsidence as the water moves westward. The local depth of the water mass may be influenced by atmospheric pressure as well. Normally, atmospheric pressure changes little in this area, with a change of 3-6 mm of mercury within a month being considered large. However, as a tropical pressure trough moves through the Caribbean, the pressure is severely reduced, causing the water level to be raised, pushing the upper water mass to the side, and upwelling the cooler, more saline water mass below. This upwelling would occur during a hurricane and, to a lesser degree, during a tropical wave or a tropical storm. The effect on an operating OTEC power plant could be at least to severely reduce the plant's already low operating efficiency, in the case that the plant had not already been shut down.

The water mass directly beneath the TSW is called the Subtropical Underwater (SUW). This lower water mass (Figure 3) originates directly beneath the Bermuda atmospheric high pressure zone. The Bermuda High is the atmospheric downwelling component of the Hadley cell which gives rise to the Equatorial Atmospheric Trough, which in turn is related to the origin of the TSW discussed above. The air under the Bermuda High is

generally warm and dry. Due to the lower relative humidity, evaporation is great and the salinity is increased. This water mass contains the most saline water in all the Caribbean. The SUW descends to form the upper portion of the thermocline in the Caribbean. The salinity within the SUW does not vary much (36.8-37.2 ppt) because the water rarely comes into contact with any diluting agent. During conditions of low atmospheric pressure, this water is drawn upward, as evidenced by the high salinity seen at or near the surface during these occasions.

The temperature range within the SUW is 20°C to 24°C. Due to thermal conduction, the temperature does not remain as invariant as does the salinity. The density difference between the TSW and the SUW is usually about two sigma-t units, which is large enough that the two remain distinct water masses.

The SUW moves southward from the higher latitudes near Bermuda and enters the Caribbean through passages along both the north and east under the faster moving, more turbulent TSW. From these passages, the water moves generally southward or westward, or both, to spread throughout the entire Caribbean beneath the TSW. Near Puerto Rico, the water enters the Caribbean southward through the Anegada (east of P.R.) and the Mona (west of P.R.) Passages. The core of this water mass generally lies at about 125-150m in the Caribbean near Puerto Rico.

Below the SUW lies a Transition Zone (Figure 3) of indistinct characteristics. The Transition Zone contains the lower portion of the thermocline, and extends into the cold

water sphere. This transition water is a mixture of North Atlantic Central Water and diffused and diluted Mediterranean Water. The salinity ranges from about 36.8 ppt, from the water mass above it, down to about 35 ppt. The temperature range is from 20°C to 7°C. This Transition Zone extends from a depth of about 200 m down to about 600 m. Just below this zone lies the oxygen minimum, which many people define as the boundary of the cold water zone inthe oceans. This transition water enters the Caribbean from the north and from the east, and probably moves southward and westward.

The Antarctic Intermediate Water (AIW) is found just below (600 m - 800 m) the Transition Zone. This water is formed in an area where precipitation far exceeds evaporation. The AIW is seen moving northward from its area of formation, and makes its way into the Caribbean over the moderately deep sills of the Lesser Antilles, the Anedaga Passage, and the Windward Passage, between Cuba and Hispanola. These latter deep sills may also form a path of departure from the Caribbean for the AIW that has entered through the Lesser Antillian passages. This water mass spreads to cover much of the Caribbean Basin. The movement of the AIW near Puerto Rico could be either south and west (having entered either through the Lesser Antilles or the Anegada Passage) or even north and east (departing through the Anegada or Windward Passages). As the water has moved northward through the Atlantic, it has been in contact with higher salinity water, therefore, the salinity of the AIW as it passes Puerto Rico is no longer the

34ppt of its origin, but rather about 34.8-34.9 ppt. The temperature is 6°C to 7°C.

A second Transition Zone can be found from 800 meters down to 1000 meters depth. This thin zone is the transition between the AIW and the North Atlantic Deep Water (NADW).

From about 1000 meters depth down to the bottom of the Caribbean Basin the water has most of the characteristics of the NADW. This water mass is formed in the high northern latitudes, and while descending both in depth and latitude, it entrains some of the Mediterranean water, thereby increasing its salinity, density, and depth even more. The water enters into the Caribbean only through the deep sills of the Windward and Anegada Passages. The water moves mainly westward from the Windward Passage, but south and west from the Anegada Passage so as to fill all the deep basins in the Caribbean. This water is characterized by 4-5°C temperatures and a salinity of 35ppt. After this water mass has moved into the Caribbean, it is virtually trapped, with only a small passage out through the Yucatan Strait. The water remaining in the Basin is slightly different in silicate content from its origin, the NADW, found outside the Caribbean Basin. For this reason, some people choose to call this deep, cold water mass the Venezuela Bottom Water (VBW). In some areas of the Caribbean Basin, the NADC (or VBW) is over 3000 meters thick.

1.1.3 TIDAL ACTIVITY

The dominant tidal action along the northeast coast of Puerto Rico is caused by the amphidromic system that has its node in the North Atlantic. This system produces a semi-diurnal tide, and is easily seen at San Juan, where reliable height predictions are available (U.S. D.O.C., 1979). The same activity also continues down the east coast of the island. The tidal motion along the south coast of the island, however, is a manifestation of the system with its amphidromic point in the north-central caribbean, just south of Puerto Rico. This second system produces a diurnal oscillation along the south coast, with a week semi-diurnal component (Hernandez Avila et al., 1979). The waters at Punta Tuna may be affected by either, or both of these systems, as both the west coast and the south coast activities could produce a visible influence on the waters at our study area.

Evidence of a tidal presence in the area has been clearly seen in the works of Lee et al. (1978), where sharp current reversals were seen off St. Croix, V.I., during a spring tidal period, and vertical fluctions of temperature, salinity, etc., were also seen on a diurnal and semi-diurnal basis. The best available evidence indicates that an ebbing tide at Punta Tuna produces an easterly current.

1.2 WATER CURRENTS

Although very few water current measurements have been made in the Caribbean, the general circulation has been described by Wust (1963), Worthington (1971), Gordon (1967),

Sturges (1965), and Perloth (1971), among others. Summaries of their discussions and the results of the few measurements in the area will be discussed in this report for completeness.

The Caribbean (surface) Current is a warm, westward flow which is formed from the junction of the North Equatorial Current and the Giuana Current. Most of the water for the Caribbean Current enters the Caribbean Sea through the straits of the Lesser Antilles. As the water passes across the Caribbean, the main flow crosses the Jamaican Ridge, southwest of Jamaica, moves west through the Cayman Basin, and into the Gulf of Mexico by passing through the Yucatan Strait. From this point it becomes part of the Florida current (Burns and Car, 1975). The Caribbean Current does display some seasonality with speeds reaching a maximum at the surface in the summer and a minimum in the fall.

1.2.1 WATER CURRENTS - HISTORICAL

Very few water current measurements have been made near Puerto Rico. Surface drifters were used by Duncan et al. (1977), Metcalf et al. (1977), Metcalf and Stalcup (1974), and Bane (1965). Current meters both moored and over-the-side, were used by Burns and Car (1975), Lee et al. (1978), Goldman et al. (1979), Oser and Freeman (1969), and Ostericher (1967).

In virtually all the surface drifter studies mentioned above, the drifters moved westerly. There have been variations, such as northwest or southwest, but always westerly. The surface waters of the Mona Passage, for example, oscillate at

more than 50 cm/sec north and south with the tidal flow. But this simply gives a north or south component to the strongly predominantly westerly drift.

In the results reported by Burns and Car (1975), three arrays of current meters were moored near Puerto Rico; Array #11, Array #14, and Array #14A.

Array #11 was set in 1975 meters of water at 17°50.9' N. Latitude, 65°47.6' W. Longitude, which is about 18 km south-southeast of Punta Tuna. This array had reported results from only the 220 meter depth meter. About 75% of the directional observations with this meter showed the water moving between southwest-to-northwest. The speeds ranged from 5-35 cm/sec, with the average speed about 16 cm/sec. This water would be located near the top of the Transition Zone, beneath the SUW.

Array #14 was set in 1915 meters of water at 17°52.9' N, 65°54.6' W, or 12 km south of Punta Tuna. Although there were five reported depths for this array (100m, 105m, 810m, 1905m, and 1910m), the results of the upper two shall be combined for this discussion, as will the lower two. The water at 100 meters depth moved westerly 60% of the time. Virtually all the speed observations were less than 20 cm/sec, with an average of 5 cm/sec. These meters were usually in the SUW. The water at 810 meters depth (the lowest portion of the AIW) moved toward the west about two-thirds of the time, and the speed observations were all less than 15 cm/sec, with the average value being 4 cm/sec. The bottom water, at 1900 meters depth

(VBW) moved primarily northeast or west. The speed averaged less than 1 cm/sec.

The third array, #14A, was moored in 1430 meters of water at 17°58.4' N, 65°37.8' W, or 27 km east of Punta Tuna. There were four depths reported for this array; 240m, 605m, 1335m, and 1420m. The 240 meter deep water (probably just beneath the SUW) moved westerly virtually all the time, having an average speed of 8 cm/sec. The water at 605 meters (upper portion of the AIW), was seen to move primarily northeast-to-northwest at an average of 5 cm/sec. The deeper water (VBW) moved either northeast-to-east or southwest-to-northwest at even slower speeds.

Oser and Freeman (1969) report the installation of two deep-water current meter arrays in the area during December 1968. The arrays were located between the island of Vieques and Punta Tuna, and were in 100 m and 1500 m of water, respectively. The generalized reported results of these arrays are that the upper waters (about 300 meters depth) showed up to 25 cm/sec at maximum speed, and was moving primarily westerly. One meter at 600 meters depth showed a maximum speed of about 50 cm/sec, with a primary direction indicated as northeast. The 1000 meter deep water showed itself to be moving northwest and east, and had a maximum speed of 15 cm/sec.

Ostericher (1967) also reports both current meter and drogue measurements that were made just south of Punta Tuna in 1967. The current meter results are not given in the report, by the drogue data indicate a westerly or southwesterly

drift in the surface waters during the six hours of observation.

Lee et al. (1978) reported over-the-side current meter results from a moored vessel over about 3600 meters of water, while located 15 km north of St. Croix, V.I., at about 17°52' N, 64°41' W. The water motion was measured during the summer of 1977 at 10 meters depth at least daily (when possible), and frequently bihourly. These results indicate a strong easterly drift for about 2 weeks, then about 2 weeks to the west. After that time, for one week, a strong diurnal east-west reversal was seen, corresponding to a spring tidal period. After this period, for about one month, the currents were variable in direction, with some tidal influence visible. Another easterly drift occurred after about 1½ weeks. This second easterly flow lasted 3-4 days, then degenerated again. Typical speeds of 25-50 cm/sec were seen throughout the measurement period. Also, during this measurement period, a single current profile was taken in September, 1979. During the profile, the TWS was moving southeast, the SUW moved northwest, and all the rest of the water column, down to 800 meters, moved westerly. The water in the Transition Zone between the AIW and the VBW was moving northwest. The speeds generally decreased from about 20 cm/sec near the surface to 10 cm/sec at 1000 meters depth.

Goldman et al. (1979) reported the results of over-the-side current meter profiles and one current meter array. The profile results were taken bimonthly from August 1978 until

June 1979 at 17°57.6' N, 65°51.9' W (4 km southeast of Punta Tuna) while moored at an OTEC DOE/UPR mooring site for biofouling and corrosion studies over 1150 meters of water. The profiles were measured four times in one day during each of the six cruises. The upper water (25m-50m--TSW) was seen to move usually toward the west or the east. The average speed was 10 cm/sec. The SUW (100m-150m) usually moved westerly, with some easterly motion. The average speed at this depth was 8 cm/sec. The Transition Zone (250m-500m) moved almost exclusively westerly, with an average speed of 7 cm/sec. The AIW (650m-750m) moved in either northwest or northeast direction at 5 cm/sec.

The current meter array reported by Goldman et al. (1979) was moored at 18°02.2'N, 65°39.7'W, or 15 km east of Punta Tuna. The two reported depths were 215m and 332m, with a total water depth beneath the array of 1216 meters. The 215 meter deep water moved in all directions, with a very slight preference toward the east and the west. The average speed was 7 cm/sec. The deeper water (332 m) had the same general directional motion, with an average speed of 5 cm/sec. These meters were probably measuring the upper water in the Transition Zone between the SUW and the AIW.

1.2.2 WATER CURRENTS - SUMMARY

In summary, the following are the directional flows seen in the historical records for the components of the water column in the Caribbean Sea, southeast of Puerto Rico.

The Tropical Surface Water (TSW) has almost always been seen to move westerly or easterly, with very little north or south component.

The Subtropical Underwater (SUW) has been seen to move basically westerly, and occasionally easterly.

The Transition Zone between the SUW and the Antarctic Intermediate Water (AIW) has been seen to move almost always westerly.

The AIW has been observed to move past the area toward virtually all directions of the compass.

The Transition Zone between the AIW and the Venezuelan Bottom Water (VBW) is documented as always moving westerly.

The VBW has been seen to move past southeastern Puerto Rico toward either the northwest or the northeast, with some easterly observations.

2.0 EQUIPMENT AND PROCEDURES

The following sections contain the programmatic and hardware design criteria as well as the actual description of the final hardware and the experimental techniques used during this program.

2.1 LAGRANGIAN VERSUS EULERIAN

The U.S. Department of Energy, as one of its near-term goals for the OTEC program, has to define the extent of an environmental insult that might occur as a result of the emplacement of a full-size (100+ MW) OTEC power plant at any of the more suitable sites. One aspect of this investigation is to look at the effects of the effluent from the plant if the two intake systems were mixed together prior to their being expelled from the plant.

There are a variety of methods that could be used to study the fate of such an effluent. However, some assumptions must be made before any particular experimental technique is decided upon. The effluent shall be assumed to be departing from the plant so that it will settle at the 100 meter depth. This means that the density of the water, that combination of temperature and salinity, will be be such that it will be equal to the normal 100 meter depth density, although the temperature and/or salinity of the effluent will most probably be considerable different from that at 100 meters depth. This 100 meter depth condition will probably be true some time, with both shallower and deeper conditions also possible. It is also assumed that the effluent shall be originating at or near

the "OTEC area" to the southeast of Punta Tuna, Puerto Rico.

The currents in the area are poorly known from an environmental impact point of view, and the circulation is even more poorly known. It was felt that, while current meter arrays were already being placed in the area to determine flow characteristics throughout the entire water column for a variety of uses, the particular type of measurement needed for this program was a lagrangian measurement that actually followed a typical water parcel that left the OTEC site at the 100 meter depth.

An eulerian (point-type) measurement, such as a current meter, is not as meaningful in this case. The speed, direction, and trajectory of the effluent was considered to be so poorly understood, that very little could be predicted of the circulation of this 100 meter deep water after it left the site.

Various types of lagrangian measurements were considered, such as dye, Swallow floats, bio/chemical tracers, radio-active tracers, and deep-sea drogues. The dye technique, as were the bio/chemical and radio-active tracing, was eliminated due to cost, ship time, and the potentially low dilution rates. Swallow floats had to be discarded at this time due to their high cost, although they are probably the most useful compromise for water-parcel tracking. The deep-sea drogue concept was adopted, as it could be easily combined with other local operations, thus minimizing cost while maximizing the scientific returns and not sacrificing many of the useful characteristics of the other techniques.

2.2 DROGUE DESIGN CRITERIA

After the decision was made to use a lagrangian-type of measurement in the form of deep-sea drogues, the following design criteria were accepted to determine the design of the hardware, the materials, and the experimental procedures.

1. The design of the hardware for the drogue and its basic components were to have already been proven as functional, reliable, and suitable for this program's needs. There was no allocation in the program for even a modest experimental or developmental phase. A literature survey was made, however, to help evaluate the variety of potential design concepts.

2. All hardware used for the construction of the drogue and any ancilliary equipment must have already been proven to be materials that were suitable for their proposed use. Again, no material testing program was anticipated, due to the time and resource limitations. Therefore, materials, their capabilities, assembly, and use, must be known before they were incorporated into the drogue design.

3. All hardware to be used at sea must be deployable and recoverable from the available 13 meter long ship-to-shore vessel under reasonable sea conditions. As a drogue tracking operation is time-intensive, the availability of a large, chartered vessel to be on-call during the entire cruise operation was prohibitive. Therefore, by compromise with the DOE/OTEC Biofouling Group and the UPR/CEER OTEC Division, all field operations that were to be accomplished by this trajectory program would be in concert with the already operating Biofouling

and Corrosion study at the Punta Tuna site. The Biofouling and Corrosion study had, as part of its daily operation, the use of the 13 meter ship-to-shore vessel, along with the moored mother ship. The use of these two vessels would minimize cost and simplify operations for the drogue tracking study.

4. The drogues were required to be sensitive to the water motion at 100 meters depth (or any other subsequently chosen reasonable depth). In satisfying this criterium, the assembly was to have little air or wind/water-surface drag, compared to the drag at the 100 meter depth. This requirement would apply to any lagrangian measurement (or virtually any type of measurement, as high signal-to-noise ratio). The wind at Punta Tuna averages about 5-10 m/sec, with frequent higher gusts, and as the wind may be moving in a direction different from that of the 100 meter deep water, this "sail effect" must be minimized. Furthermore, the water current at the surface frequently moves at high speeds, and in different directions from that at 100 meters. Therefore, any error due to this velocity shear must also be minimized.

5. The field equipment is subject to the usual location/positioning and cost constraints of a modest program, such as this. Therefore, sophisticated techniques were not anticipated, if not already available in-house. Conventional techniques and equipment were acceptable, if they were already part of the available capabilities.

6. The equipment and procedures were to be useable for a period of about one year, the length of the program. The

program length and resource constraints limited the life-expectancy of the equipment to this period. A further extension of any equipment capabilities could result in a severe rise in cost and design time, neither of which was necessary to accomplish the programmatic goals.

2.3 HARDWARE DESIGN

In an attempt to satisfy the above criteria for the deep-sea drogues, the final design is but a minor modification of the basic design of Terhune (1965) or Monahan (1975).

This design, as seen in Figure 4, consists of three of the usual drogue components: a surface buoyancy/locating member, a deep-sea motion-sensitive surface, and a connecting line between the two.

The subsurface, motion-sensitive surface is a large, flat sheet or window-shade shaped panel. The panel is made of 0.15 mm (6 mil) thick plastic sheeting, about 6 meters wide by 15 meters deep. The panel is weighted by a heavy pipe at the bottom to keep it firmly extended downward. The top is supported in the open position by a lighter pipe. To prevent excessive vertical stress on the plastic, vertical lines are tied top-to-bottom from the ends of both pipes. The lines are cut to be slightly shorter than the panel, so the lines, not the plastic, will hold the weight of the bottom pipe. The panel is then kept open to its full area but feels very little of the weight of the heavy bottom pipe.

The panel assembly is attached through a multi-connection yoke to the 6.44 mm (1/4 inch) diameter nylon connecting line

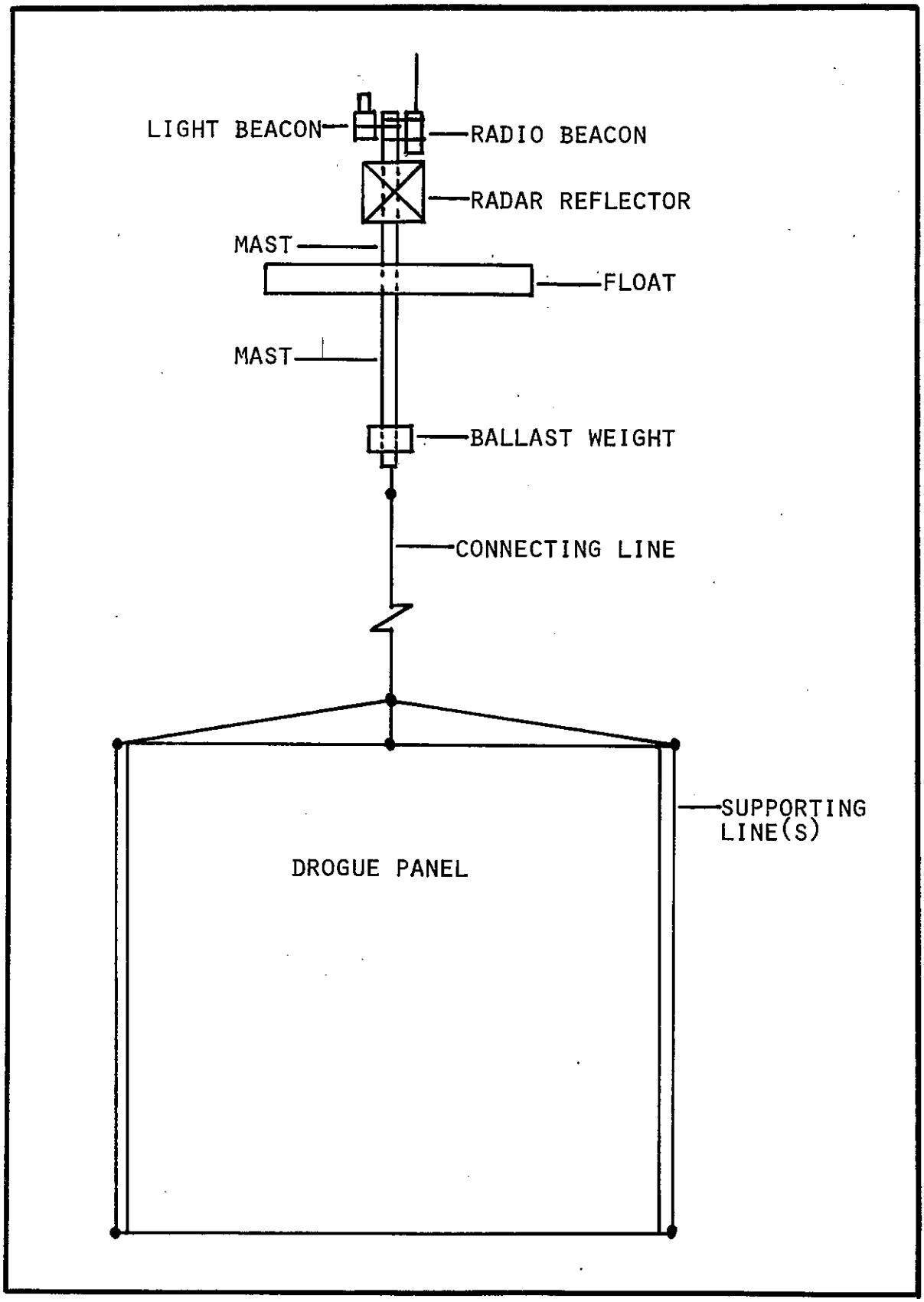

Figure 4. Final drogue design

that extends up to the surface member.

The flotation component of the surface assembly consists of a 1.2m by 1.2m by 0.15m (4 ft by 4 ft by 1/2 ft) piece of molded styrofoam, originally designed as insulation for walk-in refrigerators and freezers. The styrofoam is sandwiched between pieces of plywood. Resin and epoxy cover the entire flotation assembly to minimize abrasion, breakage, and water contact. This assembly is designed to float about mid-way out of the water, with the large cross-section facing up and down, presenting the minimum drag surface to the air/water interface. A six meter long mast is connected vertically through the float at about the mid-point of both the float and the mast. The subsurface portion of the mast is weighted near its bottom to maintain good vertical stability, even with the connecting line and subsurface panel, and its associated drag (and downward force) not present. The uppermost portion of the connecting line from the panel is attached to the mast immediately below the weights. The upper portion of the mast contains a 1 meter by 1 meter brightly colored flag, two radar flectors, a continuously flashing beacon light, and a continuously transmitting radio beacon. All these devices on the mast are used to help locate the float and drogue beneath it.

In order to evaluate the relative success of this design with regard to the design criteria, the following comparison is made:

1. Proven design: The pattern and tests for this "window shade" design were reported as early as 1965 (Terhune, 1965), with actual use of such a pattern extending back as much as 400 years (Monahan and Monahan, 1973).

2. Proven hardware: This design uses no material or component that has not previously been used for either our intended use directly, or one similar.

3. Operation from a 13m vessel: This particular overall design was chosen because the panel can be easily removed from the free-floating surface assembly, then can be rolled up on either of the two supporting pipes, much as a window shade rolls onto its roller. Also, using this technique, the entire drogue can be conveniently deployed from the small vessel by placing the surface member into the water, then, after connecting the line between the float's mast and panel, simply unroll the panel into the water. Recovery is accomplished by simply reversing the procedure.

4. Sensitivity to 100m depth: Briefly, the area of the panel is about 100 times as great as the combined cross-sectional areas of all the other elements of the drogue. Under the most severe conditions, this will easily satisfy the requirement that the trajectory of the entire assembly will, in fact, move with the water parcel at a depth of 100 meters.

5. Positioning/locating techniques: The use of a radar system, complimented by both hand-bearing compass and/or horizontal sextant readings, maximized the available in-house capabilities.

6. One year life: Although the equipment is not necessarily heavy duty, care was taken in chosing the component materials to insure a reasonable and rugged life. The projected weak links in the equipment durability were the mast flexibility, the upper panel supporting pipe, and the panel, itself. Experience proved us correct, and the appropriate steps were taken during the program to correct any weaknesses as they appeared. The radar gave us problems, but these appear to be due to the particular instrument, rather than the model or design.

2.4 EXPERIMENTAL PROCEDURES

With few exceptions, the following procedures were used during the field and data processing aspects of this program.

The field operations revolved aroudn the mother ship, the LCU-1470. This vessel is under contract to the UPR/CEER by the U.S. DOE to perform Biofouling and Corrosion studies while moored in deep, nearshore water off Punta Tuna. The taut-line mooring in 1150 meters of water gives the mooring buoy a possible 0.5 km radius excursion-circle at the surface. The mooring is located at $17^{o}57.6'$ N, $65^{o}51.9'$ W, about 4 km southeast of Punta Tuna. Because the vessel did not appear on station until mid-January 1980, the first cruise of this program was conducted from aboard the R/V SULTANA during the course of its CEER-Punta Tuna operations in November 1979. Subsequently, all drogue operations used the LCU and its associated ship-to-shore vessel.

The LCU-1470 (Landing Craft Utility) is 35 meters long, 10 meters wide. The ship-to-shore vessel is 13 meters long, and made at least one daily round-trip excursion between land to the LCU, when possible. During our round-the-clock operations, the ship-to-shore vessel was used primarily for drogue recovery (during the daylight hours) or for sextant or hand-bearing compass positioning, if the drogue had travelled beyond the range of the radar aboard the LCU.

Prior to deployment from the LCU, all the drogue components and auxilliary equipment were checked for good repair and proper operation. The connecting line (running from beneath the mast to the panel) was premeasured to insure that the mid-depth of the panel was set at 100 meters, a depth not varied purposefully throughout the program. All components of the drogue were then collected on the deck of the LCU.

The mast was placed into the water first. However, before its launching, all flags, radar reflectors, radio beacons, lights, and lines were suitably attached and made operational.

The next step was the unrolling of the drogue panel, a three-man operation. With the panel fully unrolled and connected to the mast via the connecting line, the panel was released to descend to its present depth. At this point, care was taken to try to prevent entanglement between the connecting line and panel, and any sub-surface lines or equipment near the LCU. Occasionally this entanglement did occur, and the necessary corrections were made, if the fouling was noticed.

