Results of a Program to Measure the Trajectory of Water at a Depth of 100m South of Punta Tuna, Puerto Rico - December 1980 by Gary C. Goldman, Center for Energy and Environment Research.

Results of a Program to Measure the Trajectory of Water at a Depth of 100m South of Punta Tuna, Puerto Rico by Gary C. Goldman for the Center for Energy and Environment Research, University of Puerto Rico, College Station Mayaguez, Puerto Rico 00708 - December 1980. This work was done under a contract (DE-ACO5-760R01833) between the University of Puerto Rico and the Oak Ridge Operations Office of the U.S. Department of Energy.

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 examining the oceanographic conditions around the island. The main emphasis is being directed towards 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 to determine where potentially mixed warm and cold water effluent may go after leaving a full-scale OTEC plant.

The project includes:

- The design and construction of deep-sea current followers, or drogues, at 100 meters depth in the Caribbean.
- A series of cruises, during a one year period, to the Punta Tuna area in order to release and track these drogues.
- The analysis and interpretation of the results from these water following cruises.
- Recommendations for future studies of the Puerto Rico OTEC oceanographic water current program.

The final drogue design is a balance between ease of field operation, sensitivity to the 100-meter depth, and cost. The design consists of a surface flotation member, complete with radar reflector, radio beacon, light beacon, and flag, and a large two-dimensional underwater panel, unfurling similar to a window shade, and located at a depth of 100 meters. During the contract period, a

A total of eight cruises were made to the Punta Tuna area to deploy and follow these drogues, which were designed to be sensitive to water motion. The cruises took place on the following dates:

- 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, which was 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 tracked relative to the moored vessel as a function of time using 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 had not yet been established, 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 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 degrees) about 60% of the time, and easterly (045-134 degrees) 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 occasionally 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 occasional tidal cycle. Neither of these seriously altered any prevailing flow direction. There was an 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. Ninety 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.

TABLE OF CONTENTS

"Cruise of 25 March 1980. Table 12 - Summary of Drogue "EZ" water motion measurement. Cruise of 25 March 1980. Table 13 - Data and calculations for Drogue "E-1". Cruise of 7-8 May 1980. Table 14 - Summary of Drogue "E-1" measurements. Cruise of 7-8 May 1980. Table 15 - Data and calculations for Drogue "E-2". Cruise of 8-10 May 1980. Table 16 - Summary of Drogue "E-2" measurements: Cruise of 8-10 May 1990.

List of Figures:

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

Figure 14. - Trajectory of Drogue "C" off Punta Tuna, Puerto Rico, beginning at 1500 on 24 March 1980.

Figure 15. - Trajectory of Drogue "E" off Punta Tuna, Puerto Rico, beginning at 1800 on 25 March 1980.

Figure 16. - Drogue trajectory for Drogue "P-1" off Punta Tuna, Puerto Rico from 0800 on 7 May 1980 until 1400 on 8 May 1980.

Figure 17. - Trajectory for Drogue "E-2" off Punta Tuna, Puerto Rico from 1600 on 8 May 1980 until 0200 on 10 May 1980.

Figure 18. - Trajectory for Drogue "E" off Punta Tuna, Puerto Rico from 1200 on 10 May 1980 until 1400 on 11 May 1980.

Figure 19. - Trajectory for Drogue "V" off Punta Tuna, Puerto Rico from 1500 on 9 May 1980 until 0600 on 11 May 1980.

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

Figure 21. - Trajectory for Drogue "A".

Off Punta Tuna, Puerto Rico from 1200 on 10 June until 0300 on 12 June... See Figure 22. - Directionality of drogue and predicted tidal currents during the period from 10-12 June 1980 at Punta Tuna, Puerto Rico. See Figure 23. - Trajectory for Drogue "A" off Punta Tuna, Puerto Rico from 1700 on 25 June 1980 until 1600 on 26 June... See Figure 24. - Trajectory for Drogue "A" and progressive vector for current meter results off Punta Tuna, Puerto Rico from 24-27 June 1980. See 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... See Figure 26. - Trajectory for Drogue "A" and progressive vector for current meter results off Punta Tuna from 16-23 July 1980... See 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...

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. Dr. Peter Duncan, of the University of California's

Lawrence Berkeley Laboratory, was most helpful with frequent discussions and advice during the field and analysis phases of the study. Dr. Lloyd Lewis of the U.S. Department of Energy was instrumental during the conception and implementation phase of the program. A very special acknowledgement and thanks goes to Mr. Thomas Sadler of the OTEC Division of UPR/CEER. He gave inexhaustible help, time, effort, care, and concern.

During the design, construction, and field phases of the study, Tom was truly the backbone of the program. Finally, I want to thank the Puerto Rico Electrical Power Authority (PREPA) for their farsightedness and support. They originally integrated this study with their OTEC activities to encourage us to gather an environmental understanding of the area, anticipating 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 liquefies 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/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 vaporizer where

it is heated to the gaseous state and

The fluid is drawn back into the condenser area again. The turbine is the mechanism that can convert the kinetic energy of the moving fluid into either electrical energy or work directly. As this process proceeds, the warmed or cooled (gina * Toriginar + 20°) water is then discarded back into the sea as effluent. The water may be returned separately 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 deep and surface water. This mixture would be released toward some mid-depth, depending on its final temperature, salinity (density), and mixed ratio.

There are numerous benefits and potential environmental hazards with this OTEC type of energy conversion. Some benefits include: no air pollution, it is 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 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 limitation significantly affects primary productivity, with the normal phytoplankton standing crop being much lower than that of nutrient-rich oceanic areas. The addition of large quantities of artificially upwelled nutrients could potentially increase the phytoplankton population, causing considerable changes in the normal ecosystem. These changes could alter the standing crop of grazers and predators, as well as change the water's turbidity, thereby reducing light penetration to deeper organisms. Moreover, the 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 scope of this study to evaluate or enumerate the ecological possibilities that might occur. Instead, the study aimed to make assumptions about the physical characteristics of a potential mixed effluent from a hypothetical OTEC plant 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. This report discusses 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 the 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 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 same geographical region.

Part of the Antilles Chain of islands extends 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. At 18° N Latitude and 65° W Longitude, Puerto Rico is considered subtropical and is affected by the east-to-west trade 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 have biseasonal characteristics. 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 yet.

From a geological standpoint, Puerto Rico, Hispaniola, 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 Hispaniola and Cuba, forms the western edge of the ridge.

The Mona Passage lies between Puerto Rico and Hispaniola, and is about 100 km wide. This passage has a maximum depth of less than 600 meters, with much of

The area is 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° downward slope to about 7.

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. For completeness, these will be mentioned again as the source, depth location, movement, and characteristics of these water masses are essential to the understanding of the results described 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 force 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 have been further affected by the general and local climate of the area through which it has passed.

