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RESULTS OF OCEANIC MEASUREMENTS RELATABLE TO AN

OTEC INSTALLATION AT PUNTA TUNA, PUERTO RICO

AND DANIEL PESANTE

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CENTER FOR ENERGY AND ENVIRONMENT RESEARCH,

[UNIVERSITY OF PUERTO MICO ? U.S. DEPARTMENT OF ENERGY i

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RESULTS OF OCEANIC MEASUREMENTS RELATABLE TO AN OTEC INSTALLATION AT PUNTA TUNA, PUERTO RICO

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EXECUTIVE STATEMENT

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

?This document is in response to a portion of a 4-phase project design to secure and evaluate oceanic data specifically at the Punta Tuna site. The phases provide for:

1, The compilation of ayearly set of periodically sampled oceanic data at the Benchmark site of Punta Tuna.

2. An interpretation of the relevant literature, recently procured data, and long-term current meter data taken concomitant to this program.

3. A thorough historical literature and data search

of oceanic data and an interpretation thereof,

4. Recommendations for future studies of the OTEC

oceanographic program.

?This document addresses the first and second phases, and includes @ revision on the fourth phase of the project.

During the contract period, the Punta Tuna site was visited for hydrographic measurements six times:

arly August, 1978

mid October, 1978

early December, 1978

mid February, 1979

Tate April, 1979

early June, 1979

The purpose of each of the cruises was to measure the physical, chemical, and biological vartables at many depths and finally look at the temporal changes of those variables

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throughout the year. This program was supplemented by

the U.S. Navy Underwater System Laboratory, New London,

Conn. which placed two subsurface current meter moorings near Punta Tuna. The recorded data from two of the recovered current meters is also discussed herein.

?As the Punta Tuna site was the primary focus, this location is emphasized, in both themeasurements and in the results. However, a nearby site, off Vieques island is compared to Punta Tuna, as are two west coast locations and numerous sites along the south coast. Punta Tuna was determined to offer the best overall potential operating efficiency with the clbsest offshore distance.

The temperature measurement results show there is virtually no change in the deep water (1000 m) temperature throughout the year at Punta Tuna. The surface water temperature changes by as much as 3 C*, froma low in late winter to a high in early autumn, The Thermal Resource for a full-size OTEC plant could be expected to vary from 20-23 C° annually, if the condenser water intake were at the 1000 m depth and the evaporator water intake were at about 20 m depth. These results would change at other Puerto Rico sites. At the Vieques location, the surface temperature 1s consistantly about 1/4-1/2 C° cooler than at Punta Tuna. At Punta Borfnquen, on the northwest coast, the deep water (1000 m) is about 2 C* warmer than at Punta Tuna, thereby reducing the northwest coast site's operating efficiency considerably.

The Mixed Layer Depth at Punta Tuna was found to vary seasonally from a depth of as much as 90 m during the wintel when the weather is more rough, to virtually zero in the summer, when the weather is calm. The Mixed Layer Depth at Vieques ? was not much different than that at Punta Tuna, Since the evaporator intake for a full size OTEC plant may be at a depth of 20-25 m, a plant in Puerto Rico waters might draw water from below the Mixed Layer during part of the summer.

The basic water colunn structure did not change from one Jocation to another, although the temperature structure was tv

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slightly different, as mentioned previously. With a similar vertical density structure, the effluent from either a mixed (cold and warm water together) or separated discharge at any of the investigated locations would probably have similar vertical dynamics. The horizontal water motion, however, will influence the fate of the discharge more than the relative density.

Very little ts known about the subsurface water currents around Punta Tuna, or even Puerto Rico in general. As a result of the water current profile measurements taken during each cruise, and the moored current meter returns, (about one month of data), diurnal and semi-diurnat tidal components were identified moving east and west along the south coast past Punta Tuna. Eastward and westward motion appeared dominant at Punta Tuna down to about 500 m during the profiling, with considerable motion in all other directions as well. Between 650-750 m the water direction turns primarily to the northeast and northwest. This scattered information is stil] insufficient to predict the dynamics of a plant discharge.

Dissolved oxygen results at Punta Tuna compared well with the historical values, showing high surface and near surface values, and a relative minimum at mid-depth, and generally increasing values below 800 m. Likewise, chlorophyll results showed typical patchiness, but within the normally expected ranges for tropical oceanic waters.