From this temporal point in the procedure, all times were recorded, such as deployment, position fixing, and recovery. All times were noted as local time (Atlantic Standard Time - A.S.T.).

To obtain the location of the drifting drogue (position fixing), the radar aboard the LCU was employed, when possible. This radar is a Raytheon, Model 3100-MKII, with distance (range) scales of 0.5, 1.5, 3, 6, 12, and 32 nautical miles and a probable error on each range of $\pm$0.05 km, $\pm$ 0.25 km, $\pm$0.6 km, $\pm$1.1 km, and $\pm$3 km, respectively. The range data from the radar was observed and recorded in nautical miles, then converted to kilometers during the data analysis. The direction from the axis of the ship to the drogue (bearing) was determined from the radar, and was readable to $\pm$1 degree, with an overall probable error of $\pm$5 degrees. The viewing screen of the radar was 17.5 cm in diameter. To accurately locate a remote object, the radar was first used to observe two known terrestrial locations so as to fix both the location of the LCU and its orientation with respect to true north (deg-T). The radar was then used to make a range and bearing measurement to the drogue. These two sets of measurements, the fixed locations and the drogue, had to be made within only a few seconds to insure the same relative orientation of the LCU to the land points and the drogue, as the vessel was always swinging from its mooring line. This procedure was repeated from the time of deployment until recovery at intervals of .5-2 hours, or longer, depending on the conditions of the radar and the availability of personnel.

On the few occasions where the drogue was beyond the 10 km range of the radar (the range is forshortened because of the low height of the drogue mast), the radar was out of order, and the ship-to-shore vessel was available, this small vessel was used to determine the location of the drogue. The vessel was brought to a position near the float/mast assembly of the drogue. From the deck of the ship-to-shore vessel, prominent land features were chosen that were both easily identifiable and locatable on both the charts and by either a hand-bearing compass or a horizontal sextant. In the case of the hand-bearing compass, the bearing (relatable to magnetic north) was determined to as many of the landmarks as possible. Using the horizontal sextant, the directional distance, in absolute degrees, was measured between at least three different landmarks. As this procedure from aboard the ship-to-shore vessel involved more in-the-field errors, the technique was reserved only to extreme cases.

A typical radar data sheet is shown in Figure 5. The data sheet shows the radar range and bearing values to known land locations (i.e., Punta Tuna, Punta Yeguas, Punta Toro), the range and bearing to the drogue, time, date, wind speed and direction, and surface current direction.

The actual location plotting is done on a chart, #25659-Punta Maunabo (N.O.S., 1975), with a scale of 1:20,000, or 1cm = 0.2km. A three-arm protractor has its two movable arms set to the bearings toward the fixed land points. After these arms are set on the chart range to both locations, the origin

CRUISE # LC-910. PAGE 1 OF 2.

RADAR METHOD OF DETERMINING DROGUE LOCATIONS (SIGHTINGS TAKEN FROM LCU)

T.I M E 10-DAY-YR-AST	DROG #	WIND SPD-DIR FROM	SEA ST	SURFACE DRFT CM/S-DIR TOWARDS	To Drogue DEG-DIST	To Light DEG-DIST	To Pt. Toro DEG-DIST	COMMENTS
0950 7-19-80	A	Released from LCU						Note A
1020 7-19-80	A	15 SE	1	E.	167°/0.2	255°/2.0	298°/2.8	
1100 7-19-80	A	15 SE	1	E	163°/0.8	256°/2.0	300°/2.8	
1200 7-19-80	A	15 SE	1	WNW	149°/0.8	255°/2.0	299°/2.8	Moveing S
1325 7-19-80	A	15 SE	1	WNW	151°/1.25	254°/2.0	297°/2.8	W
1405 7-19-80	A	15 SE	1	WNW	153°/1.5	253°/2.0	296°/2.8	W
1500 7-19-80	A	15 SE	1	W	173°/1.9	271°/2.1	313°/2.9	W
1605 7-19-80	A	15 SE	1	SW	168°/2.2	261°/2.1	305°/2.9	
1700 7-19-80	A	15 SE	1	W	150°/2.5	245°/2.0	290°/2.8	W
1815 7-19-80	A	15 SE	1	W	154°/2.9	246°/2.0	291°/2.8	
1900 7-19-80	A	20 E	1	W	162°/3.2	255°/2.0	299°/2.9	
2000 7-19-80	A	20 E	1	W	166°/3.4	252/2.0	296°/2.8	
2100 7-19-80	A	20 E	1	W	167/3.9	257°/2.0	300°/2.8	
2130 7-19-80	A	20 E	1	W	169/4.0	244/2.0	291/2.8	
2200 7-19-80	A	20 E	1	W	No Can See!!			TNX OK
2300 7-19-80	A	20 E	1	W	162°/4.8	244/2.0	289/2.8	
2400 7-19-80	A	20 E	1	W	No Can See!!			
					can not see			

Figure 5. Example of typical data sheet

of the protractor then locates the LCU, and the non-movable arm of the protractor faces the direction of the radar "zero" bearing. The angular scale of the protractor is now showing the bearing to the drogue, and the range is measured from the origin, using the proper scale. The distance to each successive point and from Punta Tuna are taken from this chart, and all the distance and direction information is calculated and then transferred to a chart with a scale of 1:100,000 for ease of display. In a few cases, either the subsequent transfer had to be further reduced, or the trajectory was so short as to eliminate any need for changing the scale from that of the original chart.

2.5 ERROR ANALYSIS

There are a variety of errors that are encountered during this type of measurement and analysis program. As with all measurements, an attempt is made to minimize those errors over which there is some control, understand and acknowledge the systemic errors and, finally, chose the measurement procedure, equipment, and analysis method to optimize the compromise between accuracy, efficiency, cost and time. The procedure, described previously, is such a compromise. The final results of this program can then be evaluated after taking into consideration, that these results may include a combination of various errors. The major errors will now be enumerated and discussed, with quantitization indicated, where possible.

The final product of this program is to produce knowledge regarding the trajectory of the water moving past Punta Tuna

at 100 meters depth. Therefore, the results shall be a drawn trajectory that is made up of a series of connected vectors. Each vector shall describe the speed and the direction of the water during a specific time interval. These results are created from a series of basic measurements. Calculations are then performed, and the values are plotted onto a chart to describe the motion. However, the actual speed and direction are not the primary product of this method, they are a final product and, therefore, are based upon all the previous results (and the associated errors) leading up to the mathematical determination of the speed and the direction. A more accurate description of the data analysis is seen in Figure 6. The basic measurements are "DISTANCE" and "DIRECTION" to the various points (landmarks and the drogue) from the vessel that is secured to the buoy. The buoy is moving relative to the unknown, also. It is acted upon by various forces, both at the water surface and along its anchoring line. The vessel (the LCU) is also moving relative to the buoy, twisting, swaying, and swinging on its mooring line. All these various factors must be taken into account to determine both the desired results of this study, and a true estimate of the accuracy of those results.

The major mileposts along the measurement and analysis path (assuming the typical experimental procedure) are:

1. Time Measurement
2. Range Measurement
3. Bearing Measurement

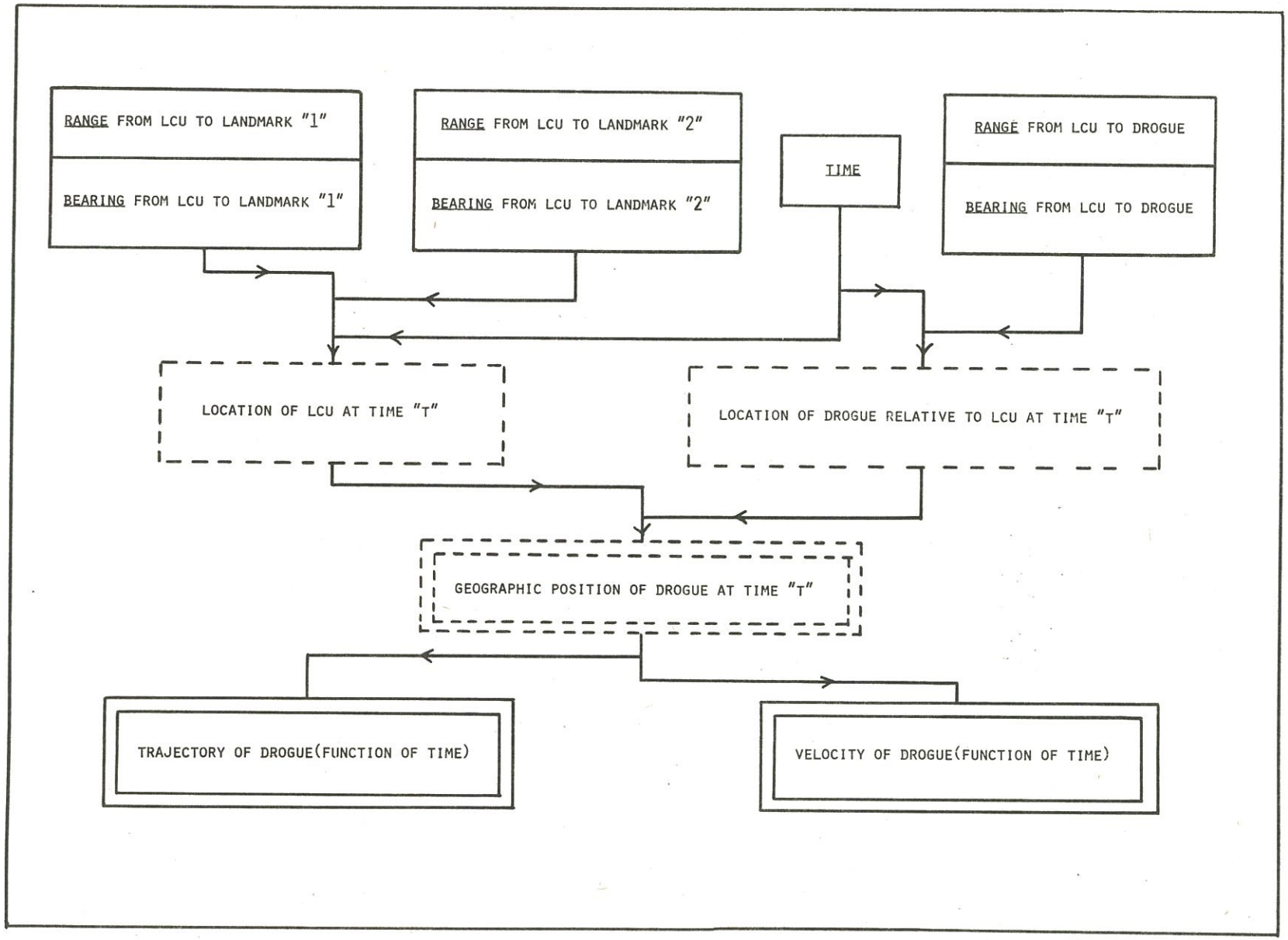

Figure 6. Data flow chart for drogue data

4. Position Determination of the LCU

5. Position Determination of the Drogue - the Trajectory

6. Determination of the Elapsed Direction

7. Determination of the Elapsed Time

8. Determination of the Elapsed Drogue Travel

9. Determination of the Drogue Speed

Time Measurements - This is a primary measurement, usually read from a single, hand-held clock or watch during the course of the cruise. As the reading of range and bearing to the two landmarks and to the drogue may take about one minute (60 sec), and the watch is readable to ±1 sec, the estimated error shall be indicated as ±30 sec. The relative percentage of this error will change, depending on the elapsed time between readings. During this error discussion, a time interval of one hour (3600 sec) shall be assumed for the calculations, yielding a possible error of ±1%.

Range Measurements - This is a secondary measurement. The radout is through the eye of an observer and is interpreted off an electronically produced image on the radar screen. The radar manufacturer states that the error could be as high as ±2% of the reading. However, this estimated does not take into account the rolling and moving of the ship, and the rush to complete the measurement before the LCU swings on the mooring line. A better estimate of the true error of this measurement is ±7%. For this discussion, a typical distance measurement will be taken to be 4 km (2 nautical miles) from the ship, yielding a probable error of ±0.25 km.

Bearing Measurements - This is also a secondary measurement that is read from the radar screen, as is the range measurement. The manufacturer's specificatins indicate only that the bearing measurement is readable to ±1 degree of bearing. However, considering the motion of the vessel and the parallax involved in reading from the screen, a ±2.5 degree error is more realistic.

Position Determination of the LCU - This measurement is a complex series of steps using the previous range and bearing values toward at least two separate, but known landmarks, then transferring these values to a chart by using a three-arm protractor and a chart scale of 1 cm = 0.2 km. The resultant procedure yeilds an error of up to ±0.15 degrees of latitude or ±0.28 km, and ±0.28 degrees or ±0.49 km of longitude. This is the maximum error, with the probable error (typically a circle of confusion) being less than half that value.

Position Determination of the Drogue - the Trajectory - This is also a combination of measurements, one of which is the Position Determination of the LCU. As a result, the maximum error for this measurement, using the assumed 4 km distance from the LCU as a working distance, could be as high as ±0.25 degrees of ±0.46 km of latitude, and ±0.45 degrees or ±0.79 km of longitude. However, again, these values may be reduced realistically to ±0.18 degrees of ±0.33 km of latitude, and ±0.25 degrees or ±0.46 km of longitude. The average probable error for the 4 km distance is then ±0.4 km, or ±10%.

Determination of the Elapsed Direction - This measurement is determined from the results of two successive Position Determinations of the Drogue, and has a probable error of ±15 degrees-True (relative to North being 000 deg-T).

Determination of the Elapsed Time - This is simply the subtraction of two consecutive Time Measurements, with a resultant probable error of ±45 sec, and a maximum (but unrealistic) error of up to ±60 sec.

Determination of the Elapsed Drogue Travel - This determination is the charg distance between two successive Position Determinations of the Drogue. A realistic estimate of the probable error in this measurement is based on the probable errors between the two successive events, or ±0.56 km, based on our previous assumptions.

Determination of the Drogue Speed - This calculation is based on the results of both the Determination of the Elapsed Drogue Travel and the Determination of the Elapsed Time. The most probable error for this calculation is ±10%, with the maximum possible erros being up to ±20%, using the maximum possible errors for each of the constituent parts.

3.0 RESULTS

During the course of this program, extending from September 1979 until October 1980, eight cruises were conducted in the waters near Punta Tuna. The purpose of each of the cruises was to follow the trajectory of water parcels leaving the possible OTEC site. The method, in all cases, was to determine the trajectory starting from the site at $17^{o}56.9'$ N, $66^{o}51.9'$W, by using deep-sea drogues set to be sensitive to the 100 meter depth. This depth was decided upon after consultation with OTEC designers, environmental measurement experts, and environmental impact modelers.

The cruises occurred in virtually all seasons of the year, beginning with the autumn of 1979 and extending through to the summer of 1980. The actual dates of the cruises were:

9 November 1979

28 January to 1 February 1980

18 to 22 February 1980

24 to 25 March 1980

7 to 11 May 1980

10 to 12 June 1980

24 to 27 June 1980

16 to 23 July 1980

In the following sections, each cruise will be described, with its results discussed.

3.1 CRUISE OF 9 NOVEMBER 1979

On 9 November 1980 a cruise was conducted to Punta Tuna. The following sections describe that cruise, as it pertains to this purpose.

3.1.1 NARRATIVE

The drogue operation described herein was performed by members of the Marine Ecology Division of UPR/CEER during the course of their operations in the vicinity of Punta Tuna, P.R.

The drogue, without its radar reflectors, radio beacon, or flashing light, was launched at 0800 A.S.T. on 9 November 1979. The location of the deployment was 0.4 km at a bearing of 241 deg-T from the mooring buoy. Unfortunately, during this entire cruise all ranges and bearings were taken relative to the mooring buoy, rather than fixed landmarks. The buoy may have moved through a circle of radius of at least 0.5 km during the time of the cruise.

The vessel used for deployment and for all range and bearing measurements was the R/V SULTANA, operated by the UPR/CEER. This vessel is 14 meters long, and is equipped with an onboard radar whose capability is probably more accurate than $\pm$ 0.1 km and $\pm$ 5^{o}, when operated on its most sensitive range by experienced personnel.

During the deployment, the drogue's mast was broken, it was repaired while still in the field, with subsequent structural weakening. The previously described method for deployment was not used.

The drogue trajectory was followed from 0800 until 1540 that afternoon, a period of almost 8 hours. The drogue was last seen on the radar at 1630, but not again. At its last siting, it was about 0.5 km northeast of the deployment position. The drogue was never recovered.

3.1.2 RESULTS

The 100 meter deep water was tracked for slightly less than eight hours (0817-1540 A.S.T., 9 November 1979). During that time, the trajectory took the path shown in Figure 7. Although the net travel during the total period was to the northwest, the water moved northeast then westerly, with a gyre developing during hours 2-6 of the observation period.

During the drifting period the wind was generally out of the east at 2-4 m/sec.

The elapsed time between drogue sitings ranged from 0.9-1.7 hours, and the distances traveled during the elapsed time ranged from 0.04-0.56 km (not considering any error due to the buoy movement). This information and other used to determine the statistical properties of the drogue movement can be seen in Table 1. The speeds observed during the cruise ranged from 1-10 cm/sec, with an average of 5 cm/sec. As seen in Table 2, the percent of time of the speeds was between 1 and 10 cm/sec and is fairly uniform, as are the direction of motion observations.

Figure 8 shows the predicted directionality for the two tidal systems as well as the observed directionality of the drogue. The tides do not appear to be influencing the observed drogue motion.

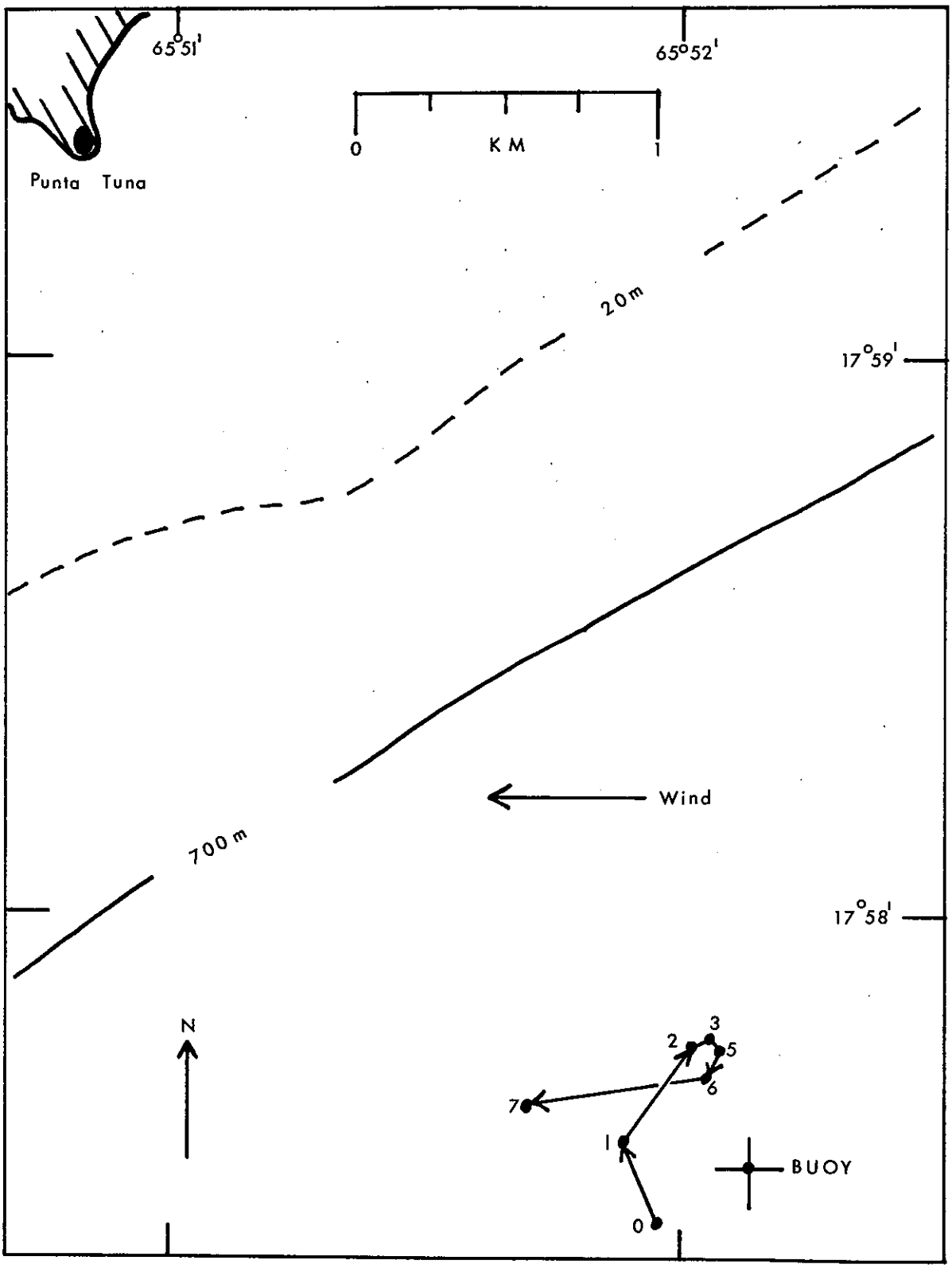

Figure 7. Trajectory for drogue off Punta Tuna, Puerto Rico begining 0830 on 9 November 1979.(Numbers are elapsed time in hours; depth is 100 meters)

TABLE 1

DROGUE DATA AND CALCULATIONS:

Cruise of 9 November 1979

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1979)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-T)	SPEED FROM PREVIOUS PT. (cm/sec)
17°57.6'	65°51.9'	9 Nov	0817	0.0	---	----	---	--
					1.5	0.26*	338	5
17°57.7'	65°52.0'	9 Nov	0945	1.5	---	----	---	--
					1.0	0.35*	037	10
17°57.9'	65°51.8'	9 Nov	1043	2.5	---	----	---	--
					0.9	0.05*	071	2
17°57.9'	65°51.8'	9 Nov	1138	3.4	---	----	---	--
					1.5	0.04*	142	1
17°57.9'	65°51.8'	9 Nov	1308	4.9	---	----	---	--
					0.9	0.09*	204	3
17°57.8'	65°51.8'	9 Nov	1400	5.8	---	----	---	--
					1.7	0.56*	261	9
17°57.8'	65°52.1'	9 Nov	1540	7.5	---	----	---	--

* No correction is made for any Buoy movement

TABLE 2

SUMMARY OF DROGUE "A" WATER MOTION MEASUREMENTS:

Cruise of 9 November 1979

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	33	345 - 014	
3 - 5	32	015 - 044	13
6 - 8	0	045 - 074	12
9 - 11	36	075 - 104	
12 - 14	0	105 - 134	
15 - 17	0	135 - 164	20
18 - 20	0	165 - 194	
21 - 23	0	195 - 224	12
24 - 26	0	225 - 254	
27 - 29	0	255 - 284	22
30 - 32	0	285 - 314	
33 - 35	0	315 - 344	20

Average Speed = 5 cm/sec

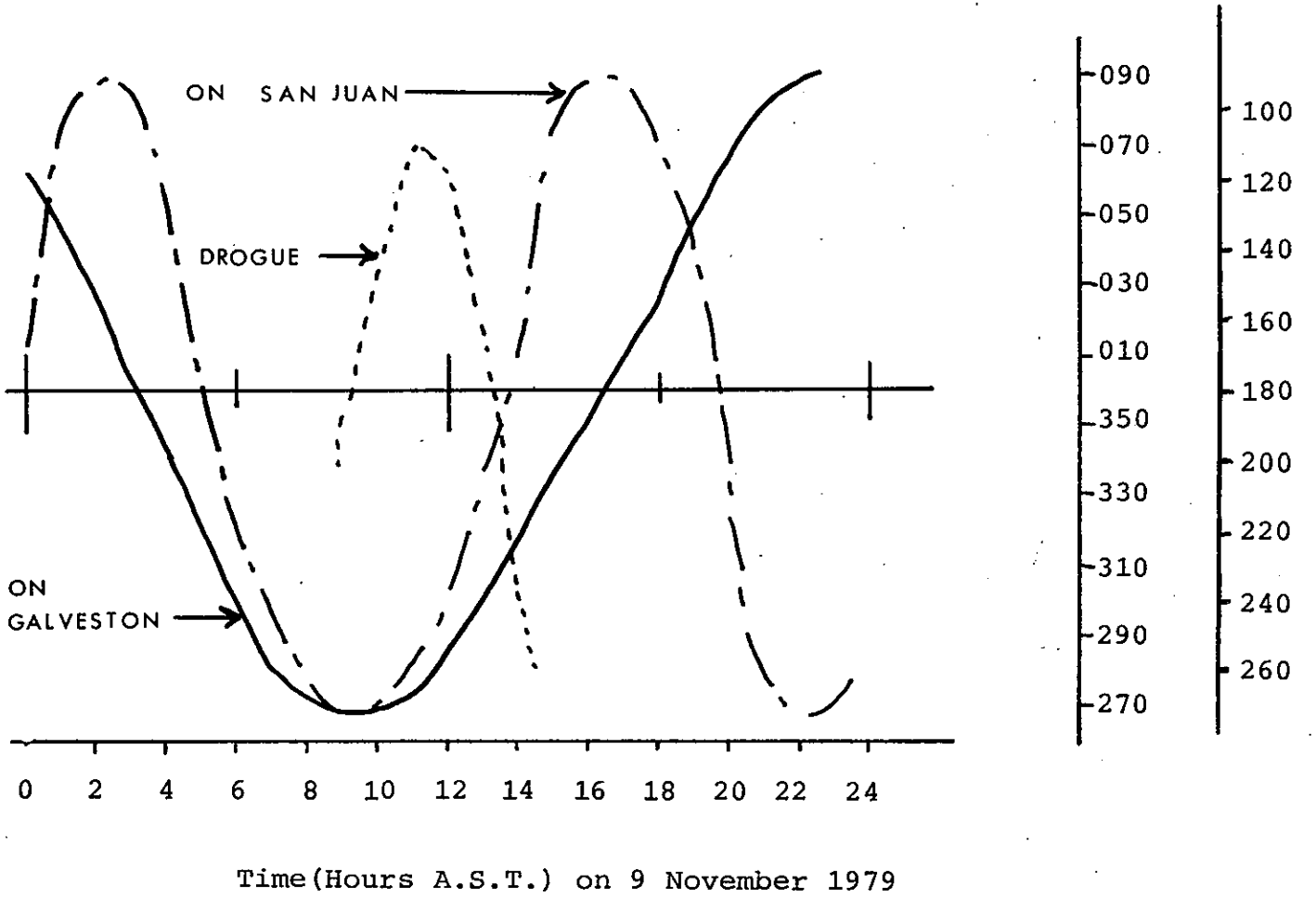

Figure 8. Directionality of drogue and predicted tidal currents on 9 November 1979 at Punta Tuna, Puerto Rico.

drogue motion.