Additional precipitation and runoff (although slight), evaporation from wind and insulation could further influence both the temperature and salinity. In the TSW, 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 wind and currents.

In Figure 3, the Caribbean Sea water column structure south of Puerto Rico is shown, featuring the various water masses and their characteristics.

Geostrophic subsidence occurs 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, when a tropical pressure trough moves through the Caribbean, the pressure is severely reduced. This causes the water level to rise, pushing the upper water mass to the side and upwelling the cooler, more saline water mass below. This upwelling occurs during a hurricane and, to a lesser extent, during a tropical wave or storm. The effect on an operating OTEC power plant could be significant, potentially severely reducing the plant's already low operating efficiency, especially if 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, as shown in 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. This, 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 high and the salinity increases. This water mass contains the most saline water in all of 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 (between 36.8 and 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 constant as the salinity. The density difference between the TSW and the SUW is usually about two sigma-t.

The units, which are large enough that the two remain distinct water masses. The Subtropical Underwater (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 Tropical Surface Water (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 in the 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 Anegada Passage, and the Windward Passage, between Cuba and Hispaniola. These latter deep sills may also form a path of departure from the Caribbean for the AIW that has entered through the Lesser Antillean 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 same as that of its origin, but rather about 34.8-34.9 ppt. The temperature is 6° to 7°.

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.

1.2.3 TIDAL ACTIVITY

The dominant tidal action along the northeast coast of Puerto Rico is caused by the amphidronic system that has its node in the North Atlantic. This system produces a semi-diurnal tide, and is easily seen at San.

Juan, 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 weak 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 fluctuations 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 Guiana 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...

There is 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 Carr (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 1s --- Page Break --- 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 Carr (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 surface water.

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, 610m, 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 surface water. The water at 810 meters depth.

The lowest portion of the AIW moved towards the west approximately two-thirds of the time, and all speed observations were less than 15 cm/sec, with the average value being 4 cm/sec. The bottom water, at 1900 meters depth, moved primarily northeast or west, averaging speeds of less than 1 cm/sec.

The third array, #14A, was moored in 1430 meters of water at 17958.4' N, 65°37.8' W, or 27 km east of Punta Tuna. Four depths were reported for this array: 240m, 605m, 1335m, and 1420m. The 240 meter deep water (likely just beneath the SUW) moved westward virtually all the time, with an average speed of 8 cm/sec. The water at 605 meters (upper portion of the AIW) primarily moved northeast to northwest at an average speed of 5 cm/sec. The deeper water moved either northeast-to-east or southwest-to-northwest at even slower speeds.

Oser and Freeman (1969) reported 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 100m and 1500m of water, respectively. They reported that the upper waters (about 300 meters depth) showed up to 25 cm/sec at maximum speed, and were moving primarily westward. 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 was moving northwest and east, with a maximum speed of 15 cm/sec.

Ostericher (1967) also reported 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, but the drogue data indicated 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 approximately 17°52" N.

The water motion was measured at 64°41' W during the summer of 1977 at a depth of 10 meters. Measurements were taken at least daily when possible, and frequently every two hours. The results indicated a strong easterly drift for about two weeks, followed by a similar period of drift to the west. After that time, a strong diurnal east-west reversal was observed for one week, corresponding to a spring tidal period. Following this period, the currents varied in direction for about a month, with some visible tidal influence. Another easterly drift occurred after about ten weeks. This second easterly flow lasted 3-4 days, then deteriorated again. Throughout the measurement period, typical speeds of 25-50 cm/sec were observed.

Also during this measurement period, a single current profile was taken in September, 1979. During the profile, the Tropical Surface Water (TSW) was moving southeast, the Subtropical Underwater (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 Antarctic Intermediate Water (AIW) and the Venezuelan Basin Water (VBW) was moving northwest.

Speeds generally decreased from about 20 cm/sec near the surface to 10 cm/sec at a depth of 1000 meters. In a study by Goldman et al. (1979), the results of over-the-side current meter profiles and one current meter array were reported. 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 Ocean Thermal Energy Conversion (OTEC) Department of Energy (DOE)/University of Puerto Rico (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 usually move toward the west or the east, with an average speed of 10 cm/sec. The SUW (100m-150m) usually moved westerly, with occasional easterly motion, and an average speed of 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 a northwest or northeast direction at a speed of 5 cm/sec. The current meter array was reported by Goldman et al. (1979).

The text has been 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 towards 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 (SUM) has been seen to move basically westerly, and occasionally easterly. The Transition Zone between the SUN and the Antarctic Intermediate Water (AI) 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.

--- Page Break---

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+ ™) OTEC power plant at any of the more suitable sites. One aspect of this investigation is to look at the effects.

The effluent from the plant would result if the two intake systems were mixed together prior to being expelled from the plant. There are a variety of methods that could be used to study the fate of such effluent. However, some assumptions must be made before deciding on any particular experimental technique. The effluent is assumed to be leaving the plant in such a way that it will settle at the 100-meter depth. This means that the density of the water - a combination of temperature and salinity - will be such that it will equal the normal 100-meter depth density, even though the temperature and/or salinity of the effluent will most likely be considerably different from that at 100 meters depth. This 100-meter depth condition will probably be true at some time, with both shallower and deeper conditions also possible.

It is also assumed that the effluent will originate at or near the "OTEC area" to the southeast of Punta Tuna, Puerto Rico. The currents in the area are not well understood from an environmental impact perspective, and the circulation is even less understood. While current meter arrays are already being placed in the area to determine flow characteristics throughout the entire water column for a variety of uses, the specific type of measurement needed for this program is a Lagrangian measurement that actually follows a typical water parcel that leaves 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 are so poorly understood that very little can be predicted about the circulation of this 100-meter deep water after it leaves the site. Various Lagrangian measurement methods were considered, such as dye, swallow floats, bio/chemical tracers, radioactive tracers, and deep-sea drogues. The dye technique, as well as the bio/chemical and radioactive tracing, was eliminated due to cost.

Ship time and the potentially low dilution rates were important factors to consider. 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 ancillary 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.

"Break--- ° and Corrosion study at the Punta Tuna site" should be "Break --- 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" is correct, but can be simplified to "The Biofouling and Corrosion study used a 13-meter ship-to-shore vessel and a moored mother ship in its daily operation."

"This requirenent would apply to any lagrangian measurement (or virtually any type of measurement, as high signal-to-noise ratio)" should be "This requirement would apply to any Lagrangian measurement or virtually any type of measurement requiring a high signal-to-noise ratio."

"This "sail effect" mst be minimized" should be "This 'sail effect' must be minimized.", and "mist also be minimized" should be "must also be minimized."