The comparison between the air temperature from meteorological records in the Caribbean basin, compares well with the sea surface temperature fluctions: Furthermore, periods of sustained higher winds produced the expected increase in the Mixed Layer Depth, Zooplankton results were statistically non-definative due to the lack of replication of sampling. Little new information was learned.

As indicated in the recommendation section of the report, much of the long-term temperature information is available, at least enough to design and build a power plant. The water. currents, however, are poorly understood, therefore intake,

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discharge, and cold-water pipe dynamics are still uncertain.

Continuation of studies of nutrient chemistry must also be

carried out. Finally, the biological knowledge is the weakest,

with virtually no predictive capability for any of the ecosystem

components relative to the many interactions that the OTEC

plant will have with the biota in the sea.

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1,0. INTRODUCTION

?An Ocean Thermal Energy Conversion (OTEC) power plant uses sun-heated tropical or subtropical oceanic waters to produce usable energy. The OTEC plant uses large quantities of warm oceanic surface water and cold deep water to run a thermal engine. The usual estimate is that at least 20 c® difference between the surface and the deep water is desired to run the engine with sufficient efficiency to justify this type of energy production. The thermal engine is then used to drive an electricity producing generator. If the power plant is on, or near, shore, the electrical power can be fed into the local electrical system. If the plant is far off-shore, it may be used as the energy source for a floating energy-intensive industrial operation.

Puerto Rico is considered by most scientists and technologists as one of the prime U.S. locations for an OTEC power plant. Furthermore, Puerto Rico seems to qualify as a prime example of a location for a nearshore floating OTEC power plant. More than half of the island's 600 km shore-Tine has water of a depth of 1000 m or greater less than 13 km from shore. At some places this offshore distance is only about 3 km. In Puerto Rico, it appears that the 1000 m depth will assure at least 20 C* temperature differences from surface to deep water throughout the year (Wolff, 1978). Another advantage of Puerto Rico's location is that it is truly representative of an open ocean island, with little terrestrial runoff and only a small shelf for shallow water coastal organisms to inhabit. Although Puerto Rico is located. in the Caribbean, (Fig. 1), and therefore experiences occasional hurricanes, there are several "safe" harbors around the island for personnel and vessels. Finally, Puerto Rico is a technically modern island, with adequate road, seaport and airport facilities, a total inter-island electrical. power grid, and a vastly expanding electrical need.

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Fig. 1

= Puerto Rico and its location in the Caribbean.

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Due to these reasons, the U.S. Department of Energy has contracted the Center for Energy and Environment Research (CEER), of the University of Puerto Rico, to conduct a series of bimonthly cruises to an oceanic site (Fig. 2), about 4 km southeast of Punta Tuna, Puerto Rico (Fig. 3). The purpose of these cruises was to measure and evaluate the variability of many OTEC-related oceanic variables. Punta Tuna and its environment has been determined as one of the optimum Puerto Rico sites (please see Atwood et al., 1976 for a more complete general description of the area).

The purpose of this report -is to describe the activities and measurements involved with these bimonthly cruises as well as analyze and interpret the resulting data. Finally, recom-mendations are made applicable to subsequent oceanic OTEC measurement programs for this geographical area.

1.1 Introduction to the Measurement Program

During the measurement period, the Punta Tuna station wes occupied for hydrographic measurement purposes six times:

early August, 1978

mid October, 1978

early December, 1978

mid February, 1979

Tate April, 1979

early dune, 1979

During the first cruise (August, above), the mooring buoy was not yet implanted, and the vessel was allowed to drift while on station. All subsequent hydrographic cruises used @ mooring buoy to maintain location while at the Punta Tuna benchmark station (Station "B"). This mooring buoy was available to use with this program because the U.S; Department of Energy also plans to conduct an at-séa experiment for bio-fouling and corrosion of OTEC heat-exchanger components at the same site, and a deep sea mooring buoy was implanted at 17° 57.6'N, 65° 51.9'W (about 4 km southeast of Punta Tuna) in September of 1978 (Sasscer et al., 1979).

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Fig. 3 Map showing Puerto Rico, Vieques and surroundings.
(The occupied stations near southeast Puerto Rico
and Vieques are also shown).