The most important consideration during this brief observational period is the potential error in positioning the drogue due to the unknown location of the mooring buoy, relative to which the drogue was located. The buoy is subject to considerable surface wind and water motion, because of its large cross-sectional area. The buoy system also has a large cross-sectional area (about 5-10 times that at the surface) devoted to its 5 cm diameter 1150-meter-long anchor line. These two drag forces combine to produce a variety of directionally additive forces pushing the buoy around. At no time during this cruise was any attempt made to accurately locate the buoy relative to any landmarks. As the buoy could move anywhere within a circle of radius of 0.5 km, and as the estimated accuracy of the radar is only $\pm$ 0.1 km, and because of the greatest elapsed distance measured was only 0.56 km, it is quite possible that the error in positioning the drogue and, therefore, the water parcel is larger than the measured travel distance.

3.1.3 INTERPRETATION

Due to the large uncertainty of the buoy location, and the normal errors in locating the drogue relative to the buoy, it is unlikely that any validity can be related to the water trajectory movement during this cruise.

The time periods, both inter-siting and total for the drogue following, are short enough to leave considerable doubt as to the causes of the water motion, as well as the reliability of the description of the motion.

3.2 CRUISE OF 28 JANUARY - 1 FEBRUARY 1980

The following sections describe the activities and results of the cruise of 28 January - 1 February 1980.

3.2.1 NARRATIVE

Drogue "A" was deployed from the LCU-1470 at the mooring, as per the usual deployment procedure. The deployment was accomplished at 0830 A.S.T. on 28 January 1980. The drogue was tracked using the radar aboard the LCU for about 48 hours. However, the last eight hours of this period yielded unreliable results due to a combination of radar electronic problems and the inability of the radar to uniquely detect the above water section of the drogue at distances greater than 10 km. The next half-day of tracking involved using both the horizontal sextant sitings from the ship-to-shore vessel (maneuvered near the drogue) and using the LCU's radar to determine the position of the small vessel, rather than try to identify the drogue on the radar. The sextant readings later proved unreliable. The drogue again became clearly visible on the radar at 1700 on 31 January. The radar tracking was continued until 1400 on 1 February, for a total drift of 101 hours. The recovery using the ship-to-shore vessel was accomplished at a distance of only 3 km southwest of the LCU. Drogue "C" was deployed at 1100 on 30 January and was seen to drift until 1100 on 1 February, a period of 48 hours. However, due to a variety of reasons, no reliable trajectory data resulted for this second drogue.

3.2.2 RESULTS

Aside from the occasional losses of data for drogue "A", about 30%, and the loss of the entire trajectory of drogue "C", the cruise was moderately successful. The 101.5 hours of drifting for drogue "A" produced sufficient time to identify a variety of phenomena, as well as log the longest deep-sea drogue tracking in this part of the Caribbean sea. (This duration on a single drogue was not to be duplicated during any other tracking period throughout this program.)

As seen in Figure 9, the trajectory of drogue "A" moved in a generally easterly direction (both northeast and southeast) for about 40+ hours. After that time, the path was almost due west. Furthermore, at about hours 8, 40, and 85, a clockwise gyre was seen (hour 85 actually had insufficient data to identify any more than a short directional change). The average elapsed time between these gyres is 38+ hours. The inertial period for the latitude of the drogue is 39 hours.

Although the direction of the surface current was noted only during the first day of the observation period, that observation is significant, as the surface water moved westward while the 100 meter deep water was being observed to be moving eastward. This points out the different forces and reactions to these forces by the upper water mass (Tropical Surface Water), and the water mass of our concern, the Subtropical Underwater.

The wind was seen to be out of the easterly quadrant throughout the majority of the drifting period. Furthermore,

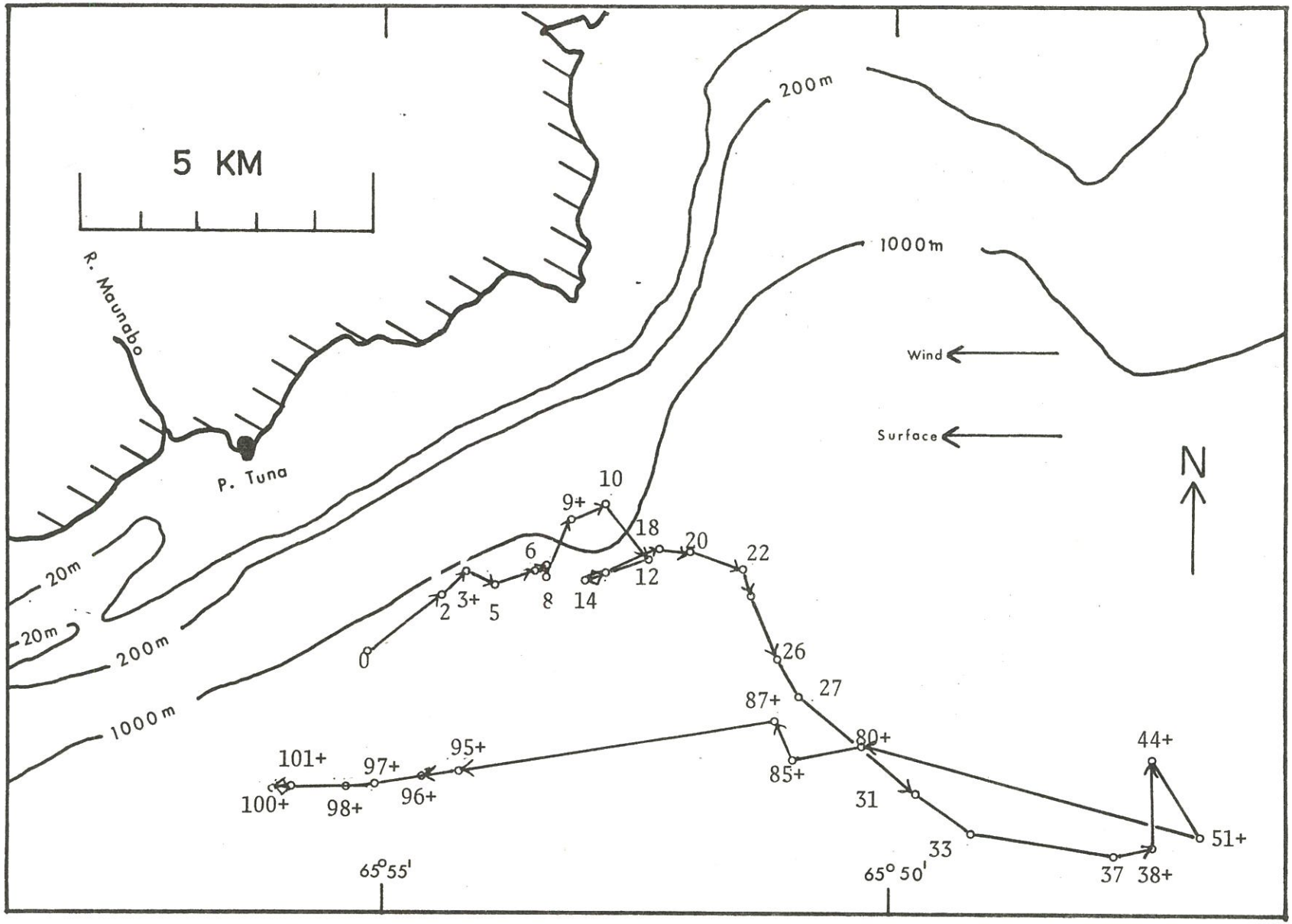

Figure 9. Trajectory for Drogue "A" off Punta Tuna, Puerto Rico from 28 January-1 February 1980.(Numbers are elapsed time in hours;depth is 100 meters)

the atmospheric pressure was moderate during the first half of the period, then dropped to the lowest in two months during the last two days of the period. Table 3 shows the data from which the statistics for the speed and direction were calculated for this cruise. The average time involved between sitings was three hours, with the actual time intervals ranging from 0.8-29 hours. The distance traveled between sitings ranged from 0.09 - 5.96 km.

The actual statistics for the speed and direction are shown in Table 4. The speeds ranged from 2-24 cm/sec, with the speed range of 6-8 cm/sec seen most of the time, and the average speed was 11 cm/sec. The distribution of observed directions of travel show the east-west bimodality of the trajectory. Forty-nine percent of the time the water moved toward between 045-164 deg-T and 46% between 255-284 deg-T.

Figure 10 shows the relationship between the two tidal systems and the drogue directions over the same time period. Of the 4 strong diurnal periods corresponding to an ebbing flow for the "Galveston" system, three correspond to a relative easterly change in motion for the drogue. However, due to the extended time involved in an inertial wave, these same three cases may also match the inertial motion, considering possible time errors. Conversely, two of the four westerly tidal drifts correspond to similar relative westward motion of the drogue.

With regard to the more pronounced semidiurnal oscillation of the "San Juan" system, only those activities that also coincided with the "Galveston" diurnal component matched any relatable east-west motion of the drogue.

TABLE 3

DROGUE DATA AND CALCULATIONS:

Cruise of 28 January - 1 February 1980

LATITUDE (deg. N)	LONGITUDE (deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°57.6'	65°51.9'	28 Jan	0830	0.0	---	----	---	--
					2.0	1.52	054	21
17°58.1'	65°51.2'	28 Jan	1030	2.0	---	----	---	--
					1.5	0.54	048	10
17°58.3'	65°51.0'	28 Jan	1200	3.5	---	----	---	--
					1.5	0.50	112	9
17°58.2'	65°50.7'	28 Jan	1330	5.0	---	----	---	--
					1.0	0.41	070	11
17°58.2'	65°50.5'	28 Jan	1430	6.0	---	----	---	--
					1.0	0.48	076	13
17°58.3'	65°50.2'	28 Jan	1530	7.0	---	----	---	--
					1.0	0.09	194	2
17°58.3'	65°50.2'	28 Jan	1630	8.0	---	----	---	--
					1.2	1.03	024	24
17°58.8'	65°50.0'	28 Jan	1740	9.2	---	----	---	--
					0.8	0.57	067	19
17°58.9'	65°49.7'	28 Jan	1830	10.0	---	----	---	--
					2.0	1.15	137	16
17°58.4'	65°49.2'	28 Jan	2030	12.0	---	----	---	--
					2.0	1.11	252	15
17°58.3'	65°49.8'	28 Jan	2230	14.0	---	----	---	--
					2.0	0.33	073	5
17°58.3'	65°49.7'	29 Jan	0030	16.0	---	----	---	--
					2.0	0.94	069	13
17°58.5'	65°49.2'	29 Jan	0230	18.0	---	----	---	--
					2.0	0.56	095	8
17°58.5'	65°48.8'	29 Jan	0430	20.0	---	----	---	--
					2.0	0.93	111	13
17°58.3'	65°48.4'	29 Jan	0630	22.0	---	----	---	--
					1.5	0.41	153	8

TABLE 3

Cruise of 28 January - 1 February 1980 (Continued)

LATITUDE (deg. N)	LONGITUDE (deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°58.1'	65°48.3'	29 Jan	0800	23.5	---	----	---	--
					2.5	1.13	153	13
17°57.5'	65°48.0'	29 Jan	1030	26.0	---	----	---	--
					1.0	0.68	149	19
17°57.2'	65°47.8'	29 Jan	1130	27.0	---	----	---	--
					4.0	3.02	130	21
17°56.2'	65°46.4'	29 Jan	1530	31.0	---	----	---	--
					2.0	1.15	124	16
17°55.8'	65°45.9'	29 Jan	1730	33.0	---	----	---	--
					4.0	2.35	099	16
17°55.6'	65°44.6'	29 Jan	2130	37.0	---	----	---	--
					1.5	0.68	080	13
17°55.7'	65°44.2'	29 Jan	2300	38.5	---	----	---	--
					6.0	1.48	006	7
17°56.5'	65°44.1'	30 Jan	0500	44.5	---	----	---	--
					7.0	1.48	152	6
17°55.8'	65°43.7'	30 Jan	1200	51.5	---	----	---	--
					28.8	5.96	284	6
17°56.6'	65°47.0'	31 Jan	1645	80.3	---	----	---	--
					4.8	1.30	260	8
17°56.4'	65°47.0'	31 Jan	2130	85.1	---	----	---	--
					2.5	0.61	338	7
17°56.8'	65°47.9'	31 Jan	2400	87.6	---	----	---	--
					8.0	5.41	261	19
17°56.3'	65°50.9'	1 Feb	0800	95.6	---	----	---	--
					1.0	0.59	261	16
17°56.2'	65°51.2'	1 Feb	0900	96.6	---	----	---	--
					1.3	0.83	258	17
17°56.2'	65°51.7'	1 Feb	1020	97.9	---	----	---	--
					0.8	0.41	267	14
17°56.1'	65°51.9'	1 Feb	1110	98.7	---	----	---	--
					2.2	1.18	269	15

TABLE 3

Cruise of 28 January - 1 February 1980 (Continued)

LATITUDE (deg. N)	LONGITUDE (deg.W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.1'	65°52.6'	1 Feb	1320	100.9	---	-----	---	--
					0.6	0.17	089	8
17°56.1'	65°52.5'	1 Feb	1355	101.5	---	----	---	--

TABLE 4

SUMMARY OF DROGUE WATER MOTION MEASUREMENTS:

Cruise of 28 January - 1 February 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	1	345 - 014	6
3 - 5	2	015 - 044	1
6 - 8	52	045 - 074	9
9 - 11	4	075 - 104	9
12 - 14	10	105 - 134	9
15 - 17	14	135 - 164	14
18 - 20	10	165 - 194	1
21 - 23	6	195 - 224	0
24 - 26	1	225 - 254	2
27 - 29	0	255 - 284	46
30 - 32	0	285 - 314	0
33 - 35	0	315 - 344	2

Average Speed = 11 cm/sec

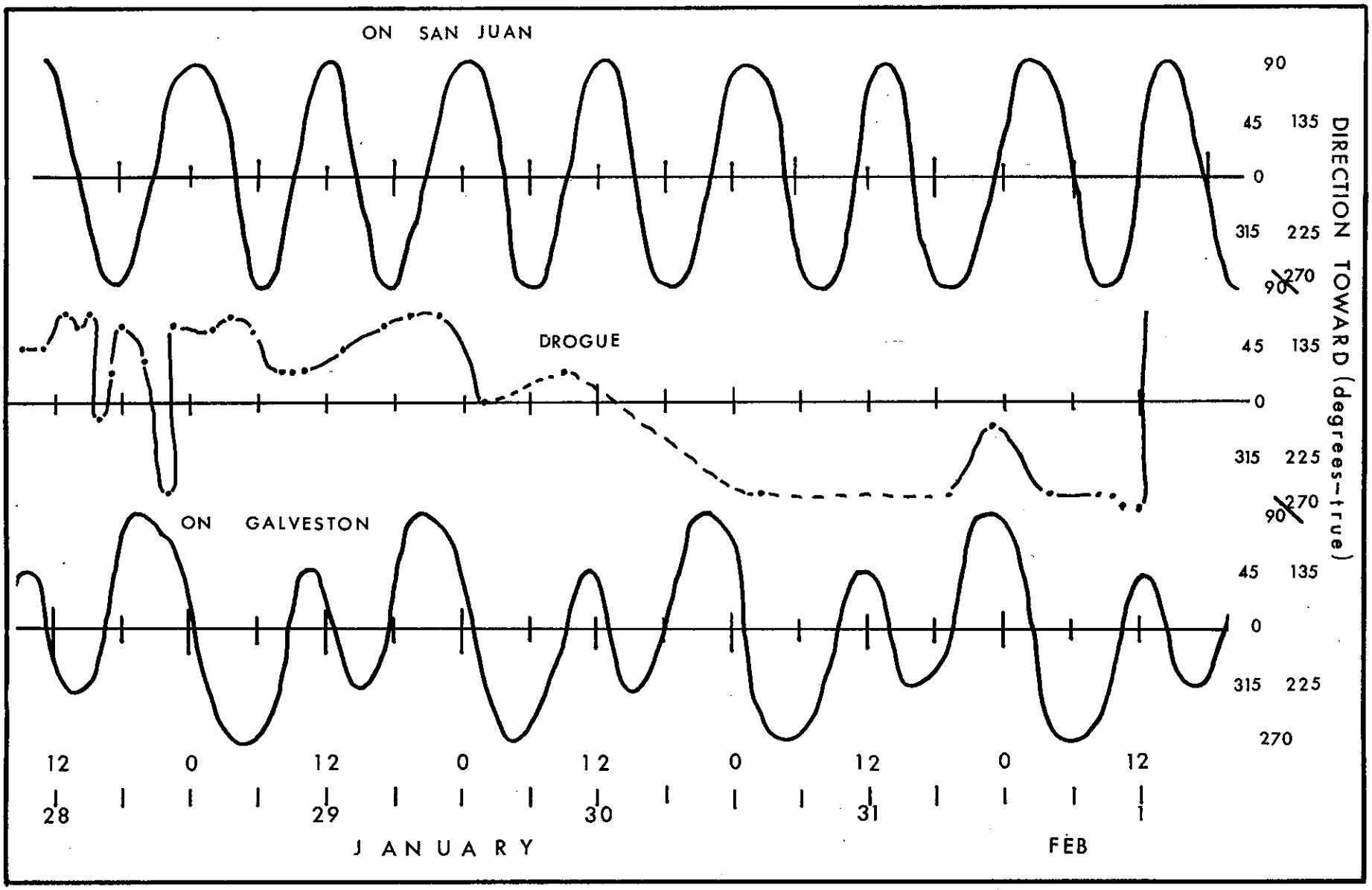

Figure 10. Directionality of drogue and predicted tidal currents during the period from 28 January-1 February 1980 at Punta Tuna

3.2.3 INTERPRETATION

During this period, the tracked water parcel that contained drogue "A" appeared to be influenced by at least three separate forces. There was some tidal relationship, there was an identifiable inertial motion, and, lastly, some longer period energy was causing the entire water parcel to move eastward for about half the 100+ hours then reverse during the latter half. The cause of this last reversal may be very difficult to identify, as we were apparently only observing a sma-l portion of the period, if any periodicity exists at all.

There is strong evidence that the lower, Subtropical Underwater, is moving independent of the Tropical surface Water, which was moving westerly, with the wind, throughout the cruise.

3.3 CRUISE OF 18 - 22 FEBRUARY 1980

The following sections describe the activities and results of the cruise of 18-22 February 1980.

3.3.1 NARRATIVE

Drogue "A" was deployed from the moored LCU at 1430 A.S.T. on 18 February 1980. The depth sensitivity (panel depth) was set at 100 meters. The drogue was tracked using the radar aboard the LCU from the time of deployment until about 0400 hours on 19 February. The position fixing was accomplished either hourly or bihourly whenever possible. After 0400 on 19 February the drogue was no longer discernable on the radar, nor was it heard transmitting on its radio frequency, nor was its beacon light visible. At 0830 on 20 February a search was conducted using the ship-to-shore vessel, but no trace of the drogue "A" was found on that day. (Note-On 26 March 1980 drogue "A" was

located in a storehouse of a fisherman who claims to have "recovered it for us" in the early morning of 19 February.) The total time for reliable data for this drogue was 13.5 hours.

Drogue "C" was deployed at 0930 on 21 February 1980. Again, the deployment was carried out from the LCU, and the drogue was set for 100 meters. This drogue was tracked successfully using the LCU's radar for just over 24 hours, whereupon it was recovered using the ship-to-shore vessel. The recovery took place at 0945 on 22 February, at a distance of 7 km southwest of the LCU. The recovery was accomplished at this time due to weakness of signal on the radar and confusion as to the fate of drogue "A"

3.3.2 RESULTS

Although one drogue was lost, and its respective tracking time forshortened, some data were collected during this cruise which both answer some questions, and ask others.

Figure 11 shows the plotted trajectory of drogue "A" from the time of its deployment at 1430 A.S.T. on 18 February 1980 until its last known location at 0400 on 19 February. The drogue trajectory is almost true west-southwest, with few minor deviations.

During the 13.5 hour tracking period of this drogue, the wind was 2-7 m/sec from the eastern quadrant. No surface currents were indicated by the observers during this period. The atmospheric pressure was medium-to-high both during this cruise and for more than a week after its completion.

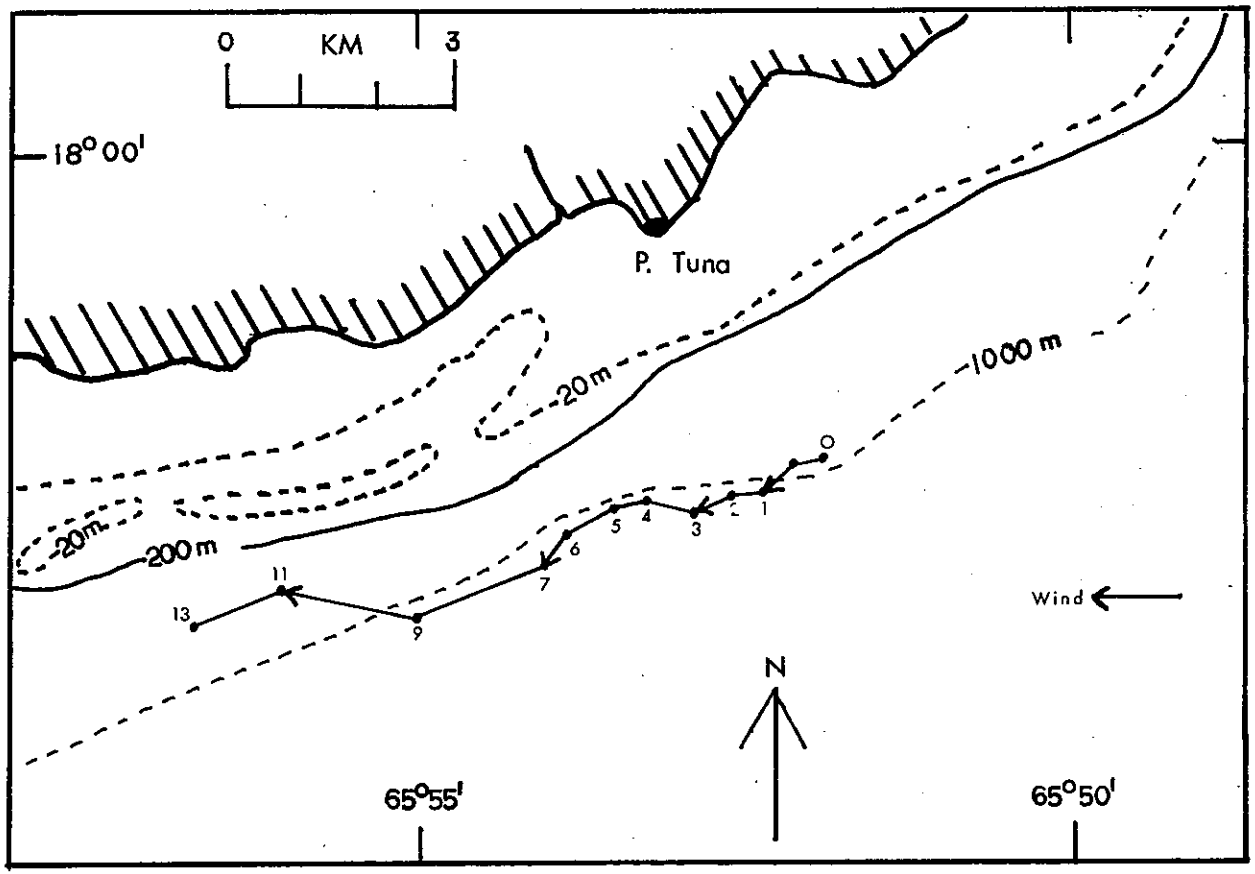

Figure 11. Trajectory for Drogue "A" off Punta Tuna, begining 1430 on 18 February 1980.(Numbers are elapsed time in hours;depth is 100 meters)

Table 5 displays the data on which the speed and direction calculations and statistics are based from drogue "A".

The total period for the drogue tracking was 13.5 hours, with an elapsed time between sitings of 0.5-2.3 hours. The range of distances traveled between the sitings was 0.4 - 1.9 km. The ranges of speed seen (Table 6) for the drogue were 10-26 cm/sec, and the most often seen speeds were 12-14, 15-17, and 24-26 cm/sec. The average speed was 18 cm/sec. The singularity of direction at the 100 meter depth during this period is seen in that 100% of the time the direction was in the range of 195-315 deg-T, with observations between 225-284 deg-T for 85% of the time.

Figure 12 shows the plotted trajectory of drogue "C" from the time of its deployment at 0930 on 21 February 1980 until its recovery at 0945 on 22 February, a period of slightly more than 24 hours. During this time the wind speeds ranged from 0-5 m/sec, and were from the east-southeast or east. No surface currents were monitored during this period. The trajectory was basically southwest, similar to drogue "A", but there were a few significant deviations to the east.

Drogue "C" was under observation for 24.2 hours from the time of deployment to recovery, with the elapsed time between observations ranging from 0.8 hours - 4 hours, and most of the time intervals being about 1-2 hours. The distances traveled between sitings ranged from 0.2 - 2.3 km.