"The field equipment is subject to the usual location/ positioning and cost constraints of a modest program, such as this" can be simplified to "The field equipment in this modest program is subject to typical location, positioning, and cost constraints."

"Conventional techniques and equipment were acceptable, if they were already part of the available capabilities" should be "Conventional techniques and equipment were acceptable if they were already part of the available capabilities."

"A further extension of any equipment capabilities could result in a Severe rise in cost and design time, neither of which wae necessary to accomplish the programmatic goals" should be "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."

"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" is correct, but could be simplified to "To satisfy the criteria for the deep-sea drogues, the final design is a minor modification of Terhune's basic design."

(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 (5 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

The line 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 midway 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 midpoint of both the float and the mast. The subsurface portion of the mast is weighted near its bottom to maintain good vertical.

Stability is maintained, even without the connecting line, subsurface panel, and its associated drag (and downward force). 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 reflectors, 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.

29. One Year Life: Although the equipment is not necessarily heavy-duty, care was taken in choosing the component materials to ensure 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 around 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°57.6" N, 65°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.

30. 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 auxiliary equipment were checked for good repair and proper operation. The connecting line (running from beneath the mast to the panel) was premeasured to ensure 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 subsurface 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 0.05 km, +0.25 km, 0.6 km, +1.1 km, and +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 +1 degree, with an overall probable error of +5 degrees. The viewing screen of the radar was 17.5 cm in diameter. To accurately locate a remote object, the radar was first

The text is used to observe two known terrestrial locations in order to fix both the location of the LCU and its orientation with respect to true north (deg). 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 ensure 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 0.5-2 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 shortened 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 for 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 (W.0.S.,

In 1975, a scale of 1:20,000, or 1cm = 0.2km, was used. A three-arm protractor had its two movable arms set to the bearings toward the fixed land points. After these arms were set on the chart range to both locations, the origin 33 was established.

The origin 33 was then used to calculate a variety of data points. The fixed arm of the protractor faced the direction of the radar "zero" bearing. The angular scale of the protractor showed the bearing to the drogue, and the range was measured from the origin, using the proper scale. The distance to each successive point and from Punta Tuna were taken from this chart, and all the distance and direction information was calculated and then transferred to a chart with a scale of 1:100,000 for ease of display.

In some cases, the subsequent transfer needed 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, choose 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 quantification indicated, where possible. The final results of this program can then be evaluated.

The product of this program is to produce knowledge regarding the trajectory of the water moving past Punta Tuna 35 at a depth of 100 meters. Therefore, the results shall be a drawn trajectory that is made up of a series of connected vectors. Each vector should 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 120) 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
4. Position Determination of the LCU
5. Position Determination of the Drogue
6. Determination of the Trajectory
7. Determination of the Elapsed Direction
8. Determination of the Elapsed Time
9. Determination of the Elapsed Drogue Travel
10. Determination of the Drogue Speed

Time Measurements - This is a...

Primary Measurement - This is 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 should be indicated as 430 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) is assumed for the calculations, yielding a possible error of +18.

Range Measurements - This is a secondary measurement. The readout 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 28% of the reading. However, this estimate 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 478. 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 kn.

Bearing Measurements - This is also a secondary measurement that is read from the radar screen, as is the range measurement. The manufacturer's specifications 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 42.5 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 yields an error of up to +0.15 degrees of latitude or 40.28 km, and 40.28 degrees or 40.49 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 and 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 40.25 degrees or 40.46 km of latitude, and 40.45 degrees or 40.79 km of longitude. However, these values may realistically be reduced to ±0.18 degrees or ±0.33 km of latitude, and 40.25 degrees or ±0.46 km of longitude. The average probable error for the 4 km distance is then ± 4 km, or ±108.39.

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 (relative to North being 000 degrees).

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 change in 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 ±108, with the maximum possible error being up to ±208, 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

The study was designed to follow the trajectory of water parcels departing from the possible Ocean Thermal Energy Conversion (OTEC) site. The method employed was to determine the trajectory starting from the site located at 17°56.9' N, 66°51.9'W, using deep-sea drogues set to be sensitive to a depth of 100 meters. This depth was chosen after consulting with OTEC designers, environmental measurement experts, and environmental impact modelers.

The cruises occurred in virtually all seasons of the year, starting in the autumn of 1979 and continuing through to the summer of 1980. The exact dates of the cruises were as follows:

- 9 November 1979
- 26 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

Each cruise will be described in the following sections, with a discussion of its results.

3.1 CRUISE OF 9 NOVEMBER 1979

On 9 November 1979 a cruise was conducted to Punta Tuna. The following sections describe that cruise in relation to this study.

3.2.1 NARRATIVE

The drogue operation was performed by members of the Marine Ecology Division of UPR/CEER during their operations near Punta Tuna, P.R. The drogue, lacking its radar reflectors, radio beacon, and flashing light, was launched at 0800 A.S.T. on 9 November 1979. The deployment was 0.4 km at a bearing of 241 deg-T from the mooring buoy. Unfortunately, all ranges and bearings during this cruise were taken relative to the mooring buoy, not fixed landmarks. The buoy may have moved within a radius of at least 0.5 km during the cruise.

The R/V SULTANA, operated by the UPR/CEER, was used for deployment and for all range and bearing measurements. This vessel is 14 meters long and is equipped with an onboard radar that is likely more accurate than + 0.1 km and + $°, when operated on its most sensitive range by experienced personnel. During the deployment, the drogue's mast was broken but it was repaired.

The previously described method for deployment was not used while still in the field, which led to subsequent structural weakening.

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 sighting, 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.7., 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 sightings 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 data 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 beginning 0830 on 9 November 1979. (Numbers are elapsed time in hours; depth is 100 meters)

The rest of the text seems to be scrambled or in a different language and requires further clarification to be corrected.

The text appears to be a mix of random characters and sentences that might be part of a scientific report. It's difficult to correct it without context, but I tried to separate coherent sentences:

Table 2 Summary of Drogue "A" Water Motion Measurements: Cruise of 9 November 1979

Speed (cm/sec)	Direction (Degrees)	Time
33	345	2
32	014	5
38	045	13
36	075	12
14	105	-
17	135	-
20	165	18
23	195	-
24	225	22
27	255	-
30	285	22
33	315	-
20	345	-

Average Speed = 5 cm/sec

Observations on the rogue motion: The most important consideration during this brief observational period is the potential error in positioning the rogue 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 + 0.1 km, and because of the greatest elapsed distance measured was only 0.56 km, it is quite possible that the...

The rest of the text is incomprehensible and cannot be fixed without further context.

There is an 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 26 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 sightings 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.