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The general plan (please see Appendix G for a typical cruise plan) for each hydrographic cruise was to board, Toad, and disembark from the western part of the island, either from La Parguera (home port for the vessel, Fig. 3) or Mayaguez, and arrive at Punta Tuna about one-half day later. Usually the Benchmark station was visitéd first, and the vessel remained at the mooring about 36 hours. During this time 2 Hydrocasts, 2 Biocasts, 4 Current profiles, 5 Zoo-plankton hauls, and numerous XBT's were taken. After leaving the mooring (referred to hereafter as Station "B") various other nearby stations were visited, taking only an X8T with a drifting current meter profile in the beginning of the program. Finally, a station was visited south of Punta Vaca, Vieques (Fig. 3). This station is located about 40 km fron Punta Tuna, and was used to determine spatial variations (funded by the Puerto Rico Water Resources Authroity). At Vieques (referred to as Station "V"), 1 Hydro/Biocast, 3 Zooplankton hauls, and 1 or 2 XBT's were taken.

In addition to these hydrographic measurements, the U.S. Navy Underwater System Laboratory of New London, Conn. was contracted by the U.S. Department of Energy to work in cooperation with CEER on the implant action of two strings of current meters in the Punta Tuna area. The schedule called for 2 to 4 months between servicing of the meters, with a possible total yearlong submersion as the goal. One mooring was set in early January of 1979 at near our Station "A" (Fig. 3). The recovery operation for this mooring occurred during our February cruise, along with the re-implanting of the mooring at Station "F* (Fig. 3) location. This second mooring had not yet been recovered as of August 1979, although an unsuccessful attempt was made in early May 1979.

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2.0 MEASUREMENT DESCRIPTION

During the bimonthly cruises, samples and/or data were taken to determine values of oceanic chemical, physical, and biological parameters at, or near, Punta Tuna, Puerto Rico (Fig. 3). These data and/or samples were taken according to a fixed temporal schedule (if possible) as well as procedure. (Please see Appendix & for @ typical cruise plan).

The data/sampling operation may be grouped into nine categories:

1. Hydrocast

2. Biocast

3. Current Profile

4, Underwater Horizontal Light Transmission

5, Zooplankton Haul

6. Expendable Bathythermograph (XBT)

7, Weather

8. Current Meter Mooring

2.0.1 Hydrocasts

The Hydrocasts were standard oceanographic water casts that reached down to about 1000 m depth. The usual procedure was to lower the hydrowire down to the maximum depth, with an open 5 liter Niskin sampling bottle set at each of the desired depths. Each Niskin bottle contained a set of 2 or 3 oceanographic reversing thermometers (discussed later). The desired sampling depths for the Hydrocasts were 0, 50, 100, 200, 250, 300, 400, 500, 600, 800, and 1000 m. During each cruise there were at least 2 Hydrocasts. One scheduled Hydrocast was at Station "B" about-noon (1000-1400 hours) and the other was scheduled about midnight on the same day (2200-0200 hours). The water collected during the Hydrocasts was apportioned for on board analysis of dissolved oxygen, and on shore laboratory analysis of salinity and nutrients.

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2.0.2 Biocasts

Biocasts were standard oceanographic water casts that reached down to about 400 m. They were designed to measure parameters primarily in and just below the photic zone.

Again, the procedure was to lower the hydrowire down to the maximum depth, with an open 5 liter Niskin sampling bottle set at each of the desired depths. As with the Hydrocasts, each of the Niskin bottles contained a set of 2 or 3 oceanographic reversing thermometers. The desired sampling depths of the Biocasts were 0, 25, 50, 75, 100, 125, 150, 175, 200, 250, 300, and 400 m. During each cruise there were at least two Biocasts. One was scheduled for about noon of the second day at Station "B" (1000-1400 hr), and the other was scheduled for about midnight (2200-0200 hr). The water collected during ?the Biocasts was apportioned for on shore analysis of salinity and chlorophy11.

2.1 Mater Temperature

Three methods were used to determine the in situ water temperature. For discrete values, reversing thermometers were used, in conjunction with the water sampling bottles mentioned above. For a continuous profile, an expendable bathythermograph (XBT) was used, and on one occasion, a Salinity-Temperature-Depth (STD) system was available.