Table 7 displays the data on which the speed and direction calculations and statistics for drogue "C" are based. The

TABLE 5

DATA AND CALCULATIONS FOR DROGUE "A":

Cruise of 18-19 February 1980

LATITUDE (deg. N)	LONGITUDE (deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.8'	65°51.9'	18 Feb	1430	0.0	---	----	---	--
					0.5	0.43	236	24
17°56.7'	65°52.1'	18 Feb	1500	0.5	---	----	---	--
					1.0	0.58	230	16
17°56.5'	65°52.3'	18 Feb	1600	1.5	---	----	---	--
					1.0	0.46	264	13
17°56.5'	65°52.6'	18 Feb	1700	2.5	---	----	---	--
					1.0	0.53	241	15
17°56.4'	65°52.8'	18 Feb	1800	3.5	---	----	---	--
					1.0	0.60	285	17
17°56.5'	65°53.2'	18 Feb	1900	4.5	---	----	---	00
					1.3	0.44	247	10
17°56.4'	65°53.4'	18 Feb	2015	5.8	---	----	---	--
					0.7	0.70	247	26
17°56.2'	65°53.8'	18 Feb	2100	6.5	---	----	---	--
					1.0	0.46	211	13
17°56.0'	65°54.0'	18 Feb	2200	7.5	---	----	---	--
					2.0	1.87	248	26
17°55.6'	65°54.9'	18 Feb	2400	9.5	---	----	---	--
					2.3	1.90	281	23
17°55.8'	65°56.0'	19 Feb	0215	11.8	---	----	---	--
					1.7	1.20	242	19
17°55.6'	65°56.6'	19 Feb	0400	13.5	---	----	---	--

TABLE 6

SUMMARY OF DROGUE "A" WATER MOTION MEASUREMENTS:

Cruise of 18-19 February 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg.-T)	TIME (%)
0 - 2	0	345 - 014	0
3 - 5	0	015 - 044	0
6 - 8	0	045 - 074	0
9 - 11	10	075 - 104	0
12 - 14	15	105 - 134	0
15 - 17	22	135 - 164	0
18 - 20	12	165 - 194	0
21 - 23	17	195 - 224	7
24 - 26	24	225 - 254	61
27 - 29	0	255 - 284	24
30 - 32	0	285 - 314	7
33 - 35	0	315 - 344	0

Average Speed = 18 cm/sec

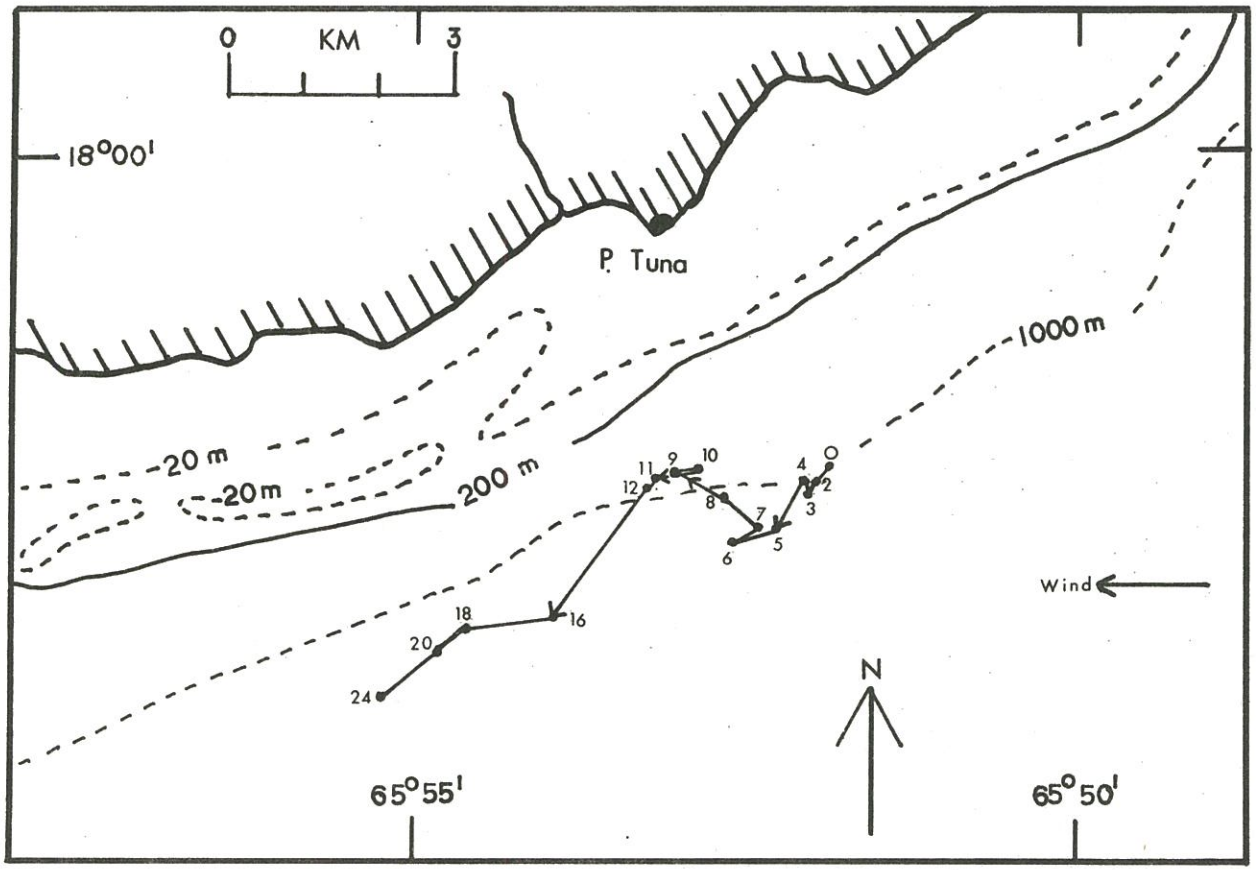

Figure 12. Trajectory for Drogue "C" off Punta Tuna, Puerto Rico begining 0930 on 21 February 1980.(Numbers are elapsed time in hours;depth is 100 meters)

TABLE 7

DATA AND CALCULATIONS FOR DROGUE "C":

Cruise of 21-22 February 1980

LATITUDE (deg. N)	LONGITUDE (deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.7'	65°51.8'	21 Feb	0930	0.0	---	----	---	--
					2.0	0.33	224	5
17°56.6'	65°52.0'	21 Feb	1130	2.0	---	----	---	--
					1.0	0.17	227	5
17°56.5'	65°52.0'	21 Feb	1230	3.0	---	----	---	--
					1.0	0.11	040	3
17°56.6'	65°52.0'	21 Feb	1330	4.0	---	----	---	--
					1.0	0.72	215	20
17°56.2'	65°52.2'	21 Feb	1430	5.0	---	----	---	--
					1.0	0.66	239	18
17°56.1'	65°52.6'	21 Feb	1530	6.0	---	----	---	--
					1.5	0.52	051	10
17°56.3'	65°53.3'	21 Feb	1700	7.5	---	----	---	--
					1.3	0.71	303	15
17°56.5'	65°52.6'	21 Feb	1815	8.8	---	----	---	--
					0.8	0.69	296	24
17°56.7'	65°53.0'	21 Feb	1900	9.5	---	----	---	--
					1.0	0.33	078	9
17°56.7'	65°52.8'	21 Feb	2000	10.5	---	----	---	--
					1.0	0.60	260	17
17°56.6'	65°53.2'	21 Feb	2100	11.5	---	----	---	--
					1.0	0.07	224	2
17°56.6'	65°53.2'	21 Feb	2200	12.5	---	----	---	--
					4.0	2.27	215	16
17°55.6'	65°53.9'	22 Feb	0200	16.5	---	----	---	--
					2.0	1.14	260	16
17°55.5'	65°54.6'	22 Feb	0400	18.5	---	----	---	--
					2.0	0.41	239	6
17°55.4'	65°54.8'	22 Feb	0600	20.5	---	----	---	--
					3.8	1.02	227	7
17°55.0'	65°55.2'	22 Feb	0945	24.2				

results of these calculations are also shown in Table 8. Drogue "C" speeds ranged from 2-24 cm/sec, with 15-17 cm/sec being the most often seen. The overall average was 11 cm/sec. The distribution of the speed observations are more uniform than those of drogue "A". The directional data does show the bimodality of both easterly and westerly motion, but more than half of the time the drogue moved toward 195-254 deg-T, and between 195-314 deg-T for 86% of the time.

Figure 13 shows the temporal and directional relationship of the predicted tidal currents and the movement of the drogue. If there is any tidal influence during this 5-day period, it remains undetected.

Overall, both drogues appeared to run somewhat parallel to the 1000 meter depth contour, which runs southwest and parallel to the coast for this part of the island. This contour turns sharply southward further west from where the drogue tracking terminated. There are insufficient data to determine if the drogues would have continued to follow the 1000 meter contour or moved onto the continental rise off the coast, south of Jobos, thus rnning aground.

Another important factor to consider is which water mass was actually being followed by the 100 meter deep drogues. No hydrographic data were taken during this cruise, however, historical data indicate that the "most probable" depth of the upper mixed layer (core of the upper, Tropical Surface Water) lies at about 100m during February and March. This TSW usually influenced by the wind, even at its deeper portions. However,

TABLE 8

SUMMARY OF DROGUE "C" WATER MOTION MEASUREMENTS:

Cruise of 21-22 February 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	4	345 - 014	0
3 - 5	16	015 - 044	4
6 - 8	24	045 - 074	6
9 - 11	10	075 - 104	4
12 - 14	0	105 - 134	0
15 - 17	34	135 - 164	0
18 - 20	8	165 - 194	0
21 - 23	0	195 - 224	33
24 - 26	3	225 - 254	32
27 - 29	0	255 - 284	12
30 - 32	0	285 - 314	9
33 - 35	0	315 - 344	0

Average Speed = 11 cm/sec

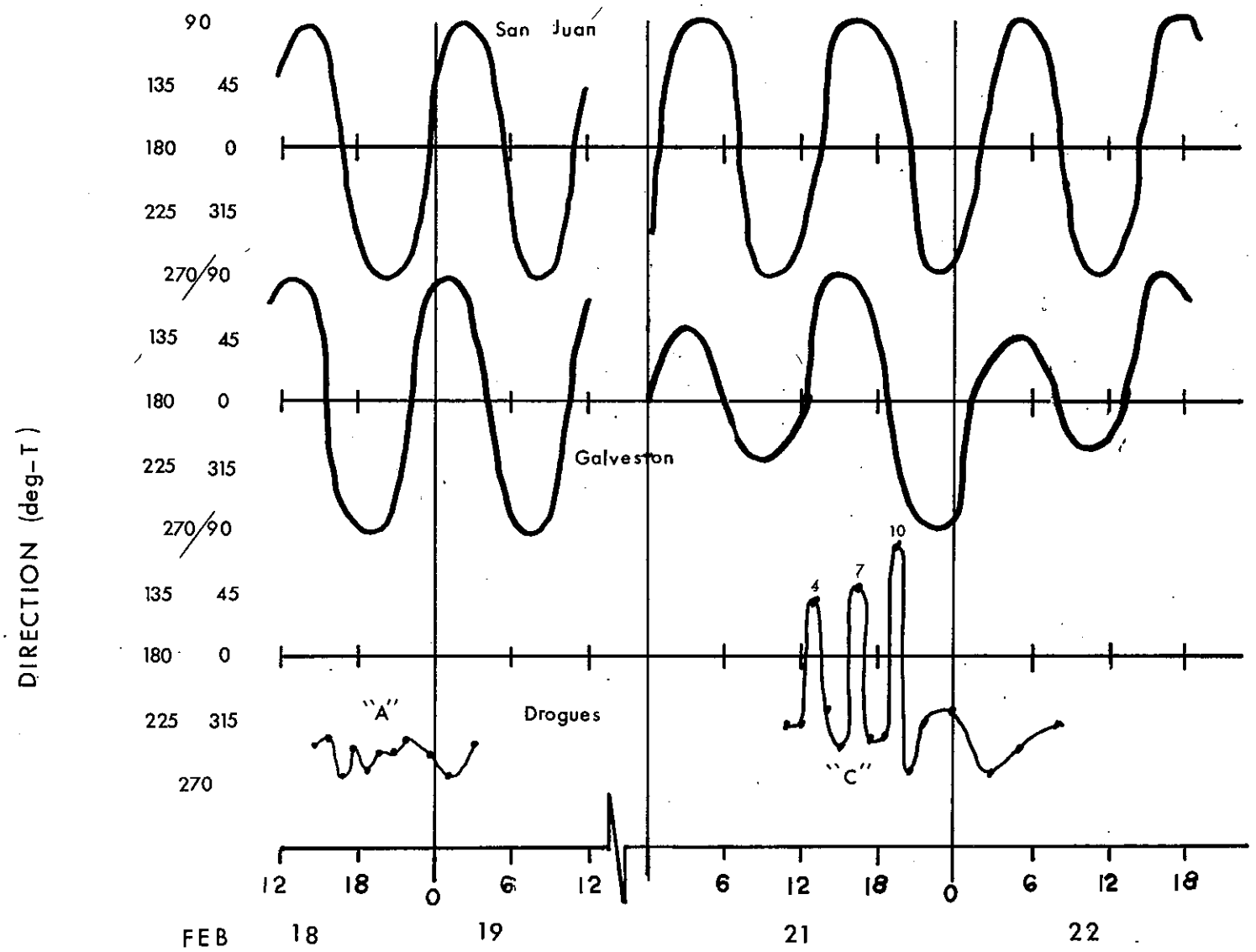

Figure 13. Directionality of drogues and predicted tidal currents from 18-22 February 1980 at Punta Tuna.

the water mass directly beneath the TSW, the Subtropical Underwater, is different in both density and water characteristics, seldom mixes with the TSW, and is driven by forces other than the local wind conditions.

3.3.3 INTERPRETATION

Although there are a few deviations from the southwest course, both drogues followed this path quite closely. There is sufficient circumstantial evidence to indicate that the 100 meter deep water was moving with the surface water mass (TSW) under the influence of the wind. At this time of the year, the lower SUW may well have been out of reach of our 100m deep drogues. If this were the case, there is a strong probability that the path followed by the drogues would have taken them up over the shallow areas to which they appeared to be headed. Finally, no clear periodic influence could be seen during this observation period.

3.4 CRUISE OF 24 - 25 MARCH 1980

The following sections describe the activities and results of the cruise of 24-25 March 1980.

3.4.1 NARRATIVE

Drogue "C" was deployed from the moored LCU at 1500 A.S.T. on 24 March 1980. The depth sensitivity (panel depth) was to have been set at 100m. The drogue was tracked approximately hourly using the LCU's onboard radar. Tracking continued until about 1200 on 25 March, however, data are available only until 1900 on 24 March. This track covers a period of only 4 hours.

Upon recovery with the ship-to-shore vessel at 1230 on 25 March, it was leanred that the panel had become entangled in the connecting line between the mast and the panel. This entanglement has probably occurred during deployment. The panel was only slightly below the 3 meter depth of the mast, and probably not fully open either. The panel was also damaged, either upon deployment or upon recovery. The drogue was 5 km southwest of the LCU upon recovery.

Drogue "E" was deployed from the LCU at 1800 on 25 March. This drogue was also set at 100 meters depth. The tracking took place hourly until 0330 on 26 March, at which time it was last seen on the radar. The last useable radar value, however, was at 2200 on 25 March, resulting in a tracking period of only 4 hours, again. At 0830 on 26 March the Radio Direction Finder indicated that the drogue, although not observable on the radar, was moving swiftly shoreward. An immediate inspection of this abnormal activity provided the recovery of the drogue from a fisherman who had "recovered it for you." He had the entire system carefully taken apart and set into his small open fishing boat (thusly verifying our concept of recovable in a small boat without damage). He also indicated that he had our drogue "A" stored on his property onshore, and we recovered that missing unit, as well.

3.4.2 RESULTS

Only eight hours of tracking were salvaged from this cruise, although considerably more time was spent collecting

data. Also, the panel for drogue "C" was tangled from the outset, resulting in the tracking of a much shallower water than desired.

Figure 14 shows the plotted trajectory of drogue "C" from the time of its deployment at 1500 A.S.T. on 24 March 1980 until 1900 on 24 March. The drogue depth was inadvertently set to be only 10-20 meters deep, and the panel was probably not fully open either. During this tracking period the wind was 10-13 m/sec from the east, and no surface currents were monitored during this cruise. The drogue moved generally southwest, with a sharp southward turn at the end. Table 9 displays the data on which the speed and direction calculations and statistics are based for this drogue. The results of these speed and direction calculations are shown in Table 10 for drogue "C". The speeds ranged from 34-86 cm/sec, with the speed being 30-49 cm/sec almost 90% of the time. The average speed for this drogue was 46 cm/sec. The directions are shown to be mainly westerly, with the flow being between 225-284 deg-T 100T of the time. Again it must be mentioned that due to both the forshortening of the depth line and the tangling of the panel, it is not clear if the drogue was following the shallow water or if the surface float was pulling the entangled panel as the float being pushed by the brisk wind. In either case the drogue was not sensitive to the desired 100 meter deep water.

Figure 15 shows the plotted trajectory of drogue "E" from the time of its deployment at 1800 on 25 March 1980 until 2200

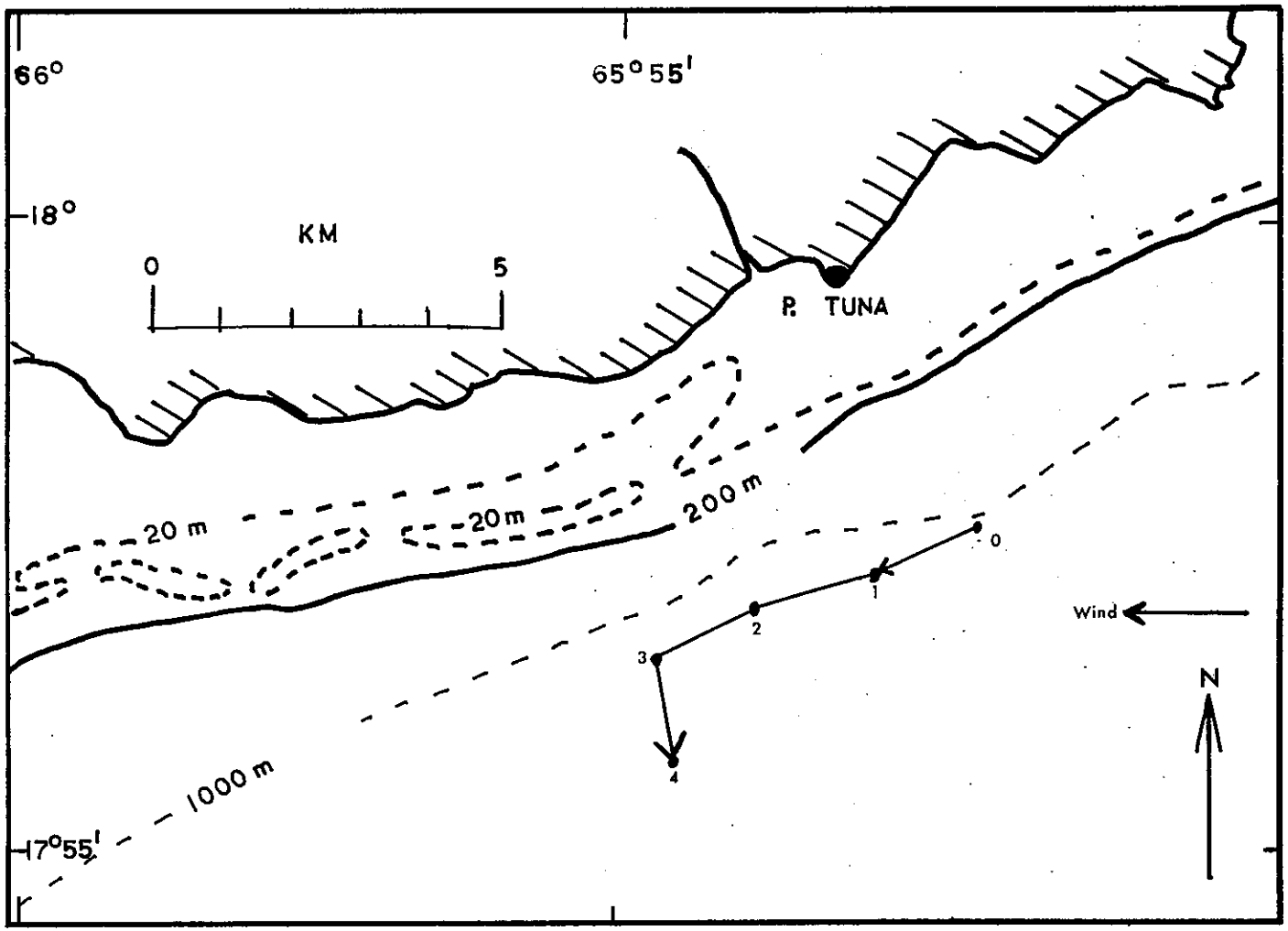

Figure 14. Trajectory of Drogue "C" off Punta Tuna, Puerto Rico begining 1500 on 24 March 1980. (Numbers are elapsed time in hours)

TABLE 9

DATA AND CALCULATIONS FOR DROGUE "C":

Cruise of 24 March 1980

LATITUDE (deg. N)	LONGITUDE (deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.6'	65°52.0'	24 Mar	1500	0.0	---	----	---	--
					1.0	1.65	255	46
17°56.2'	65°52.8'	24 Mar	1600	1.0	---	----	---	--
					1.5	1.82	263	34
17°55.9'	65°53.8'	24 Mar	1730	2.5	---	----	---	--
					1.0	1.54	243	43
17°55.5'	65°54.6'	24 Mar	1830	3.5	---	----	---	--
					0.5	1.55	169	86
17°54.7'	65°54.5'	24 Mar	1900	4.0	---	----	---	--

TABLE 10

SUMMARY OF DROGUE "C" WATER MOTION MEASUREMENTS:

Cruise of 24 March 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 9	0	345 - 014	0
10 - 0	0	015 - 044	0
20 - 29	0	045 - 074	0
30 - 39	38	075 - 104	0
40 - 49	50	105 - 134	0
50 - 59	0	135 - 164	0
60 - 69	0	165 - 194	12
70 - 79	0	195 - 224	0
80 - 89	12	225 - 254	25
Average Speed = 46 cm/sec		255 - 284	62
		285 - 314	0
		315 - 344	0

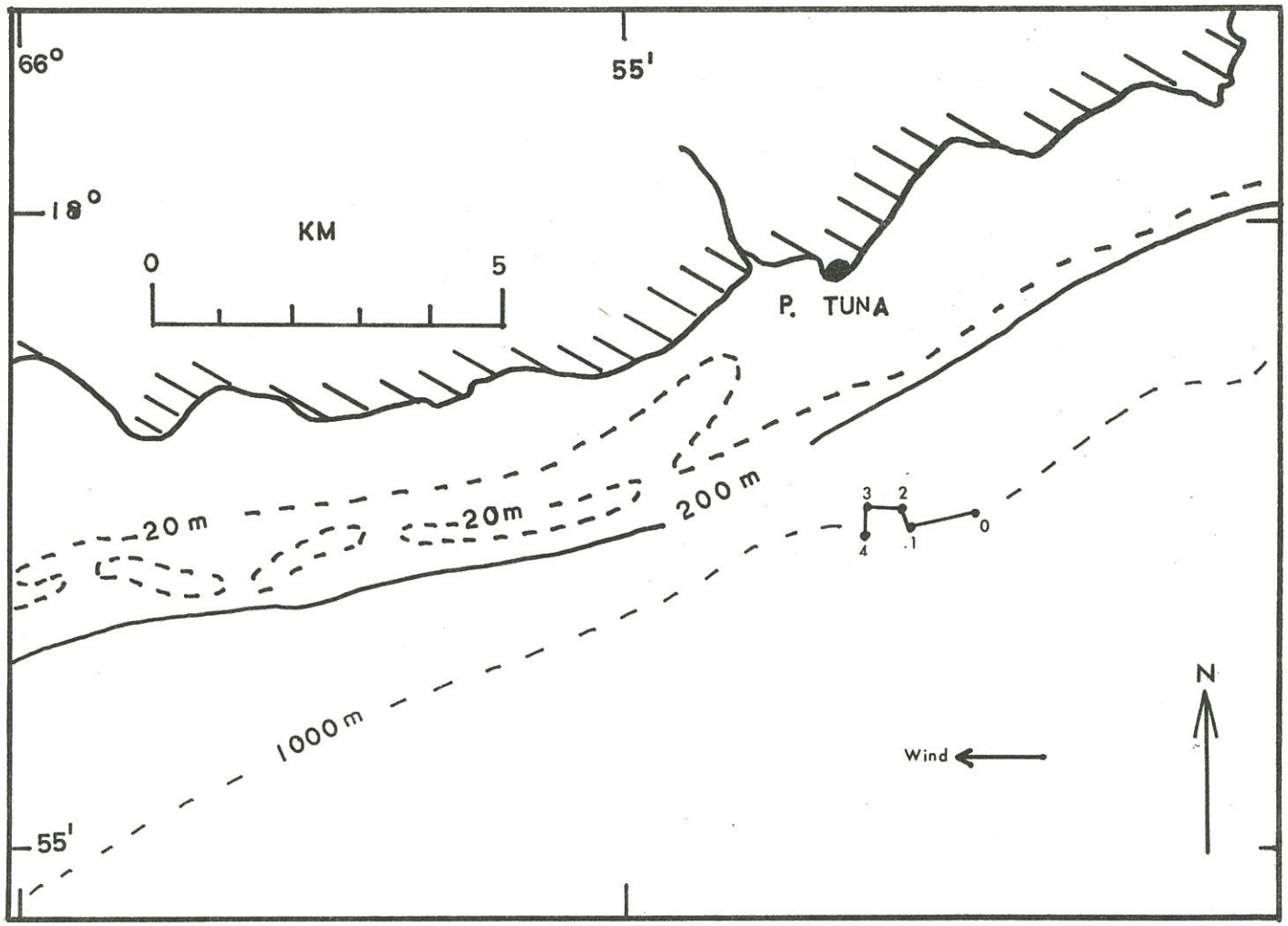

Figure 15. Trajectory of Drogue "E" off Punta Tuna, Puerto Rico begining 1800 on 25 March 1980.(Numbers are elapsed time in hours; depth is 100 meters)

on 25 March, only four hours later. This drogue remained at 100 meters depth. The wind was only 1-3 m/sec from the southeast during this time period. The trajectory shows a basically westerly movement, with a deviation somewhat northerly then back again to the west. Table 11 displays the data on which the speed and direction were calculated for drogue "E". The results of these calculations are also shown in Table 12. Drogue "E" speeds ranged from near zero to 16 cm/sec, with the speed between 12-17 cm/sec 76% of the time. The average speed was about 11 cm/sec. This drogue also moved westerly such that 87% of the time the water moved between 225-284 deg-T.

No tidal comparisons were made with the data collected from this cruise, due to the short time spans (4 hours each) involved.

Also, as no hydrographic data were taken during this cruise, it is difficult to determine directly if the two drogues were in the same water mass. Historically, the TSW frequently does extend to 100m depth in March.

3.4.2 INTERPRETATION

Both drogues moved westerly, indicating the water from the surface to 100m was moving in that direction. However, if both drogues were fully sensitive to the surrounding water (fully open panels) this short test indicates a considerably faster moving near-surface water (also subjected to a 13 m/sec wind) than the 100m deep water. The speed ratio was 4:1. The upper drogue ("C") was definitely in the TSW, but may have been pushed along primarily by the wind acting directly to

TABLE 11

DATA AND CALCULATIONS FOR DROGUE "E":

Cruise of 25 March 1980

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.6'	65°52.0'	25 Mar	1800	0.0	---	----	---	--
					1.5	0.89	247	16
17°56.4'	65°52.5'	25 Mar	1930	1.5	---	----	---	--
					0.5	0.22	337	12
17°56.5'	65°52.5'	25 Mar	2000	2.0	---	----	---	--
					1.0	0.46	257	14
17°56.5'	65°52.8'	25 Mar	2100	3.0	---	----	---	--
					1.0	0.01	238	0.3
17°56.4'	65°52.8'	25 Mar	2200	4.0	---	----	---	--

TABLE 12

SUMMARY OF DROGUE "E" WATER MOTION MEASUREMENTS:

Cruise of 25 March 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	25	345 - 014	0
3 - 5	0	015 - 044	0
6 - 8	0	045 - 074	0
9 - 11	0	075 - 104	0
12 - 14	38	105 - 134	0
15 - 17	38	135 - 164	0
18 - 20	0	165 - 194	0
21 - 23	0	195 - 224	0
24 -	0	225 - 254	62
Average speed = 11 cm/sec		255 - 284	25
		285 - 314	0
		315 - 344	12

push the surface float and mast. The deeper drogue, "E", at 100m, may have been near the bottom of the TSW, but more probably was in the SUW, whose movement could be quite differently regulated from that of the TSW above.

3.5 CRUISE OF 7 - 11 MAY 1980

The following sections describe the activities and results of the cruise of 7-11 May 1980.

3.5.1 NARRATIVE

On 7 May at 0800 A.S.T., drogue "E-1" was deployed from the moored LCU. Tracking was accomplished primarily using the radar aboard the LCU. The drogue's sensitive depth (panel depth) was set at 100 meters, as it was throughout this cruise for all the drogues. This drogue drifted southwest for about 30 hours (until 1430 on May 8), at which time it was recovered about 7 km southwest from the LCU using the ship-to-shore vessel. There were no obvious difficulties encountered during this drogue's tracking period.