9.3.2.2 RESULTS

Aside from the occasional losses of data for drogue "A", which amounted to about 30%, and the complete 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 rogue tracking in this part of the Caribbean Sea. (This duration on a single drogue was not to be replicated 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 observed (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 highlights 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, 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 sightings was three hours, with the actual time intervals ranging from 0.8-29 hours. The distance traveled between sightings ranged from 0.09 - 5.96 km. The actual statistics for the

Speed and direction are shown in Table 4. The speeds range 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 shows the east-west bimodality of the trajectory. Forty-nine percent of the time, the water moved direction 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 four 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.

[Page Break]

The remaining part of the text seems to be corrupted or improperly formatted, making it impossible to fix without additional context or information.

I'm sorry, but the text you provided appears to be a mix of nonsensical characters and phrases. It's not possible to correct it without additional context or clarity.

The text is influenced by at least three separate forces. There was a tidal relationship, an identifiable inertial motion, and lastly, some longer period energy that lasted for about half the 100+ hours then reversed during the latter half. The cause of this last reversal may be very challenging to identify, as we were apparently only observing a small portion of the period, if any periodicity exists at all. There is compelling evidence that the lower, Subtropical Underwater, is moving independently of the Tropical Surface Water, which was moving westerly, with the wind, throughout the cruise, causing the entire water parcel to move eastward.

3.3 CRUISE OF 18 - 22 FEBRUARY 1980

The following sections describe the activities and results of the cruise from 18th to 22nd February 1980.

3.3.1 NARRATIVE

Drogue "A" was deployed from the moored ICU at 1430 A.S.T. on 18th 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 19th February. Position fixing was accomplished either hourly or bihourly whenever possible. After 0400 on 19th February the drogue was no longer discernible on the radar, nor was it heard transmitting on its radio frequency, nor was its beacon light visible. At 0830 on 20th February a search was conducted using the ship-to-shore vessel, but no trace of drogue "A" was found that day. (Note: On 26th March 1980, drogue 58 was located in a fisherman's storehouse who claimed to have "recovered it for us" in the early morning of 19th February.) The total time for reliable data for this drogue was 13.5 hours.

Drogue "C" was deployed at 0930 on 21st February 1980. Again, the deployment was carried out from the LCU, and the drogue was set for 100 meters. This drogue was successfully tracked 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 22nd 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 was shortened, some data were collected during this cruise which both answer some questions and raise others. Figure 11 shows the plotted trajectory of drogue "A" from the time of its deployment at 1430 A.S.T on 18th February 1980 until its last known location at 0400 on 19th 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 stern 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.

(some text seems to be unreadable or in a different language)

Table 5 displays the data on which the speed and direction calculations and statistics are based from the drogue. The total period for the drogue tracking was 13.5 hours, with an elapsed time between sightings of 0.5-2.3 hours. The range of distances traveled between the sightings 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 degrees, with observations between 225-284 degrees for 85% of the time.

Figure 12 shows the plotted trajectory of drogue "C" from the time of its deployment at 0930 on 21st February 1980 until its recovery at 0945 on 22nd 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 time.

This period's trajectory was predominantly southwest, similar to drogue "A", but there were a few significant deviations to the east. Drogue "C" was observed for 24.2 hours from the time of deployment to recovery. The elapsed time between observations ranged from 0.8 hours to 4 hours, with most of the time intervals being about 1-2 hours. The distances traveled between sightings ranged from 0.2 to 2.3 km. Table 7 displays the data on which the speed and direction calculations and statistics for drogue "C" are based.

--- Page Break ---

Table 6 summarizes the water motion measurements of drogue "A" during the cruise of 18-19 February 1980. The average speed was recorded as 18 cm/sec.

--- Page Break ---

Data and calculations for drogue "C" for February 1980 are provided in Table 7.

--- Page Break ---

The results of these calculations are also displayed in the following sections.

Table 8. Drogue "Cc" speeds ranged from 2-24 cm/sec, with 15-17 cm/sec being the most often observed. The overall average was 11 cm/sec. The distribution of the speed observations is more uniform than those of drogue "A". The directional data shows the bimodality of both easterly and westerly motion, but more than half of the time the drogue moved toward 195-254 degrees. The drogue moved between 195-314 degrees for 968 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 is 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 running 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 is usually influenced by the wind even at its deeper portions.

SUMMARY OF DROGUE "C" WATER MOTION MEASUREMENT SPEED (cm/sec):

2 - 5, 8 - 9, 12 - 14, 15 - 17, 18 - 20, 21-23, 24 - 26, 27 - 29, 30 - 32, 33-35

Average Speed = 11 cm/sec

TABLE: Cruise of 21-22 February 1980

TIME: 24, 20, 34, 67

DIRECTION (Degrees):

345 - 014, 015 - 044, 045 - 074, 075 - 104, 105 - 134, 135 - 164, 165 - 194, 195 - 224, 225 - 254, 255 - 284, 285 - 314, 315 - 344

Unfortunately, the final part of the text is too garbled to correct.

Nowdaura 68

The water mass directly beneath the TSW (Tropical Surface Water), known as the Subtropical Underwater, differs in both density and water characteristics. It seldom mixes with the TSW and is driven by forces other than the local wind conditions.

3.3.3 INTERPRETATION

There are a few deviations from the southwest course, but overall, both drogues followed this path quite closely. There is sufficient circumstantial evidence to indicate that the 100-meter deep water was moving with the TSW under the influence of the wind. At this time of the year, the lower Subtropical Underwater might have been unreachable by our 100m deep drogues. If this was the case, there is a strong probability that the path followed by the drogues would have led them over the shallow areas they seemed to be headed towards. No clear periodic influence could be observed 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 (Landing Craft Utility) at 1500 A.S.T. on 24 March 1980. The depth sensitivity (panel depth) was 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 is 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 learned that the panel had become entangled in the connecting line between the mast and the panel. This entanglement probably occurred during deployment. The panel was only slightly below the 3-meter depth of the mast and likely not fully open. The panel was also damaged, either upon deployment or upon recovery. The drogue was located 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.

The last sighting on radar was in March, with the final usable radar value reported at 22:00 on March 25, resulting in a tracking period of just 4 hours. At 08:30 on March 26, the Radio Direction Finder indicated the drogue, though not visible on radar, was quickly moving towards shore. Immediate investigation of this unusual activity resulted in the recovery of the drogue from a fisherman who had "retrieved it for you." He had carefully disassembled the entire system and placed it in his small open fishing boat, thereby validating our concept of retrievability in a small boat without damage. He also reported having our "a" drogue stored on his property ashore, which we subsequently recovered.

3.4.2. RESULTS

Only eight hours of tracking data were saved from this mission, although a significant amount of time was spent collecting 70 pages of additional data. Also, the panel for drogue "Cc" was tangled from the outset, leading to the tracking of much shallower water than desired. Figure 14 illustrates the trajectory of drogue "c" from its deployment at 15:00 A.S.1. on March 24, 1980, until 19:00 on March 24. The drogue depth was mistakenly set to be only 10-20 meters deep, and the panel probably wasn't fully opened either. During this tracking period, the wind was 10-13 m/sec from the east, and no surface currents were monitored. The drogue moved primarily southwest, with a sharp turn southward towards the end. Table 9 displays the data used for the speed and direction calculations and statistics for this drogue. The results of these calculations are shown in Table 10 for drogue "Cc". Speeds varied between 34-86 cm/sec, with a speed of 30-49 cm/sec nearly 90% of the time. The average speed for this drogue was 46 cm/sec. The directions were primarily westerly, with the flow being between 225-264 degrees T 100% of the time. It should be noted once again that due to the shortening of the depth line and the tangling of the panel, the tracking of a much shallower water than desired occurred.

The text is not clear about whether the drogue was following the shallow water or if the surface float was pulling the entangled panel as the float was 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.

The following section is not clear and needs more clarification: (sioy uy owy3 posdeyo oxv sioqunN)*o86T YOIEH 42. UO. OST Sururfoq cory orseng ‘vung, wrung. 350 ° ‘ongoaq Jo Ar02 90001, spr oandyy ° ° n

The section of the text from "Ory Oost aH WZ STS, 59 98 ear so - _ _ STE OFT 2K 9 OTNS So ey eve ot - _ _ SZ OT MH HZ BES SED * coz wet st - _ _ _ OT 009TH HZ B*ZEAE9 A Z*9E SLT ov ssz sort ot - _ _ _ 00 00ST AH HZ O'ZESEH "IC SLT (eam) ona Bapy wey TAY Gi Tsv Wa “HT TF) ‘a SOOTAM —*d SQOTATHA “44 SMOTAMM “La SNOTAMIA TWIOI~BAIL (2H) © SIVG.@GRLIONOT. A0QLTIVT Woud QHadS WON NOTIOMIG MOY HONVUSI “MONA AIL «HSV RTL og6t woxeW Ye 30 983029 Dy BNDOHD YOK SKOTLVINIVD GRY ¥EL¥G 6 sieve 3" is not comprehensible and needs rectification.

Table 10 summarizes the water motion measurements of drogue "C" from the cruise of 24 March 1980. It presents data on speed, time, and direction. The average speed was 46 cm/sec.

The following section is not clear and needs more clarification: Buyuydeq:ooTy o3zong . (ssorom oot st wadop fsanoy ur oura posdeto oxe sxoquny) “0861 YOUN Sz UO OST BUN eIUNG FFO yi ‘ongo1g 30 A10200(4, “st aanstg 5

On 25 March, only four hours later, this drogue remained at 100 meters depth. The wind was only 1-3 m/sec from the south-east during this time period. The trajectory shows basically a 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...

The speed ranged from zero to 16 cm/sec, with the speed being between 12-17 cm/sec 76% of the time. The average speed was about 11 cm/sec. This drogue also moved in a westerly direction 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 time spans involved being short (4 hours each). Also, no hydrographic data were taken during this cruise, making it difficult to ascertain whether the two drogues were in the same water mass. Historically, the TSW frequently extends to 100m depth in March.

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 ("Cc") was definitely in the TSW, but may have been pushed along primarily by the wind.

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	3-5
3-5	38	015 - 044	6-8
6-8	62	045 - 074	9-11
9-12	38	105 - 134	13-15
13-17	38	135 - 164	16-20
18-20	0	165 - 194	21 - 23
21-23	24	225 - 254	25
Average speed = 11 cm/sec		255 - 284	25
24-25	12	285 - 314	0
26-28	8	315 - 344	0

Additional factors may influence the drogue's movement, such as the wind's ability to push the surface float and mast. The deeper

The drogue, "EB", at 100m, may have been near the bottom of the TSW, but it was more likely 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 from 7 to 11 May 1980.

3.5.1 NARRATIVE

On 7 May at 0800 AST, a 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 successfully recovered using the ship-to-shore vessel at 1100 on 10 May, more than 9 km from the LCU.

Drogue "B-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 a lesser 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, "VV", was deployed from the LCU. Drogue "VV" 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

The drogue was moved after the 39th hour had elapsed. This drogue was also recovered late in the afternoon of May 11th, using the ship-to-shore vessel.

3.5.2 RESULTS

Throughout this cruise, which lasted from May 7th-11th, 1980, all the drogues were set to be sensitive to a depth of 100m. All position tracking of the drogues was accomplished using the radar onboard the LCU. All drogues were deployed from the LCU and were all 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 80 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 May 7th, 1980, until just before its recovery at 1430 on May 8th, a 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 sightings 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 sightings 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 degrees for more than half the time.

And more than 90% of the time, the water direction was between 195-314 degrees T. At one time during the tracking period, the rogue appeared to be moving shoreward, toward shallow water, but it reversed direction and moved offshore again.

Unfortunately, the following section of text is not legible and appears to contain various errors and non-words.

Again, this section of text appears to be illegible and may contain various errors and non-words.

Once again, the text here is not legible and seems to contain various errors.

The average speed is 11 cm/sec.

Summary of Drogue "E-1" Water Motion Measurements:

Table 14: Cruise of 7-8 May 1980

Time: 2. 8 5 32 85

Direction:
345 - 014
015 - 044
045 - 074
075 - 104
105 - 134
135 - 164
165 - 194
195 - 224
225 - 254
255 - 284
285 - 314
315 - 344

Figure 17 shows the plotted trajectory of the drogue "E-2". This drogue was deployed at 1600 on 6 May and was tracked for almost 1-1/2 days. Although the recovery was completed at 1100 on 10 May.

Tracking was terminated at 02:00 on the same day, as the "Grogue" was no longer discernible on the radar screen, and the ship-to-shore vessel was unavailable for either magnetic or sextant sightings 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 "Grogue" 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 "Grogue", 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 in the 225-284 deg-T range.

Unfortunately, the text after this point becomes unclear and seems to contain a series of non-contextual words and numbers. This could be due to a formatting error or encoding issue. I suggest referring to the original data source for accurate information.

The text seems to contain several random characters and symbols, making it incomprehensible. Without more context or information, I'm unable to provide a corrected version of the text.

The text was revised as follows:

The drogue made a clockwise loop and ultimately moved from west to the northeast. Table 17 presents the data used for speed and direction calculations and statistics. Table 18 displays the results. The elapsed time between the 14 observations ranged from 1 to 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 to 1.4 km. The speeds for this period were much slower, and 92.5% of the time the speed was less than 9 cm/sec. The average speed was 6 cm/sec. The direction, although highly variable, could possibly be classified into easterly (045- 134 deg-T) 46.8% of the time and westerly (225-314 deg-T) 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 later.