Drogue "E-1" was then returned to the LCU and deployed again at 1600 on 8 May as "E-2". This time the drogue drifted west-southwest (with more short north, south, and east excursions), and was tracked for about 34 hours, until it was lost on the radar screen. The drogue was recovered successfully using the ship-to-shore vessel at 1100 on 10 May, more than 9 km from the LCU.

Drogue "E-2" was returned to the LCU, from where it was deployed as "E-3" on 10 May at 1200. Under slightly more brisk

wind, it moved less distance, and more circularly, frequently moving upwind. The radar aboard the LCU again began to malfunction, and tracking was terminated after only 26 hours, at about 1600 on 11 May. The drogue was recovered about 1 km north of the LCU.

At noon on 9 May, a second drogue unit, "V", was deployed from the LCU. Drogue "V" drifted virtually parallel to "E-2", its contemporary, moving west-southwest, with numerous short excursions from this direction. This drogue was tracked for about 49 hours but, upon analysis, it was learned that the panel had apparently become entangled with either the ocean bottom or a fisherman's apparatus, and the drogue did not appear to move after the 39th elapsed hour. This drogue was also recovered in the late afternoon of 11 May, using the ship-to-shore vessel.

3.5.2 RESULTS

Throughout this cruise, which lasted from 7-11 May 1980, all the drogues were set to be sensitive to 100m depth (panel depth). Also, all position tracking of the drogues was accomplished using the radar onboard the LCU. All drogues were deployed fromthe LCU and all were recovered using the 13 meter ship-to-shore vessel, after a total of 130 hours of drogue tracking.

During the cruise, the atmospheric pressure remained at about the monthly average, or even slightly higher. After the cruise, a significant pressure decrease did not occur for at least two weeks; however, the pressure was relatively low

3-4 days before the drogues were deployed.

Figure 16 shows the plotted trajectory of drogue "E-1" from the time of its deployment at 0800 A.S.T. on 7 May 1980, until just before its recovery at 1430 on 8 May, an elapsed tracking time of about 30 hours. During that time, the wind went from moderate (4 m/sec) out of the south to very low (0-2 m/sec) with variable direction. Also, throughout this time, the surface water was moving to the east past the LCU. The 100 meter deep water, as typified by the drogue trajectory, moved in a generally southwesterly direction with little directional deviation. Table 13 shows the data on which the speed and direction calculations were based for "E-1". Table 14 shows the overall speed and direction results for this drogue.

The elapsed time between sitings for this drogue varied from 0.5-4.0 hours, with most of the values being 2 hours or less, and the total number of observations being 22. The distance the drogue traveled between sitings ranged from 0.04-2.2 km. The average observed speed was 11 cm/sec, and 89% of the time the speed was between 6-17 cm/sec. Two speed maximums were observed, one being 6-8 cm/sec, and the other at 15-17 cm/sec. The direction of motion was between 195-254 deg-T for more than half the time, and more than 90% of the time the water direction was between 195-314 deg-T. At one time during the tracking period, the drogue appeared to be moving shoreward, toward shallow water, but it reversed direction and moved offshore again.

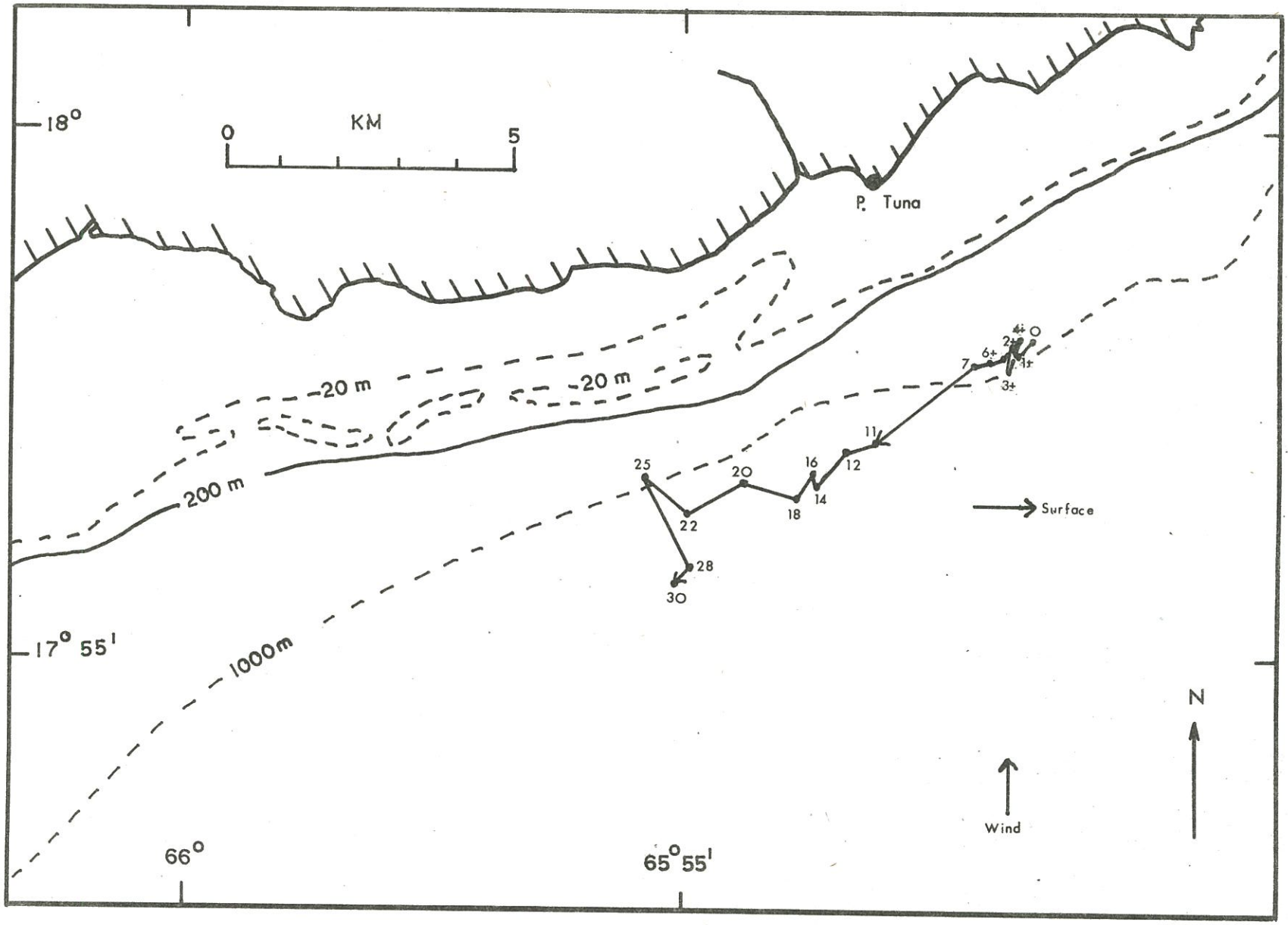

Figure 16. Drogue trajectory for Drogue "E-1" off Punta Tuna, Puerto Rico from 0800 on 7 May 1980 until 1400 on 8 May 1980. (Numbers are elapsed time in hours, 100m)

TABLE 13

DATA AND CALCULATIONS FOR DROGUE "E-1":

Cruise of 7-8 May 1980

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°57.0'	65°51.5'	7 May	0800	0.0	---	----	---	--
					1.5	0.40	208	7
17°56.8'	65°51.7'	7 May	0930	1.5	---	----	---	--
					0.5	0.04	316	2
17°56.8'	65°51.7'	7 May	1000	2.0	---	----	---	--
					0.5	0.13	314	7
17°56.9'	65°51.7'	7 May	1030	2.5	---	----	---	--
					0.5	0.09	103	5
17°56.9'	65°51.7'	7 May	1100	3.0	---	----	---	--
					0.5	0.33	206	18
17°56.7'	65°51.8'	7 May	1130	3.5	---	----	---	--
					0.5	0.27	013	15
17°56.8'	65°51.8'	7 May	1200	4.0	---	----	---	--
					0.5	0.10	329	7
17°56.9'	65°51.8'	7 May	1230	4.5	---	----	---	--
					0.5	0.43	196	24
17°56.7'	65°51.8'	7 May	1300	5.0	---	----	---	--
					0.5	0.22	357	12
17°56.8'	65°51.8'	7 May	1330	5.5	---	----	---	--
					1.0	0.17	251	5
17°56.8'	65°51.9'	7 May	1430	6.5	---	----	---	--
					0.5	0.30	261	16
17°56.7'	65°52.1'	7 May	1500	7.0	---	----	---	--
					4.0	2.22	229	15
17°55.9'	65°53.0'	7 May	1900	11.0	---	----	---	--
					1.0	0.54	245	15
17°55.8'	65°53.3'	7 May	2000	12.0	---	----	---	--
					2.0	0.72	220	10

TABLE 13

Cruise of 7-8 May 1980 (Continued)

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°55.5'	65°53.6'	7 May	2200	14.0	---	----	---	--
17°55.6'	65°53.7'	7 May	2400	16.0	2.0	0.15	308	2
17°55.4'	65°53.8'	8 May	0200	18.0	---	----	---	--
17°55.5'	65°54.4'	8 May	0400	20.0	2.0	0.42	218	6
17°55.2'	65°54.9'	8 May	0600	22.0	---	----	---	--
17°55.6'	65°55.3'	8 May	0900	25.0	2.0	0.99	280	14
17°54.8'	65°54.9'	8 May	1200	28.0	---	----	---	--
17°54.6'	65°55.0	8 May	1400	30.0	2.0	1.08	245	15
					---	----	---	--
					3.0	0.92	309	8
					---	----	---	--
					3.0	1.67	151	15
					---	----	---	--
					2.0	0.40	213	6
					---	----	---	--

TABLE 14

SUMMARY OF DROGUE "E-1" WATER MOTION MEASUREMENTS:

Cruise of 7-8 May 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	8	345 - 014	3
3 - 5	5	015 - 044	0
6 - 8	32	045 - 074	0
9 - 11	7	075 - 104	2
12 - 14	8	105 - 134	0
15 - 17	37	135 - 164	10
18 - 20	2	165 - 194	0
21 - 23	0	195 - 224	28
24 - 26	2	225 - 254	27
27 - 29	0	255 - 284	8
30 - 32	0	285 - 314	18
33 - 35	0	315 - 344	3

Average Speed = 11 cm/sec

Figure 17 shows the plotted trajectory of drogue "E-2". This drogue was deployed at 1600 on 8 May and was tracked for almost 1-1/2 days. Although the recovery was completed at 1100 on 10 May, tracking was terminated at 0200 on the same day, as the drogue was no longer discernible on the radar screen, and the ship-to-shore vessel was unavailable for either magnetic or sextant sitings until much later in the day. During the 34-hour tracking period the wind went from calm to moderate from the south near the termination. Also during this entire period, the surface water continued to move eastward past the LCU. The path of the 100 meter deep water during this data set was generally to the west-southwest, with many excursions in other directions. This drogue made a more serious excursion toward the shallow water, and might have gone aground had it continued for a short time longer on such a course. Table 15 shows the data on which the speed and direction calculations are based for this drogue, and Table 16 shows the results of the speed and direction calculations for drogue "E-2".

The elapsed time between the 23 observations for this drogue varied from 1.0-4.0 hours, with most of the values being one hour. The distance the drogue traveled between observations ranged from 0.1 - 1.2 km. The average speed during this tracking period was about 12 cm/sec. More than 60% of the time the speed was between 6-14 cm/sec, with observational peaks at 6-8 cm/sec and 12-14 cm/sec. Half of the directional observations occurred inthe 225-284 deg-T range, but there

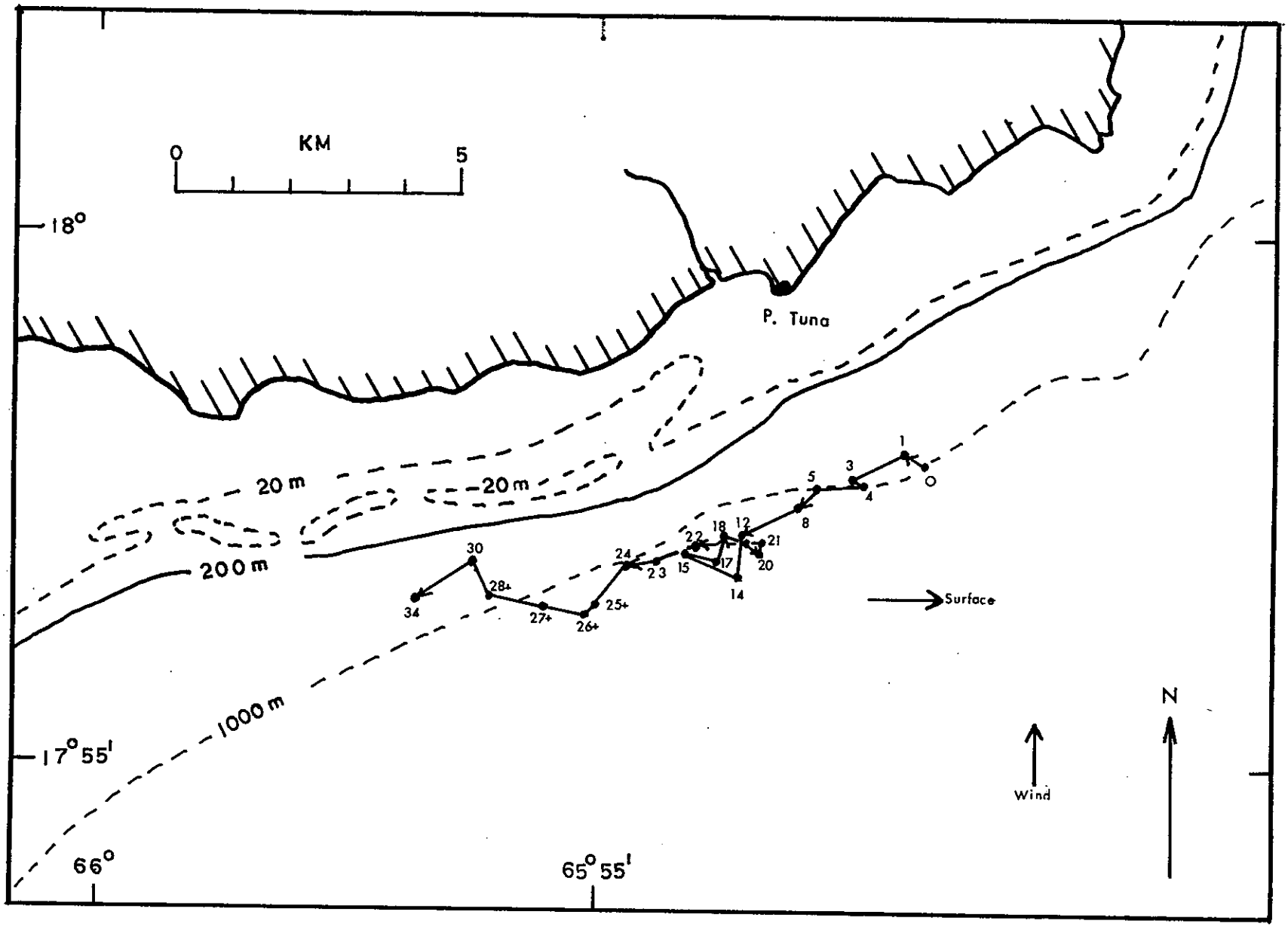

Figure 17. Trajectory for Drogue "E-2" off Punta Tuna, Puerto Rico from 1600 on 8 May 1980 until 0200 on 10 May 1980. (Numbers are elapsed time in hours, depth=100m)

TABLE 15

DATA AND CALCULATIONS FOR DROGUE "E-2":

Cruise of 8-10 May 1980

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.7'	65°51.7'	8 May	1600	0.0	---	----	---	--
					1.0	0.45	302	12
17°56.8'	65°51.9'	8 May	1700	1.0	---	----	---	--
					2.0	1.01	241	14
17°56.6'	65°52.4'	8 May	1900	3.0	---	----	---	--
					1.0	0.20	129	7
17°56.5'	65°52.3'	8 May	2000	4.0	---	----	---	--
					1.0	0.80	268	22
17°56.5'	65°52.8'	8 May	2100	5.0	---	----	---	--
					3.0	0.47	216	4
17°56.3'	65°52.9'	9 May	2400	8.0	---	----	---	--
					4.0	1.12	248	8
17°56.0'	65°53.5'	9 May	0400	12.0	---	----	---	--
					2.0	0.70	192	10
17°55.7'	65°53.6'	9 May	0600	14.0	---	----	---	--
					1.0	0.93	292	27
17°55.9'	65°54.0'	9 May	0700	15.0	---	----	---	--
					2.0	0.52	108	8
17°55.8'	65°53.8'	9 May	0900	17.0	---	----	---	--
					1.0	0.43	020	12
17°56.0'	65°53.7'	9 May	1000	18.0	---	----	---	--
					1.0	0.48	88	13
17°56.0'	65°53.4'	9 May	1100	19.0	---	----	---	--
					1.0	0.24	149	7
17°55.9'	65°53.3'	9 May	1200	20.0	---	----	---	--
					1.0	0.08	329	2
17°55.9'	65°53.4'	9 May	1300	21.0	---	----	---	--
					1.0	1.09	226	30

TABLE 15

Cruse of 8-10 May 1980 (Continued)

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°55.9'	65°54.0'	9 May	1400	22.0	---	---	---	--
					1.0	0.77	256	21
17°55.8'	65°54.4'	9 May	1500	23.0	---	----	---	--
					1.0	0.46	240	13
17°55.7'	65°54.6'	9 May	1600	24.0	---	---	---	--
					1.5	0.88	224	16
17°55.4'	65°55.0'	9 May	1730	25.5	---	----	---	--
					1.0	0.23	245	6
17°55.3'	65°55.1'	9 May	1830	26.5	---	----	---	--
					1.0	0.67	280	18
17°55.3'	65°55.5'	9 May	1930	27.5	---	----	---	--
					1.0	1.03	276	29
17°55.4'	65°56.1'	9 May	2030	28.5	---	----	---	--
					1.5	0.67	332	12
17°55.8'	65°56.2'	9 May	2200	30.0	---	----	---	--
					4.0	1.19	241	8
17°55.4'	65°56.8'	9 May	0200	34.0	---	----	---	--

TABLE 16

SUMMARY OF DROGUE "E-2" WATER MOTION MEASUREMENTS:

Cruise of 8-10 May 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	3	345 - 014	0
3 - 5	9	015 - 044	3
6 - 8	38	045 - 074	0
9 - 11	6	075 - 104	3
12 - 14	22	105 - 134	9
15 - 17	4	135 - 164	3
18 - 20	3	165 - 194	6
21 - 23	6	195 - 224	13
24 - 26	3	225 - 254	38
27 - 29	3	255 - 284	12
30 - 32	3	285 - 314	6
33 - 35	0	315 - 344	7

Average Speed = 12 cm/sec

was much variation. This drogue track varied its speed and direction much more than did drogue "E-1".

Figure 18 shows the plotted trajectory of drogue "E-3". This drogue was deployed at 1200 A.S.T. on 10 May; however, the first radar observation was not taken until 1700 of the same day due to a radar malfunction. During the 26 hours of this drogue tracking period, the wind moved from the south and southeast and remained moderate (2-5 m/sec) all the time. The surface continued to drift eastward. This drogue appeared to move in an erratic fashion, which may be either the true water trajectory or an artifact of the measurement due to continued, but undetected, problems with the radar. The drogue motion was westerly, then took a clockwise loop and ultimately moved around past west to the northeast. Table 17 shows the data on which the speed and direction calculations and statisc are based, with Table 18 showing the results.

The elapsed time between the 14 observations varied from 1-5 hours, with all but two of these time intervals being 1 or 2 hours. The distance the drogue moved between observations ranged from 0.1-1.4 km. The speeds for this period were much slower, and 925 of the time the speed was less than 9 cm/sec. The average speed was 6 cm/sec. The direction, although highly variable, may possibly be separated into easterly (045-134 deg-T) at 46% and westerly (225-314 deg-T) at 35% of the time.

Figure 19 shows the plotted trajectory of drogue "V", which was deployed at 1500 A.S.T. on 9 May and tracked until

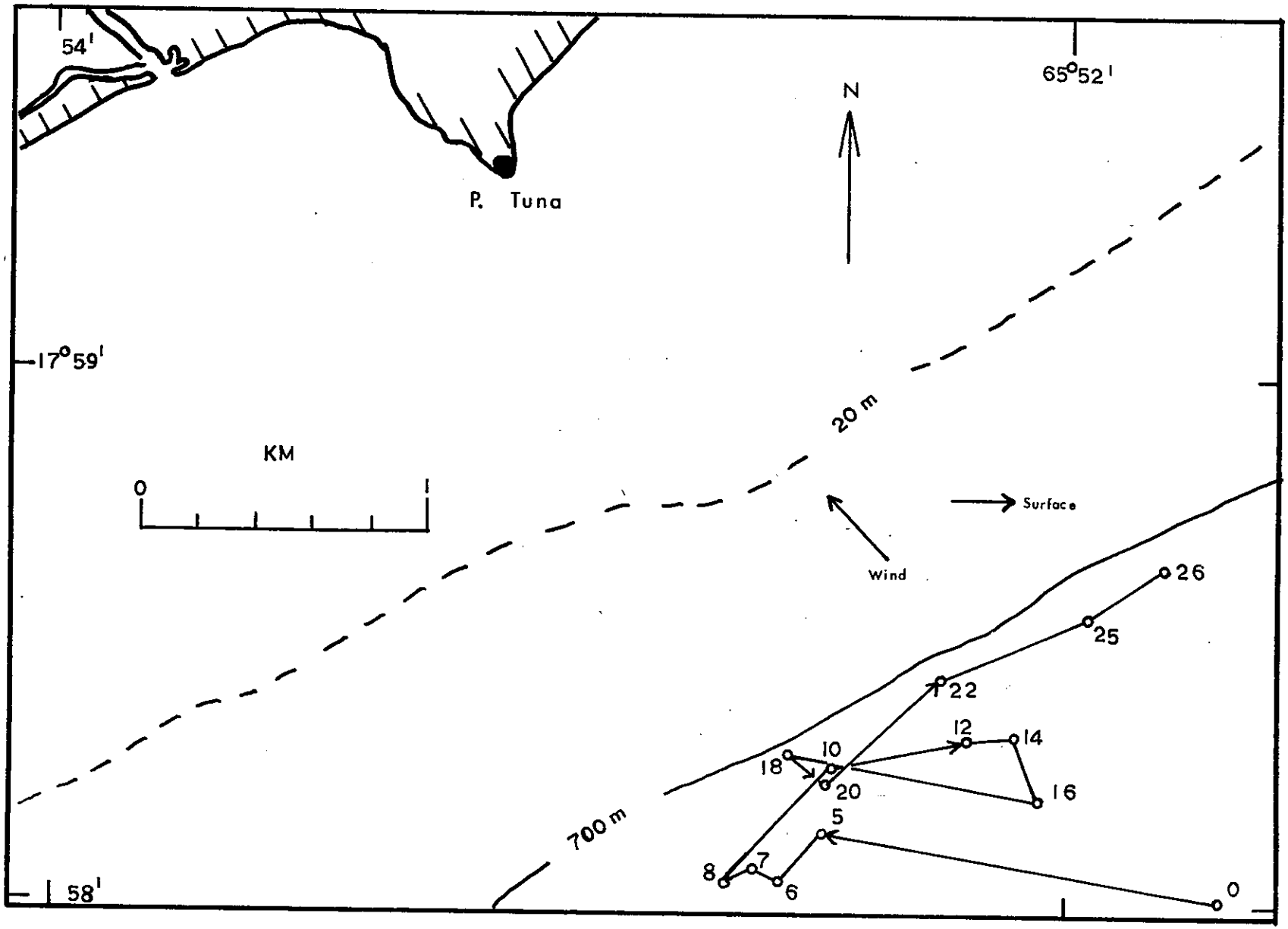

Figure 18. Trajectory for Drogue "E-3" off Punta Tuna, Puerto Rico from 1200 on 10 May 1980 until 1400 on 11 May 1980. (Numbers are elapsed time in hours, depth=100m)

TABLE 17

DATA AND CALCULATIONS FOR DROGUE "E-3":

Cruise of 10-11 May 1980

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.9'	65°51.6'	10 May	1200	0.0	---	----	---	--
					5.0	1.37	279	8
17°57.1'	65°52.4'	10 May	1700	5.0	---	----	---	--
					1.0	0.23	220	6
17°57.0'	65°52.5'	10 May	1800	6.0	---	----	---	--
					1.0	0.12	295	3
17°57.0'	65°52.6'	10 May	1900	7.0	---	----	---	--
					1.0	0.09	245	2
17°57.0'	65°56.6'	10 May	2000	8.0	---	----	---	--
					2.0	0.53	044	8
17°57.2'	65°52.4'	10 May	2200	10.0	---	----	---	--
					2.0	0.48	076	7
17°57.2'	65°52.2'	10 May	2400	12.0	---	----	---	--
					2.0	0.17	086	2
17°57.3'	65°52.0'	11 May	0200	14.0	---	----	---	--
					2.0	0.24	149	3
17°57.2'	65°52.0'	11 May	0400	16.0	---	----	---	--
					2.0	0.92	280	13
17°57.2'	65°52.5'	11 May	0600	18.0	---	----	---	--
					2.0	0.17	125	2
17°57.2'	65°52.4'	11 May	0800	20.0	---	----	---	--
					2.0	0.56	048	9
17°57.4'	65°52.2'	11 May	1000	22.0	---	----	---	--
					3.0	0.53	067	5
17°57.5'	65°51.9'	11 May	1300	25.0	---	----	---	--
					1.0	0.31	058	8
17°57.6'	65°51.8'	11 May	1400	26.0	---	----	---	--

TABLE 18

SUMMARY OF DROGUE "E-3" WATER MOTION MEASUREMENTS:

Cruise of 10-11 May 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	19	345 - 014	0
3 - 5	23	015 - 044	8
6 - 8	50	045 - 074	23
9 - 11	0	075 - 104	15
12 - 14	8	105 - 134	8
15 - 17	0	135 - 164	8
18 - 20	0	165 - 194	0
21 - 23	0	195 - 224	4
24 - 26	0	225 - 254	4
27 - 29	0	255 - 284	27
30 - 32	0	285 - 314	4
33 - 35	0	315 - 344	0

Average Speed = 6 cm/sec

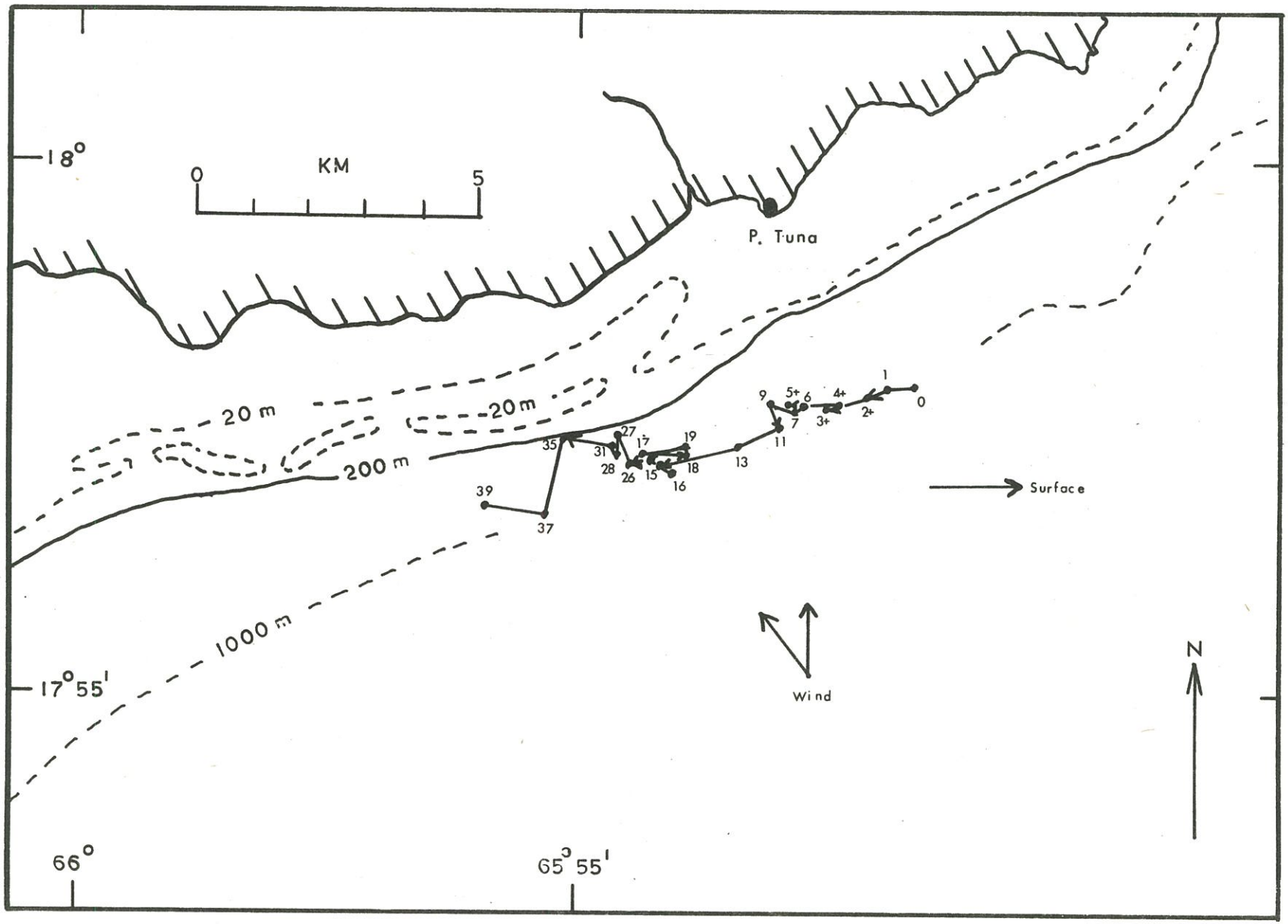

Figure 19. Trajectory for Drogue "V" off Punta Tuna, Puerto Rico from 1500 on 9 May 1980 until 0600 on 11 May. (Numbers are elapsed time in hours; depth is 100 m.)