Please provide further details or context for a more accurate revision.

The text is quite chaotic and seems to have a mix of different types of content, including mathematical equations, a narrative, and what looks like a random mix of numbers, symbols, and letters. It's difficult to provide a corrected version without context, but here's a possible interpretation:

"9-1,
075 - 104,
15 a^2 = a8,
10s ~ 134,
a as - a7,
135 - 164,
8,
1s - 20,
165 ~ 194,
21 ~ 23,
195 ~ 224,
24 - 26,
225 - 254,
27-29,
255 ~ 284,
27,
30 - 32,
285 - 314,
33 = 35,
315 - 344,
Average Speed = 6 cm/sec.

On 11 May at 1630, a total of 39 hours elapsed. This drogue was adrift during the tenure 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 "B-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 368 of the time the water moved toward between 225-264 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.

I'm sorry, but I'm unable to decipher and correct the rest of the text as it seems to be a random mix of letters, numbers, and symbols.

The text provided is highly disorganized and contains numerous errors, making it difficult to fix. However, the last section is coherent and can be rewritten as follows:

"The average speed of the water 100 meters deep was 10 cm/sec throughout this period. The speed ranged between 6-8 cm/sec for more than 30% of the time, with a total speed..."

The speed range of the observed motion was 2-30 cm/sec. There was a slightly predominant motion towards the southwest, with more than half of the observed values between 195-314 degrees. The most frequently observed range of values being 225-254 degrees and 255-285 degrees. 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 "B-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". If the two clearly clockwise gyres from drogue "5-2" 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.

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 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-SUM (east-to-west).

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 is encountered.

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

June 1980.

3.6.1 NARRATIVE

On 10 June 1980 at 1200 A.S.T., drogue "A" was deployed from the LCU. Tracking was primarily accomplished 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 drogue's position, but these values were not sufficiently accurate to be included in this report. The drogue's sensitive depth (panel depth) was set at 100 meters. The drogue drifted for 51 hours, with position fixing during the first 39 hours indicating a northeast direction. Recovery was done using the ship-to-shore vessel at 1440 on 12 June. Upon recovery, the drogue was found to be more than 10 km northeast of the LCU.

During and prior to this cruise, minor modifications were made to both equipment and procedures. Compression unions were installed above and below the flotation assembly 103 to strengthen the mast, which had been pre-weakened by drilling holes for securing 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 in case of mast separation. Additional weight was added to the lower panel supporting pipe to ensure its rapid descent, thus minimizing tangling. A solution was found for the recurring radar image problem. The radar unit can simply be turned "OFF" for a sufficient time to allow component cool-down. After this period, the image will be properly displayed again, with the instrument operating according to the manufacturer's specified accuracy.

3.6.2. RESULTS

The drogue "A", used during this cruise, was set to be sensitive to a depth of 100 meters. 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.

Later, the drogue was recovered at 14:40 on 12th 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 preceding the cruise had relatively low pressure.

(Unfortunately, this part of the text is unreadable and cannot be fixed.)

After the 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 degrees, with more than 80% of the observations between 0-180 degrees.

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 14:00-18:00 on 10th June, when the predicted tidal current was westerly. There was a strong westerly turn in the 100 meter deep water movement at that time.

The text appears to be a mix of coherent sentences and random alphanumeric strings. Below is an attempt to fix the coherent parts of the text:

The water is a meter deep, but at the elapsed time of "hour 5", the drogue took a sharp northeast turn. Also, the drogue movement occurred at about 2200 hours on June 10th and again at about 106.

Summary of Drogue Speed (cm/sec): 0-2, 3-5, 8, 9, 14, 17, 18, 20, 21-23, 24

Unfortunately, the rest of the text is incomprehensible and cannot be fixed without additional context or information.

26, 27-29, 30, 32, 33-35, 36, 38, 39 = 41, 42-44, 45-47, 48, 50, sl = 53, 54 - 56, 57 = 59, 60 - 62. Average Speed = 10 cm/sec. TIME ae 1s, 25, 16, 10.

WATER MOTION MEASUREMENTS: Cruise of 10-12 June 1980. DIRECTION (deg) 34s - 014, 015 - 044, 045 - 074, 075 ~ 104, 105 - 134, 135 - 164, 165 - 194, 195 - 224, 225 - 254, 255 - 264, 285 - 314, 315 ~ 344. TIME a 26, 2.

Sooty along ‘euny wrong 2. Og6t ouNE ZT-0T wosz porzad ay2 Suranp sauesin> [epta parotpord puw enSoxp 30 Aa¢Teuor390q7q. *z7 ounSry Nol3aa0 3, 5.

At 0900 on 11 June, the easterly wind was stronger than average, corresponding to easterly tidal flows. However, these are weak comparisons.

3.6.3 INTERPRETATION

During this cruise, the 100 meter deep water moved north-east, along with the eastward surface water, into the eye of the brisk, easterly wind. At this time of year, the 100 meter depth should be firmly in the lower Subtropical Underwater, with a separate, shallow Tropical Surface Water above it. Whatever is forcing the SUW eastward may or may not also be moving the TSW in the same direction. The tidal influence is truly 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 using the radar aboard the LCU. A current meter had been suspended from the LCU to a depth of 100 meters. 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...

The recovery took place about 7 km south-west of the LU at 1600 on 26 June. The current meter was checked every 1-2 hours throughout the cruise.

3.7.2 RESULTS

Throughout the cruise, which lasted from 24-27 June 1980, both the drogue "A" and the current meter were set to be sensitive to a depth of 100 meters. All position tracking of the drogue was accomplished using the LCU's radar. The drogue was deployed from the LU and the current meter was suspended from the same vessel. The drogue was recovered using a crane. The 13m ship-to-shore vessel was used for this purpose.

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 are based.

Page Break

Unfortunately, the rest of the text is too fragmented and lacks context to be accurately corrected. It seems to contain various measures or data points, but without further information, it's impossible to make meaningful corrections.

The text appears to be highly garbled and seems to include scientific data and observations, possibly related to a marine study. It's difficult to fully correct without having a clear understanding of the context. However, the last part seems more coherent and I can correct that as follows:

"For Drogue "A", the basis is established. Table 25 shows the actual results of the calculations. The elapsed time during the 22 observations varied from 0.53 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 m/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 degrees, and more than half the time the water moved between 195-254 degrees. 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 preceding figure, the scale is the same."

The rest of the text is too garbled to be accurately fixed without more context or information.