1630 on 11 May, a total of 39 hours. This drogue was adrift during the tenture of "E-2" and "E-3". The wind was moderate during this time, and the surface current was moving eastward. The trajectory for "V" is not unlike that of "E-2", however "V" made a further shoreward excursion and ultimately appeared to run aground in water that should have been deeper than the 100 meter depth of the drogue (according to the bathymetric charts of the area). Either an uncharted submarine rise or one of the frequently seen fishermen's "fish pots" may have stopped the drogue. The data on which the speed and direction calculations are based are seen in Table 19, and the results are seen in Table 20.

The elapsed time between the 24 observations for this drogue varied from 0.5-7 hours, with all except two being two hours or less. The distance the drogue moved between the observations ranged from 0.1-1.5 km. As this drogue's tracking period overlapped that of drogues "E-2" and "E-3", it is not surprising to see the speed results for "V" lie between those of the faster "E-2" (12 cm/sec) and the slower "E-3" (6 cm/sec). The average speed for "V" was 9 cm/sec, with considerable variation in speed values. More than half the observations were between 3-8 cm/sec. The direction of this drogue also varied quite a bit, but 38% of the time the water moved toward between 225-284 deg-T, with the rest of the values spread throughout the compass quite evenly.

Table 21 shows the overall speed and direction results for the 130 hours of drogue tracking during this cruise. The

TABLE 19

DATA AND CALCULATIONS FOR DROGUE "V":

Cruise of 9-11 May 1980

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.8'	65°51.7'	9 May	1500	0.0	---	----	---	--
17°56.8'	65°51.9'	9 May	1600	1.0	1.0	0.36	255	10
17°56.7'	65°52.1'	9 May	1730	2.5	1.5	0.39	253	7
17°56.6'	65°52.4'	9 May	1830	3.5	1.0	0.68	247	19
17°56.6'	65°52.4'	9 May	1930	4.5	1.0	0.12	060	3
17°56.6'	65°52.8'	9 May	2030	5.5	1.0	0.69	267	19
17°56.5'	65°52.8'	9 May	2100	6.0	0.5	0.11	115	6
17°56.6'	65°52.8'	9 May	2200	7.0	1.0	0.18	302	4
17°56.6'	65°53.0'	9 May	2400	9.0	2.0	0.33	265	5
17°56.3'	65°52.9'	10 May	0200	11.0	2.0	0.54	156	7
17°56.2'	65°53.4'	10 May	0400	13.0	2.0	0.83	257	12
17°56.0'	65°54.2'	10 May	0600	15.0	2.0	1.41	254	20
17°55.9'	65°54.0'	10 May	0700	16.0	1.0	0.23	143	6
17°56.1'	65°54.2'	10 May	0800	17.0	1.0	0.43	306	12
17°56.1'	65°53.9'	10 May	0900	18.0	1.0	0.62	081	17
					1.0	0.16	348	4

TABLE 19

Cruise of 9-11 May 1980 (Continued)

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-True)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.2'	65°53.9'	10 May	1000	19.0	---	----	---	--
					7.0	0.96	250	4
17°56.0'	65°54.4'	10 May	1700	26.0	---	----	---	--
					1.0	0.48	318	13
17°56.3'	65°54.6'	10 May	1800	27.0	---	----	---	--
					1.0	0.29	173	8
17°56.1'	65°54.6'	10 May	1900	28.0	---	----	---	--
					3.0	0.20	013	2
17°56.2'	65°54.6'	10 May	2200	31.0	---	----	---	--
					2.0	0.50	115	7
17°56.1'	65°54.3'	10 May	2400	33.0	---	----	---	--
					2.0	1.48	280	21
17°56.2'	65°55.2'	11 May	0200	35.0	---	----	---	--
					2.0	1.35	190	19
17°55.5'	65°55.3'	11 May	0400	37.0	---	----	---	--
					2.0	1.11	278	15
17°55.6'	65°55.9'	11 May	0600	39.0	---	----	---	--

TABLE 20

SUMMARY OF DROGUE "V" WATER MOTION MEASUREMENTS:

Cruise of 9-11 May 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	8	345 - 014	10
3 - 5	31	015 - 044	0
6 - 8	20	045 - 074	2
9 - 11	2	075 - 104	2
12 - 14	10	105 - 134	6
15 - 17	8	135 - 164	26
18 - 20	15	165 - 194	8
21 - 23	5	195 - 224	0
24 - 26	0	225 - 254	12
27 - 29	0	255 - 284	26
30 - 32	0	285 - 314	5
33 - 35	0	315 - 344	2

Average Speed = 9 cm/sec

TABLE 21

SUMMARY OF ALL DROGUE WATER MOTION MEASUREMENTS:

Cruise of 8-11 May 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	9	345 - 014	4
3 - 5	17	015 - 044	2
6 - 8	34	045 - 074	5
9 - 11	4	075 - 104	5
12 - 14	12	105 - 134	6
15 - 17	12	135 - 164	12
18 - 20	6	165 - 194	4
21 - 23	3	195 - 224	11
24 - 26	1	225 - 254	20
27 - 29	1	255 - 284	18
30+	1	285 - 314	8
		315 - 344	3

Average Speed = 10 cm/sec

average speed of the 100 meter deep water was 10 cm/sec throughout this time, with the speed being between 6-8 cm/sec more than 30% of the time, and a total speed range of 2-30 cm/sec. There was a slightly predominant motion toward the southwest, with more than half the observed values between 195-314 deg-T, and the most frequently observed ranged of values being 225-254 deg-T and 255-285 deg-T.

Figure 20 shows the relationship between the predicted tidal currents in the area and the observed water direction at 100 meters. Predictions are given for both the Galveston and San Juan "systems", although both appear similar for this time period. There appears to be no clear tidal relationship during "E-1", however, just before noon on 9 May, both predictions tend eastward, as did "E-2". Also, about midnight of 10-11 May, both predictions show an eastward tendency, as did both "E-3" and "V".

Finally, if the two clearly clockwise gyres from drogue "E-2" at elapsed time of 12-18 hours and "E-3" at elapsed time of 8-18 hours are considered, the elapsed time between these two circular movements is 43 hours, which corresponds closely to the 39 hour inertial period.

3.5.3 INTERPRETATION

The 100 meter deep water was moving basically southwest to south-southwest during most of the cruise at a moderate average speed of 10 cm/sec. Tidal and inertial oscillations appear to be superimposed upon the general southwesterly flow. Historically, this time of the year has the 100 meter deep

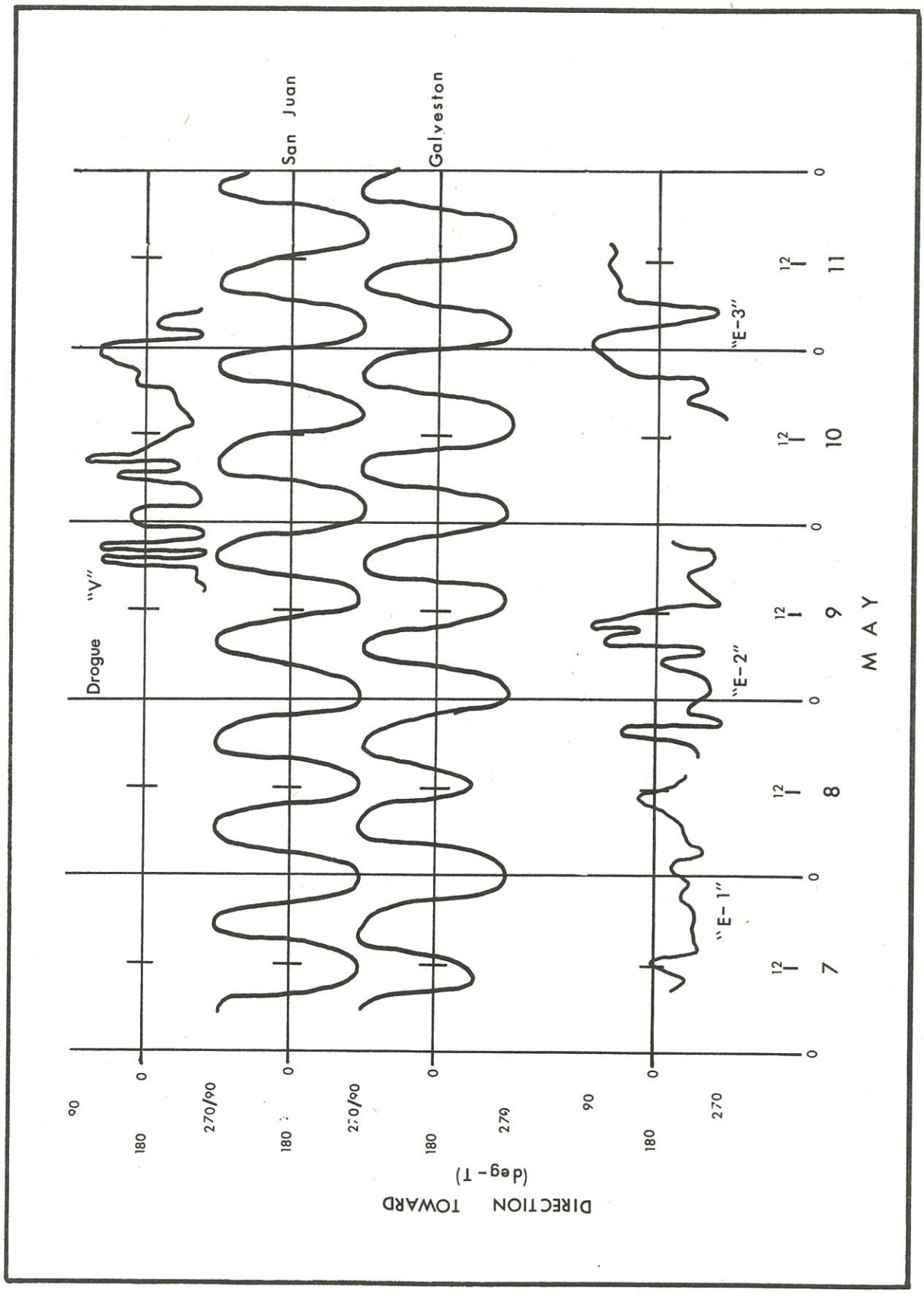

Figure 20. Directionality of drogues and predicted tidal currents during the period from 7 - 11 May 1980 at Punta Tuna, Puerto Rico.

water lying totally within the Subtropical Underwater. The upper, Tropical Surface Water, moving eastward, was moving into the wind, forming a pair of shear zones: Wind-to surface water (southwest-to-east), and TSW-to-SUW (east-to-west). Finally, if a 100 meter deep drogue did actually run aground only 7 km west of the possible OTEC site, a power plant effluent might do likewise, if released in the same location. In the case of flowing water, the effluent would move along the bottom, possibly upwelling until another path of egress in encountered.

3.6 CRUISE OF 10 - 12 JUNE 1980

The following sections describe the activities and results of the cruise of 10-12 June 1980.

3.6.1 NARRATIVE

On 10 June 1980 at 1200 A.S.T., drogue "A" was deployed from the LCU. Tracking was accomplished primarily by using the radar aboard the LCU. When the drogue was no longer visible on the radar, an attempt was made to use hand-bearing compass readings from the ship-to-shore vessel to fix the position of the drogue, but these values were not sufficiently accurate to be included in this report. The drogue's sensitive depth (panel depth) was set to be at 100 meters.

The drogue drifted 51 hours, with position fixing during the first 39 hours indicating that the direction was to the northeast. Recovery was done using the ship-to-shore vessel at 1440 on 12 June. The drogue was more than 10 km to the northeast of the LCU upon recovery.

During and before this cruise some minor modifications to both equipment and procedures were made. Compression unions were installed above and below the flotation assembly

on the mast to strengthen the mast, which was pre-weakened by drilling holes to secure it to the float. A safety line was attached from the top of the mast to the float to prevent total loss of all above-water equipment if a mast separation should occur. And more weight was added to the lower panel supporting pipe to assure its more rapid descent than that of the top pipe and thusly minimize tangling. Finally, a solution was found for the recurring radar image problem. The radar unit can be simply turned "OFF" for a sufficient time to allow for component cool-down. After this period, the image again will be properly displayed, with the instrument operating according to the manufacturer's specified accuracy.

3.6.2 RESULTS

The drogue "A", which was used during this cruise, was set to be sensitive to a depth of 100 meters. The successful tracking of the drogue was accomplished using the radar onboard the LCU.

Figure 21 shows the plotted trajectory of the drogue from the time of deployment (1200 A.S.T. on 10 June 1980) until its image was lost on the radar, 39 hours later. The drogue was recovered at 1440 on 12 June. During the time of drift, the wind was brisk, coming from the east or southeast at 9-13 m/sec. However, the surface water moved into the wind (eastward). The drogue moved in a northeasterly direction with numerous clockwise loops. Throughout the cruise the atmospheric pressure was moderate-to-high. However, the two days preceeding the cruise had relatively low pressure. After the

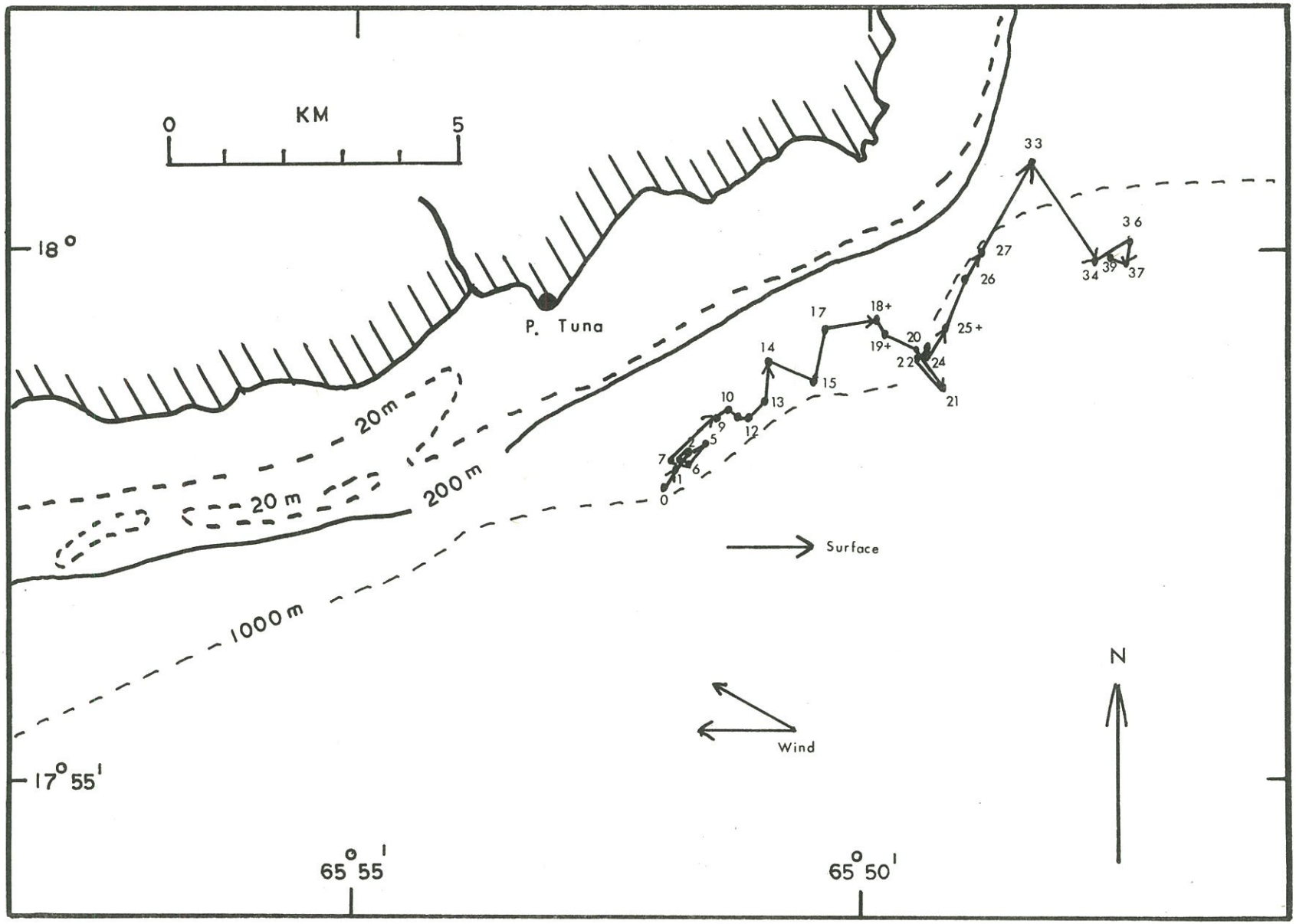

Figure 21. Trajectory for Drogue "A" off Punta Tuna, Puerto Rico from 1200 on 10 June 1980 until 0300 12 June. (Numbers are elapsed time in hours;depth is 100m)

cruise, the pressure continued to rise.

Table 22 shows the data from which the speed and direction of the drogue were calculated and Table 23 shows the results of those calculations. The time that elapsed between each of the 31 observations varied from 0.7-6 hours, with only one value greater than 2 hours. The distance traveled by the drogue between observations ranged from 0.04-2.0 km.

The average speed during the 39 hours of tracking was 14 cm/sec, with a range of 1-56 cm/sec. The speed was between 3-11 cm/sec more than half the time, with 94% of the observations less than 27 cm/sec. The direction traveled most often was between 015-044 deg-T, with more than 80% of the observations between 0-180 deg-T.

Figure 22 shows the relationship between the predicted tidal currents in the area and the observed water direction at the 100 meter depth. The predictions are given based on both the San Juan and the Galveston tidal systems. Both systems appear similar during this period, however, the San Juan system is more clearly a semi-diurnal cycle, and the Galveston does have a much smaller semi-diurnal component added to its dominant diurnal period. If any correlation between the tidal currents and the 100 meter deep water movement might be seen, it could be at about 1400-1800 on 10 June, when the predicted tidal current was westerly. There was a strong westerly turn in the 100 meter deep water, but at elapsed time "hour 5", the drogue did take a sharp northeast turn. Also, the drogue movement at about 2200 hour on 10 June and again at about

TABLE 22

DATA AND CALCULATIONS FOR DROGUE "A":

Cruise of 10-12 June 1980

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-T)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.7'	65°51.9'	10 June	1200	0.0	---	----	---	--
					1.0	0.23	008	6
17°56.9'	65°51.8'	10 June	1300	1.0	---	----	---	--
					1.0	0.35	050	10
17°57.0'	65°51.7'	10 June	1400	2.0	---	----	---	--
					2.0	0.21	240	3
17°56.9'	65°51.8'	10 June	1600	4.0	---	----	---	--
					1.0	0.56	052	16
17°57.1'	65°51.5'	10 June	1700	5.0	---	----	---	--
					1.0	0.37	224	10
17°57.0'	65°51.7'	10 June	1800	6.0	---	----	---	--
					1.0	0.24	261	7
17°56.9'	65°51.8'	10 June	1900	7.0	---	----	---	--
					2.0	1.09	046	15
17°57.4'	65°51.4'	10 June	2100	9.0	---	----	---	--
					1.0	0.26	047	7
17°57.4'	65°51.3'	10 June	2200	10.0	---	----	---	--
					1.0	0.19	136	5
17°57.4'	65°51.2'	10 June	2300	11.0	---	----	---	--
					1.0	0.18	097	5
17°57.4'	65°51.1'	10 June	2400	12.0	---	----	---	--
					1.0	0.43	040	12
17°57.5'	65°51.0'	11 June	0100	13.0	---	----	---	--
					1.0	0.70	010	19
17°57.9'	65°50.9'	11 June	0200	14.0	---	----	---	--
					1.0	0.82	121	23
17°57.7'	65°50.5'	11 June	0300	15.0	---	----	---	--
					2.0	0.98	014	14
17°58.2'	65°50.4'	11 June	0500	17.0	---	----	---	--
					1.2	0.88	076	20

TABLE 22

Cruise of 10-12 June 1980 (Continued)

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-T)	SPEED FROM PREVIOUS PT. (cm/sec)
17°58.3'	65°49.9'	11 June	0615	18.2	---	----	---	--
					1.0	0.29	152	8
17°58.2'	65°49.8'	11 June	0715	19.2	---	----	---	--
					0.8	0.62	110	23
17°58.0'	65°49.5'	11 June	0800	20.0	---	----	---	--
					1.0	0.86	145	24
17°57.6'	65°49.2'	11 June	0900	21.0	---	----	---	--
					1.0	0.81	322	22
17°58.0'	65°49.5'	11 June	1000	22.0	---	----	---	--
					1.0	0.14	038	4
17°58.1'	65°49.4'	11 June	1100	23.0	---	----	---	--
					1.0	0.04	146	1
17°58.0'	65°49.4'	11 June	1200	24.0	---	----	---	--
					1.3	0.44	045	9
17°58.2'	65°49.2'	11 June	1320	25.3	---	----	---	--
					0.7	0.94	022	39
17°58.7'	65°49.0'	11 June	1400	26.0	---	----	---	--
					1.0	0.62	029	17
17°59.0'	65°48.8'	11 June	1500	27.0	---	----	---	--
					6.0	1.74	030	8
17°59.8'	65°48.4'	11 June	2100	33.0	---	----	---	--
					1.0	2.03	146	56
17°58.9'	65°47.7'	11 June	2200	34.0	---	----	---	--
					2.0	0.67	060	9
17°59.1'	65°47.4'	11 June	2400	36.0	---	----	---	--
					1.0	0.39	202	11
17°58.9'	65°47.5'	12 June	0100	37.0	---	----	---	--
					2.0	0.26	294	4
17°59.0'	65°47.6'	12 June	0300	39.0	---	----	---	--
		12 June	1440	50.7	RECOVERY			

TABLE 23

SUMMARY OF DROGUE "A" WATER MOTION MEASUREMENTS:

Cruise of 10-12 June 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (deg-T)	TIME (%)
0 - 2	2	345 - 014	11
3 - 5	18	015 - 044	26
6 - 8	25	045 - 074	22
9 - 11	16	075 - 104	6
12 - 14	8	105 - 134	5
15 - 17	10	135 - 164	14
18 - 20	6	165 - 194	0
21 - 23	7	195 - 224	5
24 - 26	2	225 - 254	3
27 - 29	0	255 - 284	3
30 - 32	0	285 - 314	5
33 - 35	0	315 - 344	3
36 - 38	0		
39 - 41	2		
42 - 44	0		
45 - 47	0		
48 - 50	0		
51 - 53	0		
54 - 56	2		
57 - 59	0		
60 - 62	0		

Average Speed = 10 cm/sec

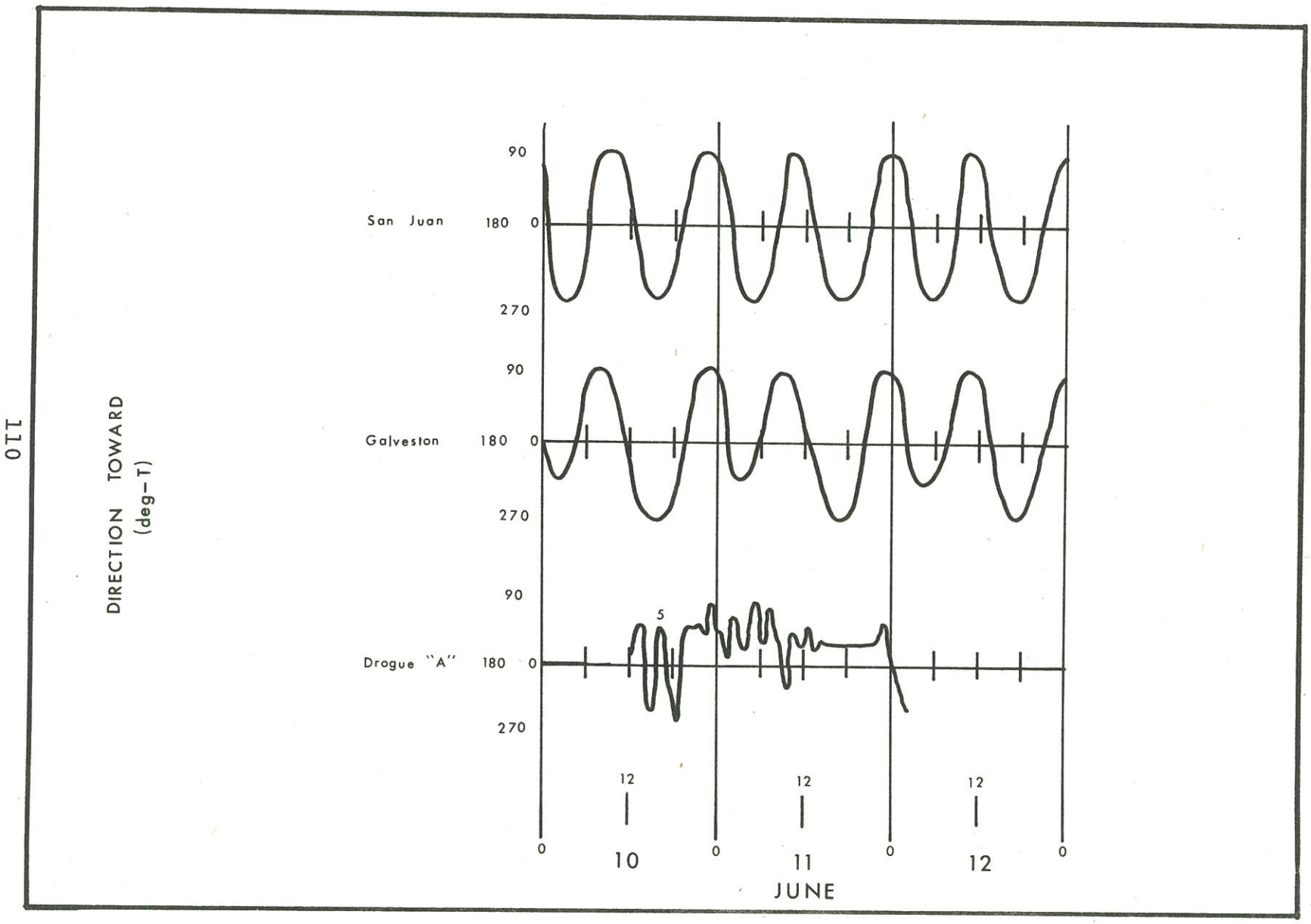

Figure 22. Directionality of drogue and predicted tidal currents during the period from 10-12 June 1980 at Punta Tuna, Puerto Rico.

0900 on 11 June was more easterly than "average", and those times did correspond to easterly tidal flows. These are weak comparisons however.

3.6.3 INTERPRETATION

During this cruise the 100 meter deep water moved northeast, and along with the eastward surface water, moved into the eye of the brisk, easterly wind. This time of the year should have found the 100 meter depth fimrly into the lower Subtropical Underwater, with a separate, shallow Tropical Surface Water above it. Whatever is forcing the SUW eastward may, or may not be also moving the TSW in the same direction.

Any tidal influence is truely weak during this period.

3.7 CRUISE OF 24-27 JUNE 1980

The following sections describe the activities and results of the cruise of 24-27 June 1980.

3.7.1 NARRATIVE

Drogue "A" was deployed from the LCU at 0930 A.S.T. on 25 June 1980. The depth sensitivity of the drogue (panel depth) was set at 100 meters. Throughout the 23 hours of tracking, the position of the drogue was determined by using the radar aboard the LCU. A current meter had been suspended from the LCU to a depth of 100 meters also. This meter would enable a check of the general drogue operation.

The lines of the drogue running to the bottom of the panel became entangled with the current meter upon deployment. However, this situation was not promptly diagnosed, and then

a solution was not affected until 1700 that same day. After this time, the drogue drifted freely in a southwesterly direction for the next 23 hours. It was recovered about 7 km southwest of the LCU at 1600 on 26 June.

The current meter was ready every 1-2 hours throughout the cruise.

3.7.2 RESULTS

Throughout the cruise, lasting from 24-27 June 1980, both the drogue "A" and the current meter were set so as to be sensitive to the depth of 100 meters. Also, all position tracking of the drogue was accomplished using the LCU's radar. The drogue was deployed from the LCU and the current meter was suspended from the same vessel. The drogue was recovered using the 13m ship-to-shore vessel.

Figure 23 shows the plotted trajectory of drogue "A" from the time of its release from entanglement with the current meter line (1700 A.S.T. on 25 June 1980) until its recovery 23 hours later at 1600 on 26 June. During that time, and for a significant previous period, the wind was moderate to brisk (5-13 m/sec) out of the southeast to northeast. The atmospheric pressure remained at least normal or higher both before and during the cruise. A noticeable decrease in pressure did not occur until about two weeks after the termination of the cruise. The surface current ran toward the west (with the wind) most of the time. The water parcel containing the drogue moved steadily southwesterly with very little deviation. Table 24 contains the data on which the speed and direction calculations

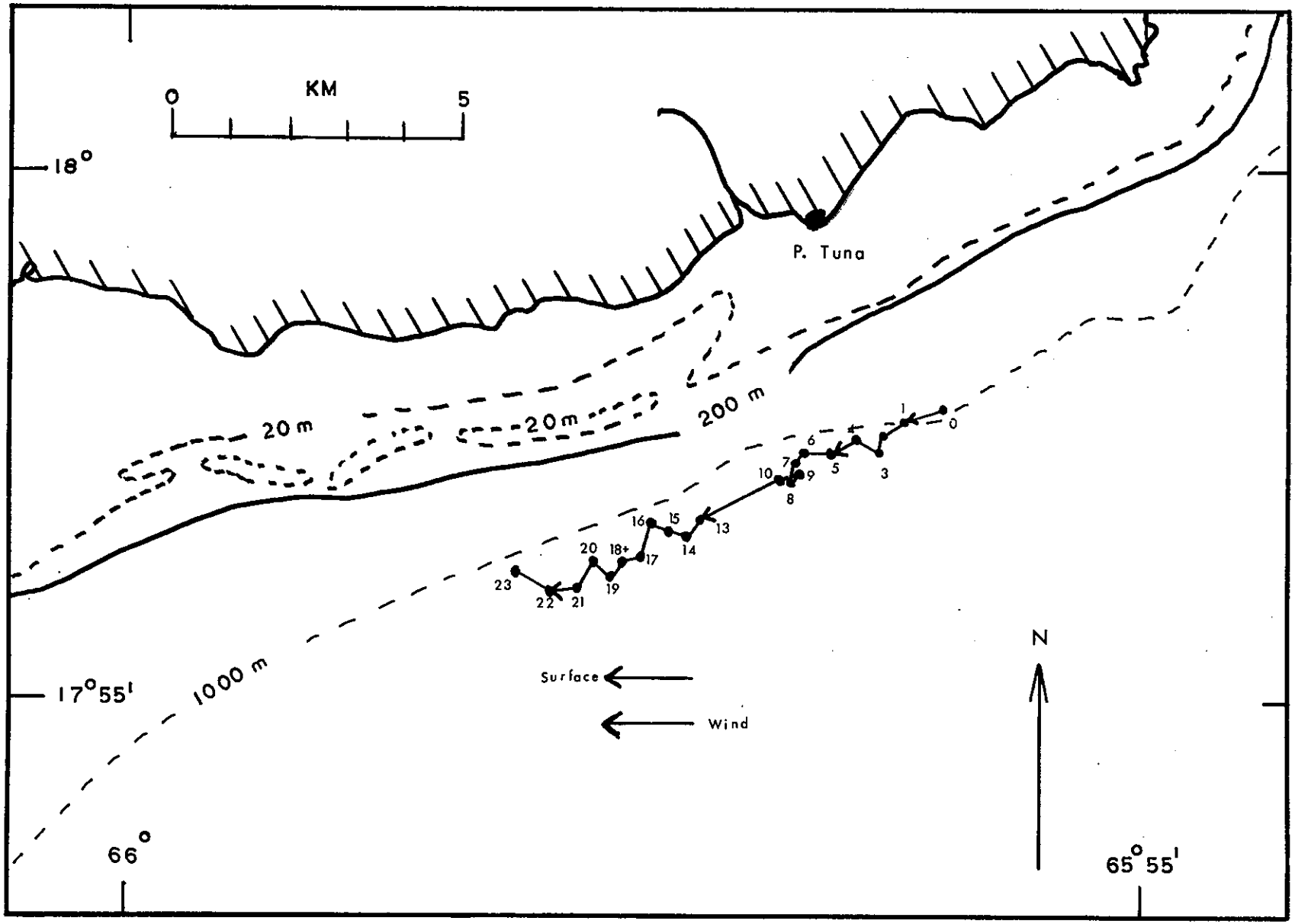

Figure 23. Trajectory for Drogue "A" off Punta Tuna, Puerto Rico from 1700 on 25 June 1980 until 1600 on 26 June. (numbers are elapsed time in hours;100m depth)

TABLE 24

DATA AND CALCULATIONS FOR DROGUE "A":

Cruise of 25-26 June 1980

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-T)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.7'	65°52.0'	25 June	1700	0.0	---	----	---	---
					1.5	0.64	249	12
17°56.6'	65°52.3'	25 June	1830	1.5	---	----	---	--
					1.0	0.39	241	11
17°56.5'	65°52.5'	25 June	1930	2.5	---	----	---	--
					0.5	0.31	201	17
17°56.3'	65°52.5'	25 June	2000	3.0	---	----	---	--
					1.0	0.46	296	13
17°56.4'	65°52.8'	25 June	2100	4.0	---	----	---	--
					1.0	0.48	237	13
17°56.3'	65°53.0'	25 June	2200	5.0	---	----	---	--
					1.0	0.48	269	13
17°56.3'	65°53.3'	25 June	2300	6.0	---	----	---	--
					1.0	0.23	212	6
17°56.2'	65°53.3'	25 June	2400	7.0	---	----	---	--
					1.0	0.25	203	7
17°56.0'	65°53.4'	26 June	0100	8.0	---	----	---	--
					1.0	0.10	060	3
17°56.0'	65°53.4'	26 June	0200	9.0	---	----	---	--
					1.0	0.27	245	8
17°56.0'	65°53.5'	26 June	0300	10.0	---	----	---	--
					3.0	1.55	241	14
17°55.6'	65°54.3'	26 June	0600	13.0	---	----	---	--
					1.0	0.38	234	10
17°55.5'	65°54.4'	26 June	0700	14.0	---	----	---	--
					1.0	0.26	285	7
17°55.5'	65°54.6'	26 June	0800	15.0	---	----	---	--
					1.0	0.36	294	10
17°55.6'	65°54.8'	26 June	0900	16.0	---	----	---	--
					1.0	0.66	192	18

TABLE 24

Cruise of 25-26 June 1980 (Continued)

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-T)	SPEED FROM PREVIOUS PT. (cm/sec)
17°55.3'	65°54.9'	26 June	100	17.0	---	----	---	--
					1.2	0.27	262	6
17°55.2'	65°55.0'	26 June	1115	18.2	---	----	---	--
					0.8	0.28	224	10
17°55.1'	65°55.2'	26 June	1200	19.0	---	----	---	--
					1.0	0.38	301	10
17°55.2'	65°55.3'	26 June	1300	20.0	---	----	---	--
					1.0	0.53	214	15
17°55.0'	65°55.5'	26 June	1400	21.0	---	----	---	--
					1.0	0.51	262	14
17°55.0'	65°55.8'	26 June	1500	22.0	---	----	---	--
					1.0	0.61	305	17
17°55.2'	65°56.1'	26 June	1600	23.0	---	----	---	--
		26 June	1700		Recovery			

for drogue "A" are based. Table 25 shows the actual results of those calculations.

The elapsed time during the 22 observations varied from 0.5-3 hours, with all but two being less than 1.5 hours. The distance the drogue moved between observations ranged from 0.1 - 1.4 km. The average speed was 11 cm/sec, and the water moved in the range of 6-14 cm/sec more than 80% of the time. The range of observed speed values was 3-18 cm/sec, and the most frequently seen values are 12-14 cm/sec, followed closely by 9-11 cm/sec and 6-8 cm/sec. As verification of the westerliness of the drogue's motion, 95% of the time the water moved between 195 - 314 deg-T, and more than half the time the water moved between 195-254 deg-T. The drogue again closely followed the 1000 meter contour toward the southwest.

Figure 24 shows the plotted trajectory of drogue "A" together with the plotted progressive vector of the current meter results. Although the scale of this figure differs from that of the preceeding figure, the scale is the same for both the drogue and current meter. The elapsed times (in hours) are shown for both instruments, using the drogue disentanglement time (1700 on 25 June) as "0" hours. The separation in the current meter vector resulted from the false values of the instrument that occurred during the entanglement with the drogue. The current meter "trajectory" appeared to follow that of the drogue quite closely; however, the estimated distances are much greater for the current meter due to its much greater indicated speed. The current meter data was

TABLE 25

SUMMARY OF DROGUE "A" WATER MOTION MEASUREMENTS:

Cruise of 25-26 June 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	0	345 - 014	0
3 - 5	4	015 - 044	0
6 - 8	23	045 - 074	4
9 - 11	21	075 - 104	0
12 - 14	37	105 - 134	0
15 - 17	11	135 - 164	0
18 - 20	4	165 - 194	4
21 - 23	0	195 - 224	19
24 - 26	0	225 - 254	37
Average Speed = 11 cm/sec		255 - 284	14
		285 - 314	22
		315 - 344	0

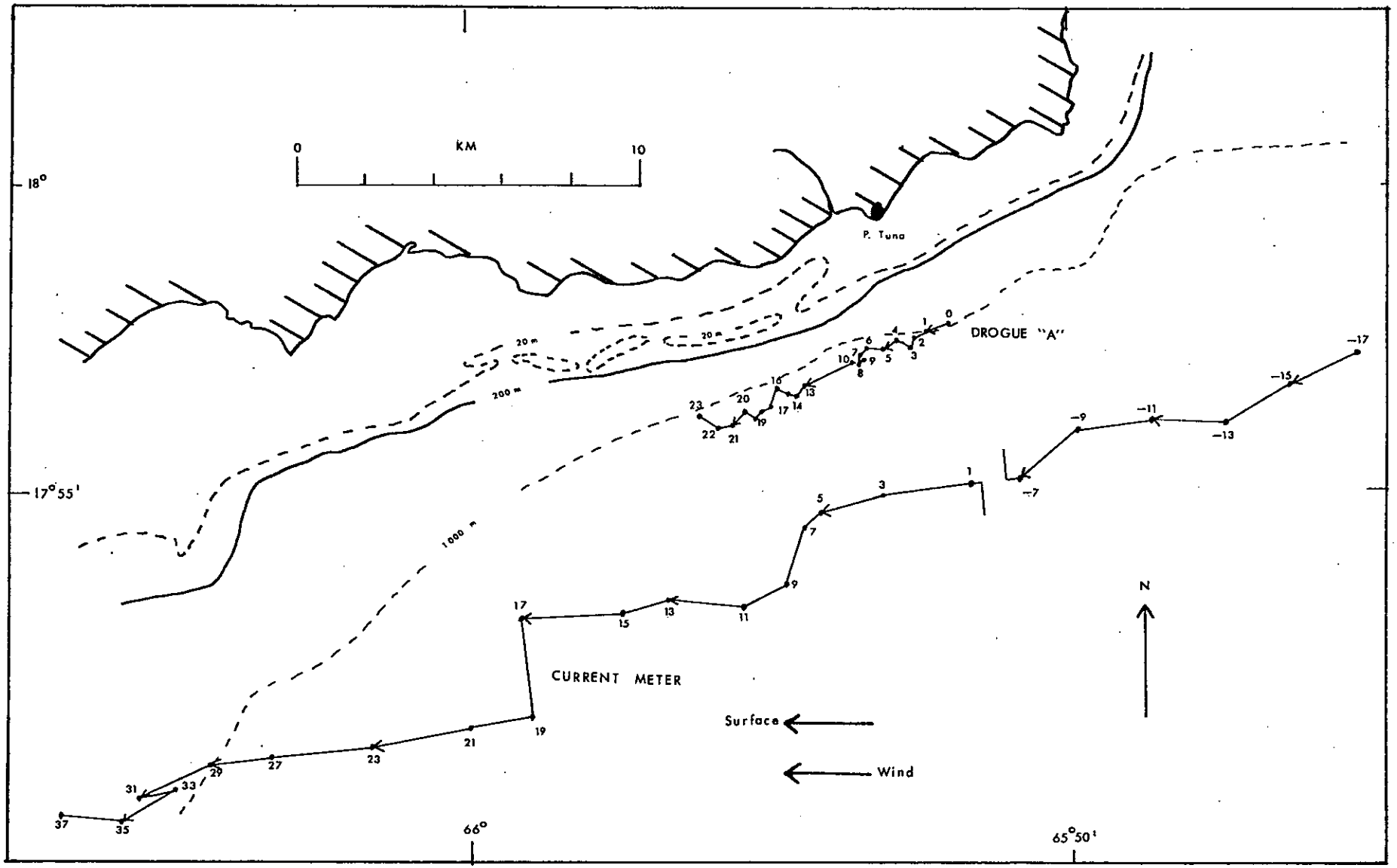

Figure 24. Trajectory for Drogue "A" and progressive vector for current meter results off Punta Tuna, Puerto Rico from 24 - 27 June 1980.(Numbers are elapsed time in hours from 1700 on 25 June;depth is 100 meters)

observed over an elapsed time of more than 50 hours.

Table 26 displays the results of the current meter speed and direction. The average observed speed for the current meter was 29 cm/sec, with a range of 10-41 cm/sec. The most frequently observed values were 24-26 cm/sec and 30-32 cm/sec. Almost 80% of the observations were greater than 23 cm/sec. These values are about triple those of the drogue, which may be due to the readability of the instrument, calibration, actual differences, or errors due to the swing of the LCU on its mooring. (On subsequent investigation of the current meter, it was found to be horizontally misoriented, and after proper alignment, the speeds decreased noticeably. The directionality of the current meter, however, was much more closely related to that of drogue. The most frequently observed values were between 225-284 deg-T, with only 4% of the observations not between 165-314 deg-T, compared to 5% for the drogue.

Figure 25 shows the relationship between the predicted tidal currents in the area and those observed water directions seen by either the drogue or the current meter (both at 100 meters depth). The predictions are given for both Galveston and San Juan tidal systems. During this cruise, both of these predictions appear quite similar, although the reduction of the semi-diurnal component for the Galveston system is evident. There appears to be little correlation between the drogue direction and any tidal influence, when observed alone. However, there seems to be some tidal effects in the current

TABLE 26

SUMMARY OF CURRENT METER WATER MOTION MEASUREMENTS:

Cruise of 24-27 June 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (Deg-T)	TIME (%)
0 - 2	0	345 - 014	0
3 - 5	0	015 - 044	0
6 - 8	0	045 - 074	0
9 - 11	4	075 - 104	4
12 - 14	0	105 - 134	0
15 - 17	4	135 - 164	0
18 - 20	12	165 - 194	4
21 - 23	0	195 - 224	12
24 - 26	29	225 - 254	25
27 - 29	0	255 - 284	50
30 - 32	29	285 - 314	4
33 - 35	0	315 - 344	0
36 - 38	0		
39 - 41	21		
42 - 44	0		

Average Speed = 29 cm/sec

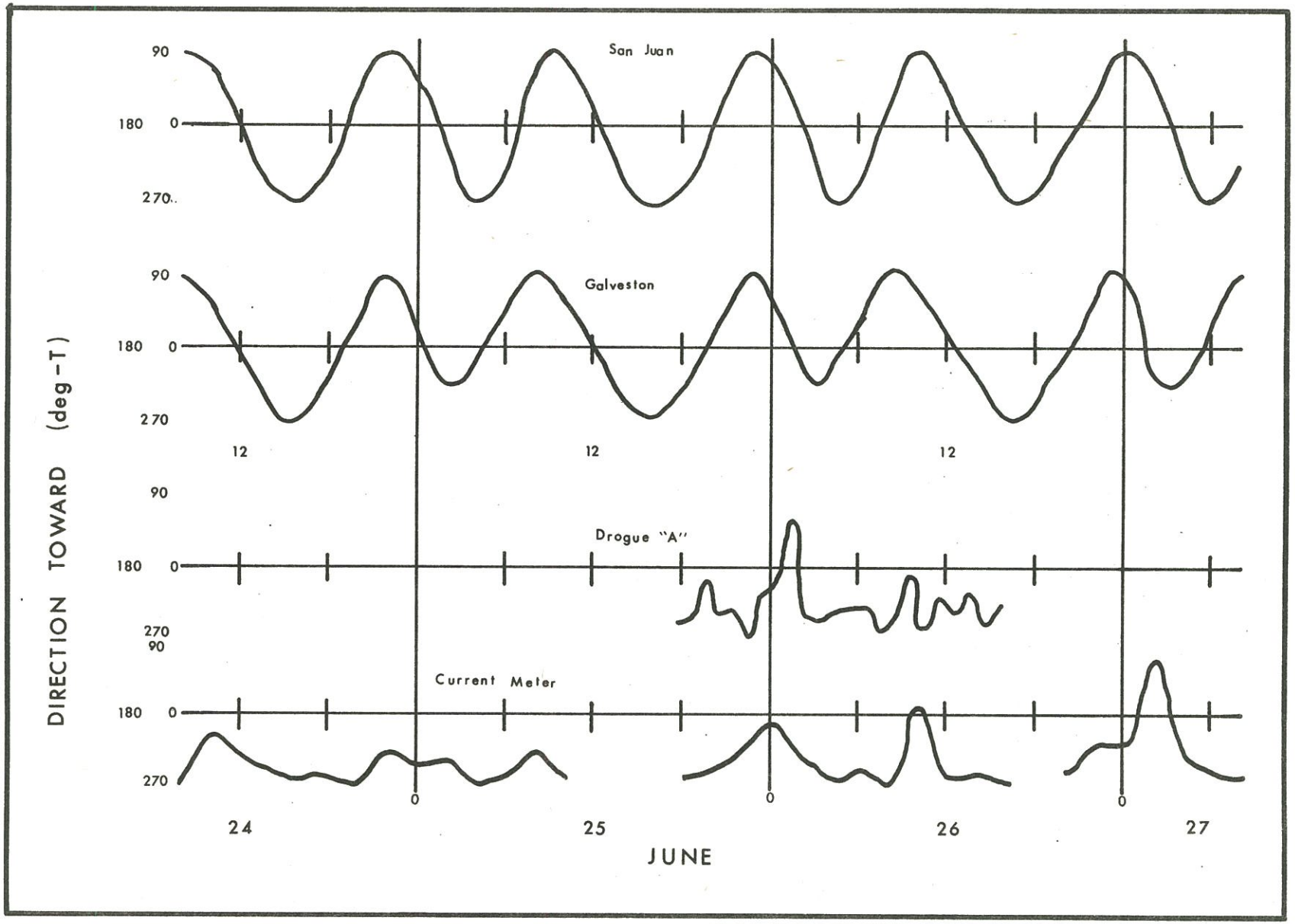

Figure 25. Directionality of drogue and current meter observations compared to the predicted tidal currents during the period from 24-27 June 1980 at Punta Tuna.

meter directionality as seen early on 24 June, late 24-early 25 June, mid 25 June, midnight 26 June, and maybe 1000 on 26 June. All these occasions show easterly shifts that correspond to an easterly tidal flow. When these observations are seen next to the drogue results, some possible influence may be implied in the drogue results as well.

3.7.3 INTERPRETATIONS

The water at the 100 meter depth is moving parallel and slightly seaward of the 1000 meter contour. This was satisfactorily confirmed by good agreement between the directional results of the drogue and the current meter. This motion appears to be somewhat parallel to the surface water mass, which may be wind-driven at this time.

3.8 CRUISE OF 16-23 JULY 1980

The following sections describe the activities and results of the cruise of 16-23 July 1980.

3.8.1 NARRATIVE

On 15 July 1980 the group left Mayaguez and arrived at the LCU in anticipation of deployment of the drogues the next day. Although the cruise participants were aboard the LCU by the afternoon of 15 July, poor weather, in the form of a tropical wave, prevented the ship-to-shore vessel from leaving port until 19 July. As the small vessel is considered a necessary back-up for the drogue operation (both during tracking and recovery), the drogue deployment was postponed. The period from 16 - 18 July was devoted to current meter rebalancing for

more accurate speed measurements (the meter was originally balanced so as to be pointing nearly vertical, and it also had tangled its electrical line with the support line.) This work was completed by 16 July. As rough seas remained throughout the cruise, only one drogue was deployed so as to minimize possible losses due to the seas or not being able to affect recovery.

The actual drogue "A" deployment was accomplished from the deck of the LCU at 0900 A.S.T. on 19 July 1980. The depth sensitivity of the panel was set at 100 meters. However, upon recovery, it was determined that the panel had been severely damaged, leaving only a small portion of the upper part of the panel intact, and no weight at the bottom. This damage changed the depth sensitivity of the panel considerably. Upon deployment, the drogue began to move beneath the LCU, so a small vessel was used to tow the drogue assembly about 15 meters northwest of the LCU so as to prevent entanglement with other down-lines. Immediately, a diver was dispatched to inspect the drogue assembly for damage, but none was found at that time.

The drogue was tracked for a total of 76 hours. During the first 14 hours, the position of the drogue was determined by the radar aboard the LCU. After that time, the ship-to-shore vessel visited the drogue, locating it by the RDF beacon. Positioning was accomplished during the last 60 hours of tracking by the use of a hand bearing compass aboard the ship-to-shore vessel and using known locations on land. Due

to the rough seas and increasing distance from the LCU, these trips to the drogue were limited to once daily. The drogue was recovered at 1300 on 22 July, after it had been drifting for 76 hours, and was about 60 km southwest of the LCU, near Isla Caja de Muertos. However, sometime during the drift, the panel was damaged, producing a change in the depth sensitivity, drag, and drift characteristics.

The current meter, untangled, rebalanced, and set back into the water at the 100 meter depth on 16 July, was read bihourly, when possible, until 1300 on 23 July, for a total elapsed time of 164 hours.

On 23 July, after recovery of the drogue, an XBT trace was obtained with the help of Mr. D. Corales of CEER.

3.8.2 RESULTS

Throughout the testing period, 16 - 23 July, the comparative current meter was set at 100 meters depth. The drogue was originally set to this depth also, but sometime during the drifting period, the lower half of the panel was torn away, causing the panel to lose its anchoring weight, and more than half its drag area at 100 meters. These losses have probably resulted in the panel, rising up into the upper water mass, thereby no longer being valid as a follower of the 100 meter deep water. The time of this separation and change can only be weakly surmised from the data, and shall be discussed later.

The position tracking for the first 14 hours of the drogue's drift was accomplished using the LCU's radar. The drogue was deployed from this vessel, and the current meter

was also suspended therefrom. During the remaining drogue drift (elapsed times of 30 to 76 hours), the positioning was done with a hand bearing compass from aboard the ship-to-shore vessel. This vessel was also used during the recovery of the drogue.