For both the drogues and current meter, the elapsed times (in hours) are shown using the drogue disentanglement time (1700 on 25 June) as "0" hours. The discrepancy in the current meter vector resulted from the incorrect values of the instrument that occurred during the entanglement with the drogue. The current meter "trajectory" seemed to follow that of the drogue quite closely. However, the estimated distances are much greater for the current meter due to its much higher indicated speed. The current meter data was as follows:

TABLE 25. SUMMARY OF DROGUE "A" WATER MOTION MEASUREMENTS: Cruise of 25-26 June 1980

SPEED THe DIRECTION (cm/sec) (Deg)

0-2 345-014
3-5 015-044
6-8 045-074
9-11 075-104
12-14 105-134
15-17 135-164
18-20 165-194
21-23 195-224

24-26 225-254

Average Speed = 11 cm/sec 255-264 265-314 315-344

The current meter was 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 meter on its mooring. On subsequent investigation of the current meter, it was found to be horizontally misoriented. After proper alignment, the speeds decreased noticeably. However, the directionality of the current meter was much more closely related to that of the drogue. The most frequently observed values were between 225-264 degrees, with only 44 of...

The observations not between 165-314 deg, compared to 58 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 TIME DIRECTION (cm/sec) (Deg)

0- 2 ° 345 - 014

3-5 ° 015 - 044

6-8 ° 045 - 074

9-11 ° 075 - 104

12-14 ° 205 - 134

15-17 ° 135 - 164

18 - 20 ° 165 - 194

21 - 23 ° 195 - 224

24 - 26 ° 225 - 254

27 - 29 ° 255 - 284

30 - 32 ° 285 - 314

33-35 ° 315 - 344

36 - 38 ° 345 - 014

Average Speed = 29 cm/sec

During the period of 24-27 June 1980, the directionality of the current meter was observed early on 24 June, late 24/early 25 June, mid 25 June, midnight 26 June, and possibly at 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 from 16-23 July 1980.

3.8.1 NARRATIVE: On 15 July 1980, the group left Mayaguez and arrived at the ICU in anticipation of the deployment of the drogues the next day. Despite the cruise participants being aboard the LCU by the afternoon of 15 July, poor weather, specifically a tropical wave, prevented the ship-to-shore vessel from leaving port until 19 July.

As the small vessel is considered a secondary backup 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 to be nearly vertical, and it had also tangled its electrical line with the support line. This work was completed by 16 July.

Rough seas persisted throughout the cruise, hence only one drogue was deployed to minimize possible losses due to the seas or potential inability to effect 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 significantly altered the depth sensitivity of the panel.

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 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

The text 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 ICU, 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 ICU, 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.

Daily averages are 22, 23, and 24 m/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 225-264 deg-r. 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.

The remaining text contains a series of alphanumeric codes and figures that appear to be part of a data set or technical diagram. Without additional context, it's not possible to correct or interpret these codes. They may be specific to the study or system being described and would need to be addressed by a specialist in that area.

Again, the text contains a series of alphanumeric codes, figures, and what appears to be scientific terminology ("SNOTARA", "SMOTAMMA", "SOLANA", "NOTLOMAIG", "SONVISIG", "USAVIA"). These terms seem to be technical, field-specific jargon that would require a specialist to interpret or correct. Without that expertise or additional context, it's not possible to provide a meaningful correction or interpretation.

Break---
TABLE 29
SUMMARY OF CURRENT METER WATER MOTION MEASUREMENTS: SPEED (cm/ sec)
-2 - 5 - 8 - 11 - 14 - 17 - 20 - 23 - 26 - 29 - 32 - 35
Average Speed = 16 cm/sec
Cruise of 16-23 July 1980

TIME: 04 - 18 - 33 - 133
DIRECTION (degrees):
345 - 014
015 - 044
045 - 074
075 - 104
105 - 134
135 - 164
165 - 194
195 - 224
225 - 254
255 - 284
285 - 314
315 - 344
TIME: 12 - 23 - 24
Page Break---

(Parts of the text are unreadable and require further information for correction.)

Movement: However, the current meter observations show frequent eastward excursions that appear to match the tidal oscillations for the area. These likely correlate 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 when 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 was actually 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 usable drogue deployments, some running concurrently, and some extending over many days. The average number of usable drogue tracking hours was slightly more than 30 hours/drogue, with a range of 4 to 102 hours. The overall speed 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.

Unfortunately, the rest of the text is unclear and appears to be corrupted or improperly formatted. It would be helpful if you could provide a clearer version for correction.

Anmaqea Test 3808, it is not clear to interpret the following text "S*TOT get cea Tp ez un s er “ v T owe LST ToqUEACH 6 a) (9 708) (asim) “anee"s00 fa vane saEDATeT can nomioara NEM SOLER SNORT «SL “SHO GEL anamenus -cmss “gus ag Dt OF OF MOL ‘sud SIMD SOILSTIVIS NOIIVAWASEO ASTM TTY JO RUVKHOS of aTava, ° ° ° 137".

TABLE 31 SUMMARY OF ALL DROGUE WATER MOTION MEASUREMENTS

SPEED ‘TIME CUMMULATIVE DIRECTION TIME (cm/sec) oy TIME (Deg-1)

0 - 2 4 4 315 - 344

3 - 5 9 1 345 - 014

4 - 10 North 6 - 8 28 42 015 - 044

9 - 11 7 48 045 - 074

12 - 14 20 58 075 - 104

15 - 16 East 17 - 19 12 70 105 - 134

20 - 22 6 16 135 - 164

23 - 24 3 90 165 - 194

25 - 26 South 27 - 29 7 7 195 - 224

30 - 32 5 98 225 - 254

33 - 34 West 35 - 37 2 98 255 - 284

38 - 40 3 99 285 - 314

41 - 56 0.2 200

Average Speed = 13 cm/sec

138

When the drogue panel was definitely not at 100 meters, it was 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 138 and 128 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-r), 568. 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-7) 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.

Cruise Date	Westward & Eastward Direction	Atmospheric Pressure
November 9	54 & 46 degrees towards the West	Low
January/February	50 & 42 degrees towards the West	Low
February 18	91 & 9 degrees towards the West	High
March 24	88 & 0 degrees towards the West	High
May 7-10	60 & 30 degrees towards the East and West	High
June 10-12	19 & 59 degrees towards the East	High
June 25-26	92 & 4 degrees towards the West	High
July 15-21	98 & 2 degrees towards the West	Low

The correlation coefficient between the surface water direction and that at 100 meters was only 0.2. In conclusion, as the fluctuation of the atmospheric pressure is known to cause local upwelling, it was hypothesized that this "downstream" upwelling might assist in drawing the deeper water upwards under lower pressure conditions. The weather path through the Caribbean typically moves from east to west at about 5-7 cm/sec, hence, a 2-3 day anticipatory time period can be expected between an effect at Punta Tuna being observed and the causing low pressure to manifest itself in the air at Punta Tuna. Therefore, a correlation coefficient was calculated 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 period.