Figure 26 shows the plotted trajectory of the drogue from the time of its deployment (0900 A.S.T. on 19 July 1980) until its recovery, 76 hours later, at 1300 on 22 July. During that time, the wind was moderate to brisk (7-10 m/sec) from the east-to-southeast. The surface current moved westward throughout the cruise. During this time the atmospheric pressure was at a relatively low value, compared to the average or preceding couple of weeks. Furthermore, within a week after the start of the drogue drift, the pressure reached the month's lowest value, then quickly recovered.

During the first 14 hours of the drogue track, it moved southwest, with numerous north and south excursions. The average speed during that period was 21 cm/sec, averaging the separate values. The drogue was no longer visible by radar after that time, so the ship-to-shore vessel was sent daily to determine the drogue's position by hand bearing compass. During the latter three days, the drift averaged 23 cm/sec. This lack of definite change in the drift speed appears to make any guess as to the time/location of the panel tearing almost impossible. However, other evidence may help. During the first 14 hours, the average speed, based on the total time and total distance covered, is only 17 cm/sec. The remaining

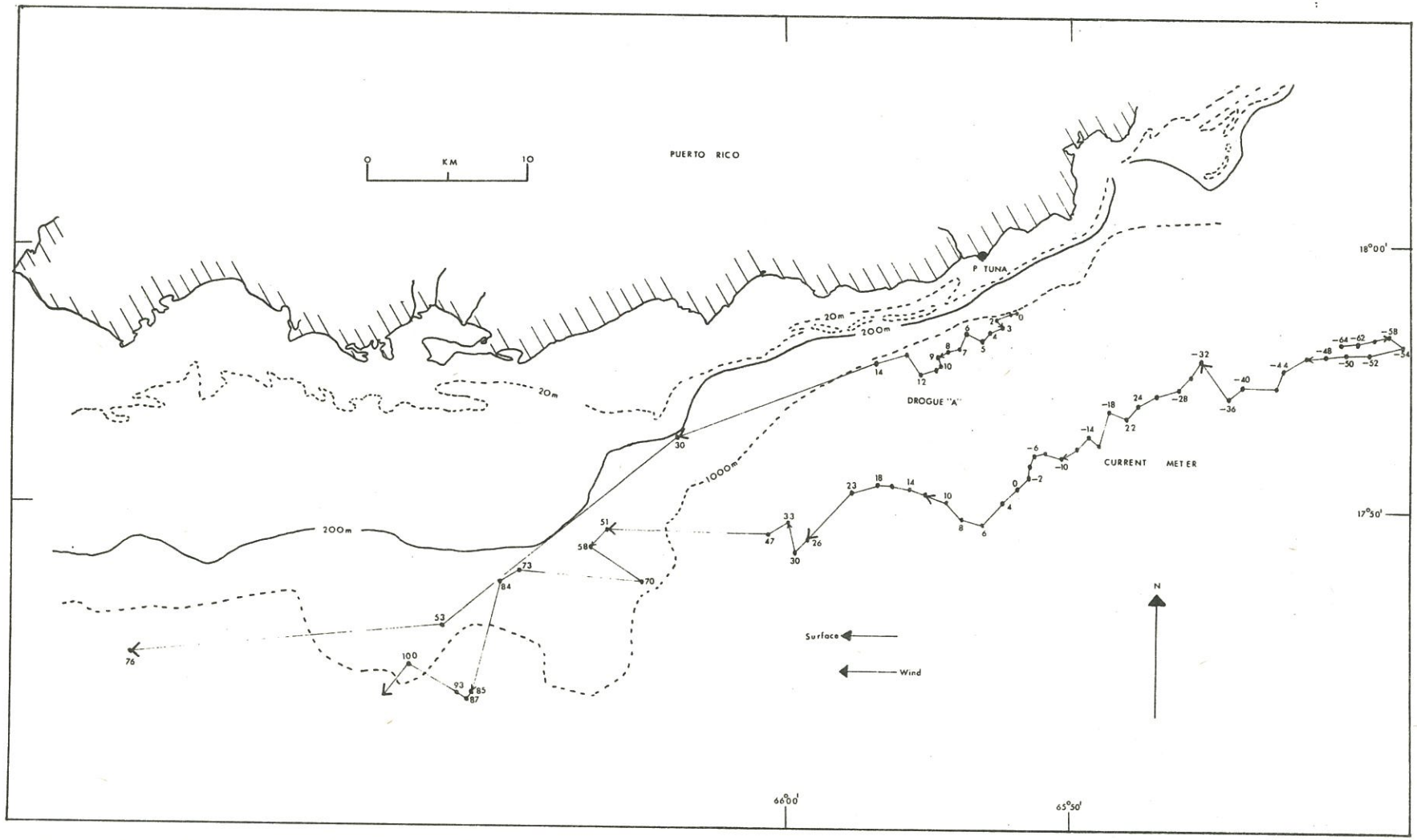

Figure 26. Trajectory for Drogue "A" and pro-vec for current meter results off Punta Tuna from 16-23 July 1980.(Numbers are elapsed time, in hours from 0900 on 19 July;depth of current meter is 100m and drogue also began at 100m, but was damaged later.)

daily averages are 22, 23, and 24 cm/sec. This may indicate that the panel tear occurred between elapsed-time 14 hours and 30 hours, as the drogue moved into the shallower water. Also, for the period from hour 30 to hour 40, the drogue was near the very steep slope of the island shelf. A slight error in drogue positioning (easily possible using the hand bearing compass) could place the drogue in less than 40 meters of water, as the bottom drops from 30 to 400 meters depth in less than 1 km in this area.

Table 27 contains the data on which the speed and direction calculations for the drogue are based. Table 28 shows the actual results of these calculations.

During the 76 hours of drift, there were a total of 17 observations. The time interval between observations varied from 0.7 hours during the first period (using the radar) to 22 hours (using the ship-to-shore vessel). The distance traveled between observations varied from 0.3 km during the early period to 19 km. Overall, the drogue averaged about 23 cm/sec, with more than 3/4 of the time the observations were between 15-26 cm/sec. The most frequently observed speed range was between 21-23 cm/sec. All the direction observations were between 135-314 deg-T, and 93% of the time, the water moved between 225-284 deg-T.

Figure 26 also shows the progressive vector of the current meter results. The scale of both the drogue and the current meter results are the same on the figure. The elapsed time (in hours) are shown for both devices, using the drogue

TABLE 27

DATA AND CALCULATIONS FOR DROGUE "A":

Cruise of 19-22 July 1980

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-T)	SPEED FROM PREVIOUS PT. (cm/sec)
17°56.6'	65°51.9'	19 July	0900	0.0	---	----	---	--
					1.3	0.37	248	8
17°56.5'	65°52.1'	19 July	1020	1.3	---	----	---	--
					0.7	0.97	244	40
17°56.3'	65°56.2'	19 July	1100	2.0	---	----	---	--
					1.0	0.55	137	15
17°56.1'	65°52.4'	19 July	1200	3.0	---	----	---	--
					1.4	1.01	229	20
17°55.9'	65°52.9'	19 July	1325	4.4	---	----	---	--
					0.7	0.49	239	20
17°55.6'	65°53.1'	19 July	1405	5.1	---	----	---	--
					0.9	1.17	293	35
17°55.9'	65°53.7'	19 July	1500	6.0	---	----	---	--
					1.1	1.11	200	28
17°55.3'	65°53.9'	19 July	1605	7.1	---	----	---	--
					0.9	0.74	256	20
17°55.2'	65°54.3'	19 July	1700	8.0	---	----	---	--
					1.2	0.73	255	16
17°55.1'	65°54.7'	19 July	1815	9.2	---	----	---	--
					0.8	0.67	155	25
17°54.7'	65°54.6'	19 July	1900	10.0	---	----	---	--
					1.0	0.32	243	9
17°54.6'	65°54.8'	19 July	2000	11.0	---	----	---	--
					1.0	1.07	256	30
17°54.5'	65°55.3'	19 July	2100	12.0	---	----	---	--
					2.0	2.76	288	38
17°54.9'	65°56.8'	19 July	2300	14.0	---	----	---	--
					16.5	13.35	250	22

TABLE 27

Cruise of 19-22 July 1980 (Continued)

LATITUDE (Deg. N)	LONGITUDE (Deg. W)	DATE (1980)	TIME (Hr) A.S.T.	ELAPSED TIME-TOTAL (Hr)	TIME FROM PREVIOUS PT. (Hr)	DISTANCE FROM PREVIOUS PT. (kM)	DIRECTION FROM PREVIOUS PT. (Deg.-T)	SPEED FROM PREVIOUS PT. (cm/sec)
17°52.4'	66°03.9'	20 July	1530	30.5	---	----	---	--
					23.0	18.80	231	23
17°46.0'	66°12.3'	21 July	1430	53.5	---	----	---	--
					22.5	19.40	265	24
17°45.1'	66°23.3'	22 July	1300	76.0	---	----	---	--

TABLE 28

SUMMARY OF DROGUE "A" WATER MOTION MEASUREMENTS:

Cruise of 19-22 July 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (deg-T)	TIME (%)
0 - 2	0	345 - 014	0
3 - 5	0	015 - 044	0
6 - 8	2	045 - 074	0
9 - 11	1	075 - 104	0
12 - 14	0	105 - 134	0
15 - 17	3	135 - 164	2
18 - 20	4	165 - 194	0
21 - 23	52	195 - 224	1
24 - 26	31	225 - 254	59
27 - 29	1	255 - 284	34
30 - 32	1	285 - 314	4
33 - 35	1	315 - 344	0
36 - 38	3		
39 - 41	1		
42 - 44	0		

Average Speed = 23 cm/sec

deployment (0900 on 19 July) as "0" hour. The "trajectory" of the current meter, or the progressive vector, is also basically southwesterly, with a short easterly excursion at the beginning (elapsed time -64 to -54 hr), and again at elapsed time 58 to 70 hours, with numerous north and south excursions throughout the period. The time interval between the two strong easterly excursions was about 125 hours.

Table 29 displays the speed and direction results of the current meter. The average speed was 16 cm/sec, with more than half the observed values between 15-20 cm/sec. No value was observed less than 9 cm/sec, and only one value was more than 23 cm/sec (and that was 31 cm/sec.). Eighty percent of the direction observations were between 195 - 314 deg-T, with the range with the highest frequenty of observations being 225 - 254 deg-T. As opposed to the drogue results, several observations were between 315 - 134 deg-T., but these usually occurred either before the drift of the drogue began, or between drogue observations, when only one drogue observation was being taken daily.

Figure 27 shows the relationship between the predicted tidal currents in the area and those observed directions seen either by the drogue or by the current meter. The predictions are given for both Galveston and San Juan systems. During this cruise, both of the predictions appear similar, although the semi-diurnal component for the Galveston system is evidently weak. As the short-term drogue observations (bihourly) lasted only 14 hours, little correlation is possible with the drogue

TABLE 29

SUMMARY OF CURRENT METER WATER MOTION MEASUREMENTS:

Cruise of 16-23 July 1980

SPEED (cm/sec)	TIME (%)	DIRECTION (deg-T)	TIME (%)
0 - 2	0	345 - 014	2
3 - 5	0	015 - 044	0
6 - 8	0	045 - 074	0
9 - 11	14	075 - 104	6
12 - 14	18	105 - 134	4
15 - 17	33	135 - 164	0
18 - 20	27	165 - 194	2
21 - 23	6	195 - 224	12
24 - 26	0	225 - 254	31
27 - 29	0	255 - 284	23
30 - 32	2	285 - 314	14
33 - 35	0	315 - 344	6

Average Speed = 16 cm/sec

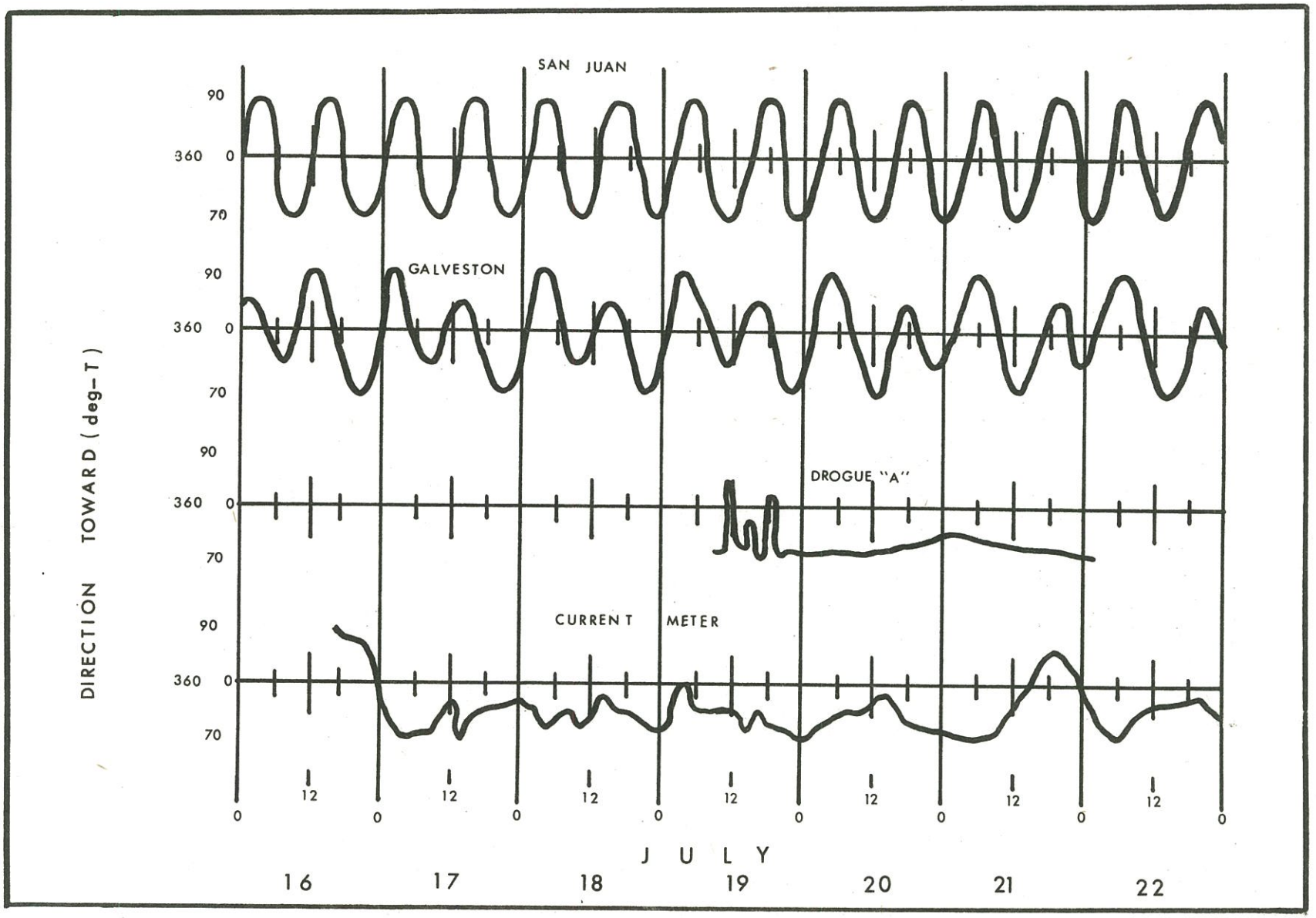

Figure 27. Directionality of drogue and current meter observations compared to the predicted tidal currents during the period from 16-22 July 1980 at Punta Tuna.

movement. However, the current meter observations show frequent eastward excursions that appear to match the tidal oscillations for the area. These likely correlates are: 1200 on 17 July, 1400 on 18 July, 0300 and 1600 on 19 July, 1900 on 21 July, and 2000 on 22 July. As most of these correlates appear during the weaker, semi-diurnal portion of the Galveston (or Caribbean) system, it might be surmised that the North Atlantic system, as seen in San Juan, may be the dominant in the Punta Tuna area.

It is fairly certain, using the information available, that both the Tropical Surface Water, the upper water mass, containing the upper mixed layer, and its lower counterpart, the Subtropical Underwater, are moving southwesterly past the test area during the time of this cruise.

3.8.3 INTERPRETATIONS

Although the 100 meter deep water clearly moved southwesterly, confirmed by both the drogue and the current meter, the speed again is in doubt due to the differences between the two instruments. Although the drogue was not observed to move over the shallow shelf that extends southward of Jobos, the reduction to only a single daily observation may have prevented observing such motion. The current meter indicated more tidal correlation than did the drogue. Furthermore, the current meter displayed two strong easterly excursions that may be related to non-tidal forcing such as internal waves, or possible atmospheric pressure forcing. These easterly movements occurred at times the drogue motion was not being monitored.

3.9 OVERALL RESULTS

This section is included to summarize all the results of the drogue data collected during this program.

The results will be evaluated on a total basis as well as seasonally.

There were a total of 421.6 hours of monitoring the drifting of 100 meter deep drogues (although some of this time actually was devoted to following drogues with a much shallower depth due to breakage).

There were eight cruises during the period from November 1979 until July 1980. Table 30 contains the information as to the dates, elapsed data time, and generalized results. Overall, there were 192 observations during the 422 hours, yielding an observation about every two hours. At least one drogue was in the water over a total of 22 days over the nine months, with a total of thirteen actually useable drogue deployments, some running concurrently, and some extending over many days. The average number of useable drogue tracking hours was slightly more than 30 hours/drogue, with a range of from 4 to 102 hours. The overall speed seen throughout the program at 100 meters depth was 12 cm/sec, with the cruise averages ranging from 5-23 cm/sec. Table 31 shows the speed and directional data in a summary form for all the cruises combined. This table weighs each of the 192 observations as to the actual elapsed time between each observation. The overall time-weighted average speed was 13 cm/sec, with the observed values ranging from 0-56 cm/sec (the 40-90 cm/sec values that were observed

TABLE 30

SUMMARY OF ALL CRUISE OBSERVATION STATISTICS

CRUISE DATES	TOTAL TIME (HR)	# OF OBS.	# OF DAYS	# OF DROGUE LAUNCHES	DRIFT DURATION-AVE. (HR)	TIME BETWEEN OBS.-AVE. (HR)	SPEED-AVE. (CM/SEC)	PREDOMINANT DIRECTION (50+ %)
9 November 1979	7.4	6	1	1	7	1.2	5	None
28 Jan-1 Feb 1980	101.5	32	5	1	102	3.2	12	West
18-21 February 1980	37.7	26	4	2	19	1.4	14	West
24-25 March 1980	8	8	2	2	4	1.0	10[A]	West
7-11 May 1980	129	58	4	4	32	2.2	10	West
10-12 June 1980	39	29	3	1	39	1.3	12	East
25-26 June 1980	23	21	2	1	23	1.1	11	West
19-21 July 1980	76	16	3	1	76	4.8	23[B]	West
TOTALS	421.6	92	24	13	32	2.2	12	West

A-One drift of 4 hours had sensitivity to the near surface water only, not 100 meters--did not enter this data in speed column, only direction and time.

B-At some time during this drift the sensitivity changed from 100 meters to somewhat less.

TABLE 31

SUMMARY OF ALL DROGUE WATER MOTION MEASUREMENTS

SPEED (cm/sec)	TIME (%)	CUMMULATIVE TIME (%)	DIRECTION (Deg-T)	TIME (%)	
0 - 2	4	4	315 - 344	2	
3 - 5	9	14	345 - 014	4	10-North
6 - 8	28	42	015 - 044	4	
9 - 11	7	48	045 - 074	6	
12 - 14	10	58	075 - 104	4	16-East
15 - 17	12	70	105 - 134	4	
18 - 20	6	76	135 - 164	9	
21 - 23	13	90	165 - 194	2	18-South
24 - 26	7	97	195 - 224	7	
27 - 29	0.5	98	225 - 254	24	
30 - 32	0.5	98	255 - 284	26	56-West
33 - 35	0.2	98	285 - 314	6	
36 - 38	0.5	99			
39 - 41	0.3	99			
42 - 56	0.2	100			

Average Speed = 13 cm/sec

when the drogue panel was definitely not at 100 meters were not included in this average). The speed with the greatest time of observation was 6-8 cm/sec, with 28% of the time, compared to 21-23 cm/sec and 15-17 cm/sec following with 13% and 12% of the time, respectively. Ninety percent of the time the speed was 23 cm/sec or less.

This table also shows the great amount of time that the drogues spent moving westward (225 - 314 deg-T), 56%. However, a significant portion of the time, 16%, was spent moving eastward, and 10% of the time the drogues moved northward.

Table 32 shows the summary of the directional data expressed as either easterly (015 - 164 deg-T) or westerly (195 - 344 deg-T) for each day that the drogue was drifting under observation. Although the greater numbers of days showed a westerly drift, numerous days also showed an easterly drift. Also shown on this table are the surface water direction for each day (where observed), the wind direction, and the future atmospheric pressure (the pressure change within the next two-three days). One or more of these three observations were looked at as to a possible correlation with the eastward moving 100 meter deep water.

The wind direction had a correlation coefficient of zero, when compared to the 100 meter deep water direction. The wind was out of the east, moving westerly, during every day, regardless of the water direction.

The surface water direction was seen to occasionally change direction, as seen historically, however, the correlation

TABLE 32

POSSIBLE CORRELATES WITH 100M DEEP WATER SOUTHEAST OF PUERTO RICO

CRUISE	DATE	WESTWARD 195-344 Deg-T (%)	EASTWARD 015-165 Deg-T (%)	SURFACE DIRECTION (TOWARD)	WIND DIRECTION (TOWARD)	FUTURE ATMOSPHERIC PRESSURE
November	9	54	46	----	West	Low
	Total	54	46			
Jan/Feb	28	12	82	West	West	Low
	29	0	100	----	West	Low
	30	50	29	----	West	Low
	31	100	0	----	West	High
	1	100	0	----	West	High
	Total	50	42			
February	18	100	0	----	West	High
	19	100	0	----	West	High
	20	72	28	----	West	High
	21	100	0	----	West	High
	Total	91	9			
March	24	75	0	----	West	High
	25	100	0	----	West	High
	Total	88	0			
May	7	94	3	East	West	High
	8	75	17	East	West	High
	9	78	22	East	West	High
	10	60	31	East	West	High
	11	30	60	East	West	High
	Total	60	30			
June-10	10	33	58	East	West	High
	11	4	83	East	West	High
	12	100	0	East	West	High
	Total	19	59			
June-25	25	100	0	West	West	High
	26	88	6	West	West	High
	Total	92	4			
July	19	87	13	West	West	Low
	20	100	0	West	West	Low
	21	100	0	West	West	High
	Total	98	2			
TOTALS		65	29			

coefficient between the surface water direction and that at 100 meters was only 0.2.

Finally, as the rising and falling of the atmospheric pressure is known to cause a local upwelling, it was considered that this "down stream" upwelling may help to draw the deeper water upward, under the lower pressure area. As the weather path through the Caribbean is from east to west at about 5-7 cm/sec, a 2-3 day anticipatory time period may be expected between an effect at Punta Tuna to be seen and the causing low pressure to make itself felt in the air at Punta Tuna. Therefore, a correlation coefficient was computed between the direction of the water at Punta and the atmospheric pressure 2-3 days after the water motion observation was made. The pressure was considered low if it was less than two standard deviations below the mean pressure over the prior 14 days. If this correlation were high, it was hoped that such an upstream pressure change could be used as a prediction aid for future plant operations. The actual anticipatory pressure could be monitored in the Lesser Antilles. The correlation coefficient was only 0.3 which shows little, if any, relationship.

On at least one, and possibly two, different occasions, the 100 meter deep drogue panels were apparently swept into the shallow waters of the south-central island shelf.

From Table 30, there is no apparent temporal pattern to the speed values, as the values were all close to the average of 12 cm/sec, with the exception of the highly inaccurate November 1979 cruise and the certainly damaged panel occurrence of July 1980.

There appears to be no seasonality to the easterly flow, as it appeared during late January, late May and June. The winter occurrence most probably had a very deep Mixed Layer Depth, whereas the MLD in the summer months usually decreases considerably.

There were frequent occurrences of tidal oscillations, however, these events usually only acted as temporary perturbations in the predominant direction. Certainly no tidal motion seemed to dominate the motion. The tidal system, centered in the North Atlantic (San Juan), with its associated semi-diurnal oscillations, appeared to be the stronger influence than the Caribbean system, with its predictive times indicated as "Galveston."

On at least one occasion clear evidence of inertial motion was seen. This was manifested as a clockwise gyre occurring while the predominant motion was taking precedence.

4.0 CONCLUSIONS

The significant conclusions resulting from this study are as follows:

--The drogues used during the program did follow the 100 meter deep water. This was confirmed both theoretically and experimentally by comparison with a current meter at the same depth.

--The speeds of the 100 meter deep water were less than 24 cm/sec 90% of the time. (The percentage would probably increase if better estimates of the time of panel tears and breaks could be made.)

--The speed of the 100 meter deep water was about one-quarter that of the surface water during the few occaisions that comparisons were possible.

--Usually the 100 meter deep water followed the bathymetric contours, moving northeast or southwest from the drop-off site. The southwest direction was most frequently seen. Historical records are similiar.

--Occaisionally the trajectory showed strong northerly excursions, but only after the trajectory had moved eastward, past the eastern coast of the island.

--Virtually no southward trajectory was seen.

--As no direct northward motion was seen immediately adjacent to the drop-off site, there may be little danger of the 100 meter deep water(OTEC effluent?) reaching the reef environment directly offshore at Punta Tuna.

--There is a real probability that the 100 meter deep water(OTEC effluent?) may encounter the steep bathymetric rise off the central south coast of the island, thereby impinging onto the reef system in that area.

--There is no obvious seasonality in the motion at the 100 meter depth.

--Inertial motion is visible at 100 meters, however, this does not seriously alter the prevailing direction of flow.

--There are weak tidal influences which show an extremely minor influence on the prevailing direction of flow.

--Some relationship may exist between easterly flow at the 100 meter depth and decreasing atmospheric pressure, but the predictability is poor.

--There is no clear correlation between the direction of the water at 100 meters depth and that at the surface.

--There is no predictive correlation between the direction of the water at 100 meters depth and the sea surface wind direction.

5.0 RECOMMENDATIONS

The following are the most important recommendations resulting from the activities, results, and conclusions of this program:

--Determine the plant design configuration in order to allow a more precise effluent characteristics and depth prediction.

--Develop modeling capabilities in anticipation of plant design characteristics and more complete water flow patterns.

--As the observed trajectory at 100 meters depth did impinge upon the south-central reef area, separate effluent systems for both the cold and warm water from the plant may be advantageous, if this separation would avoid effluent/ reef interaction.

--Increase the time scale of the ocean measurement programs to extend over many years so as to allow long-term temporal patterns to develop.

--Look for clear, definable, and discernible predictive correlates to anticipate short-term effluent direction changes during plant operation.

--Combine eulerian and lagrangian measurements to develop a better spatial and temporal understanding of the potential effluent flow pattern.

--Use a constant density(rather than constant depth) lagrangian follower to determine changes in density with depth near the deep-sea boundaries.

--Measure both the dispersion and diffusion characteristics of the suspect water column to estimate the decreasing concentration of an effluent as both a function of time and distance from the plant.

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