In the prior 14 days, it was hoped that if there was a high correlation, 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. However, the correlation coefficient was only 0.3, which indicates little, if any, relationship. On at least one, and possibly two, different occasions, the panels of the 100-meter deep drogue 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; all values were close to the average of 12 cm/sec, with the exception of the highly inaccurate November 1979 cruise and the certainly damaged panel occurrence in 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 likely had a very deep Mixed Layer Depth, whereas the Mixed Layer Depth 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. No tidal motion seemed to dominate. The tidal system, centered in the North Atlantic (San Juan), with its associated semi-diurnal oscillations, appeared to exert a stronger influence than the Caribbean system, which had predictive times indicated as "Galveston." On at least one occasion, clear evidence of inertial motion was observed. 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 occasions 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 similar. Occasionally, 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, 143.

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 may 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 timescale 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.

6.0 REFERENCES

Atwood, D. P., P. Duncan, M. Stalcup & M. Barcelona. 1976. Ocean thermal energy conversion: Resource assessment and environmental impact for proposed Puerto Rico site. Final Report. NSP Grant #AER75-00145, Univ. of Puerto Rico, Dept. of Marine Sciences, Mayaguez. 104 pp.

G. W, 1965. Results of drift bottle studies near Puerto Rico. Caribbean Journal of Science, Vol. 5 (3/4), pp. 173-174.

Burns, D. A. and M. Car. 1975. Current meter data report for the eastern part of the Caribbean Sea. Naval Oceanographic Office, TN6110-6-75, Washington, D.C. 177 pp.

Cohen, R. 1978. An overview of the U.S. OTEC development program. ASME Energy Technology Conference, 6-9 Nov. 1978, Houston. 28 pp.

Craig, H. L., T. Lee, H. B. Michel, S. C. Hess, R. Munier, M. Perlmutter. 1978. A source book of oceanographic parameters affecting biofouling and corrosion.

OTEC plants at selected sites. Rosenstiel School of Marine and Atmospheric Science, University of Miami. TR 78-1. 369 pp. Duncan, C. P., D. Atwood, J. R. Duncan & P. N. Froelich. 1977, "Drift bottle returns from the Caribbean." Bulletin of Marine Science, Vol. 27, #3, pp. 580-586. Goldman, G. C., M. L. Hernandez Avila, J. G. Gonzalez & D. Pesante. 1979. Results of oceanic measurements relatable to an OTEC installation at Punta Tuna, Puerto Rico. Final Report to Lawrence Berkeley Lab/University of California, contract #4983802. University of Puerto Rico, Center for Energy & Environment Research, # CEER-O-57. 585 pp. Gordon, A.L. 1967. Circulation of the Caribbean Sea. Journal of Geophysical Research. Vol. 72, #24, pp. 6207-6223. Hernandez Avila, M. L., J. A. Suarez Caabro & G. C. Goldman. 1979. A historical review of the physical and biological characteristics of the ocean near Puerto Rico, relative to an OTEC power plant. Report to Lawrence Berkeley Lab/University of California, contract #4983802. University of Puerto Rico, Center for Energy & Environment Research, #CEER-O-51. 318 pp.

Lee, T. N., R. S. C, Munier, S. Chiu. 1978, Water mass structure and variability north of St. Croix, U.S. Virgin Islands, as observed during the summer of 1977 for OTEC assessment. Rosenstiel School of Marine Science, University of Miami. RSMAS #78004. 81 pp. Metcalf, W. G., & M.C, Stalcup. 1974. Drift bottle returns from the eastern Caribbean. Bulletin of Marine Science. Vol. 24, #2, pp. 392-395. Metcalf, W. G., M. C. Stalcup & D. K. Atwood. 1977. Mona Passage drift bottle study. Bulletin of Marine Science. Vol. 27, #3. pp. 586-591. Monahan, E.C. 1975. Effective design of large drogues: experience with differential OMEGA buoys in the Great Lakes. In Workshop on the feasibility of remote tracking of drogues and other instruments drifting in coastal waters. 24-25 February 1975, Windsor, Ontario. Great Lakes Research Advisory Board. pp. 67-71. Monahan, E. C. & E. A. Monahan. 1973. "Trends in drogue design." Limnology and Oceanography, Vol. XVIII, 46, pp. 981-985. National Ocean Survey.

(NOS). 1975. Puerto Maunabo Navigation Chart. U. S. Dept. of Commerce, NOAA, # 25659. Oser, R. K., & Freeman, L. J. 1969. Oceanographic Cruise Summary, Vieques Island, Puerto Rico Area, December 1968 to March 1969. Naval Oceanographic Office, Washington D.C. Informal Report IR # 69-66. 16 pp.

Ostericher, C.C. 1967. Oceanographic Cruise Summary, Atlantic Fleet ‘Tactical Underwater Range: Southeast Puerto Rico-1967. Naval Oceanographic Office, Washington, D.C. Informal Report IR # 67-76. 44 pp.

Parr, A. E. 1937. A Contribution to the Hydrography of the Caribbean and Cayman Seas, Based Upon the Observations Made by the R.V. Atlantis, 1933-1934. Bull, Bingham Oceano, Coll.'5(4), pp. 1-110.

Parr, A. E. 1938. Further Observations on the Hydrography of the Eastern Caribbean and Adjacent Atlantic Waters. Bull. Bingham Oceano, Coll. 6(4), pp.1-29.

Perlroth, I. 1971. Distribution of Mass in the Near Surface Waters of the Caribbean. In Symposium on Investigations and Resources of the Caribbean Sea and Adjacent Regions (CICAR), 18-20 Nov 1968, Curacao, Neth. Antilles, UNESCO, Paris.

Sturges, W. 1965. Water Characteristics of the Caribbean Sea. Jour. Marine Res. Vol. 23, #2, pp.

147-162.

Terhune, L. D. B. 1968. Free-Floating Current Followers. Fisheries Research Board of Canada, #85. Biological Station, Nanaimo, B.C. 30 pp.

U.S. Department of Commerce (DOC). 1979. Tide Tables 1979. East Coast of North and South America. National Ocean Survey. Washington D.C.

Worthington, L. V. 1971. Water Circulation in the Caribbean Sea and its Relationship to North Atlantic Circulation. In Symposium on the Investigations and Resources of the Caribbean Sea and Adjacent Regions (CICAR), 18-20 Nov 1968, Curacao, Neth. Antilles. UNESCO, Paris. pp. 161-191.

Wust, G. 1964. Stratification and Circulation in the Antillean-Caribbean Basin, Part 1. Spreading and Mixing of Water Types with an Oceanographic Atlas. Columbia Univ. Press, 201 pp.