2.1.1 Reversing Thermometers

There were four types of reversing thermometers used during this program. About one-third of the thermometers are of Watanabe Keiki manufacture, These include both protected and unprotected units. The other two-thirds are distributed by Kahl Scientific Instrument Corp., Calff., and also include both protected and unprotected types. All these thermometers have been calibrated to within + 0.01 C°. The thermometers

were all used as per U.S. Navy manual (U.S. Navy, 1968) procedures. Two protected units were used at each depth to determine the actual temperature. After all the appropriate

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corrections were made the results of these two units were averaged. A single unprotected thermometer was used at depths of 300 m and greater to determine the accepted mea-Surement depth, again as per the USN Manual (U.S. Navy, 1968). During shipboard operations, the thermometers were allowed to equilibrate at the measurement depth for 15 minutes and "wait" on shipboard for at least one-half hour to stabilize before reading.

2.1.2 XBT

To collect a continuous graphical profile of temperature vs. depth data, an XBT probe and recorder was used. The instrument and recorder, both manufactured by Sippocon, Corp., Mass., were used as per the manufacturer's instructions. A surface "bucket" water sample was taken for the initial temperature calibration, Although the stated accuracies of the XBT probe and recorder are + 0,2 C*, and:+ 2% for depth, lack of a smooth descent can increase the error. The initial analysis of these data included offsetting the surface reading, and subsequent readings, as per the bucket temperature indication. Then, the depth for each integer centigrade degree was noted, down to the maximum readable depth of slightly more than 760 m.

2.2 Salinity

The salinity of the water at discrete depths was determined by collecting the water samples in the § liter Niskin sampling bottles and subsampling into an aged, twice rinsed, 250 ml plastic bottle, The estimated depth of the sample was recorded. The actual salinity determination was made using a Plessy Environmental Systems (Now Grundy Environmental Systems) Model 6220 Laboratory Salinometer. The salinometer was adjusted at the beginning of the measurement period, using Standard (Copenhagen) sea water, and then was monitored and corrected using a filtered, seawater secondary standard, The manufacturer's estimated accuracy after making al] appropriate corrections is + 0.003 °/e. (Plessy, 1976).

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2.3 Mater Current

2.3.1 Water Current Profiles

An Interocean, Model 135, Savonious rotor-type current meter was used to measure the water current profile. The strip-chart recording instrument was suspended off the vessel at discrete depths from 25 m down to 750 m, the limits of the meter. The depths sampled during the program varied, but an attempt was made to include representative values from each of the water masses in the water column. On the first cruise, the current profiles were taken at each station, including the Benchmark station and three auxiliary stations, Due to the inaccuracy of the vessel's location fixes, the normal error in the meters and possible induced drag errors the

total error in the speed measurement amounted to as much as

4 252. On subsequent cruises, current profiles were performed only while moored at the Benchmark station,

Originally, the timing of the profiles, which took about 2 1/2 hours to perform, was at 0000, 1200, and 1800 hours. During the program it became evident that a tidal component may be entering into the measurement, but was possibly being aliased, Therefore, during the last two cruises, the mea~ surement period was planned to occur at times of suspected peak tidal current in the area, both ebb and flood. The instrument originally was designed for full scale of 150 cn/sec with a resolution of about 1,25 cm/sec, and @ manufacturer's estimated accuracy of 1,5 cm/sec (Interocean, 1975). The instrument was modified for the last two cruises to improve the resolution. The full scale values were decreased to 50 cm/sec, with the resolution of about 0.4 cm/sec. The accu- racy was not altered, but by spreading the usable scale, the processed data should be more reliable,

The direction of the water current is sensed by a large external vane, which rotates the entire meter housing, This rotation is sensed relative to a north seeking compass internal to the housing. The manufacturer's stated accuracy is

£49 of direction.

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2.3.2 Moored Water Current Meters

On 6-8 January 1979 an expedition was conducted by Mr. Richard Noble (U.S. Navy Underwater Systems Laboratory, New Haven, Conn.) to implant 2 current meter moorings. One mooring was to be implanted at about location "A" (Fig. 3), which 1s at 18° 02.2'N, 65° 39.7'W, and the second was to be at location "B". Prior to each implantation the desired location was to be surveyed bathymetrically. Upon determining a suitable location, the mooring was to be released, using an "anchor last" deployment.

During 6 January, the area around Station "A" was surveyed (Fig. 4) using an onboard Gifft precision depth recorder for depth measurements and the U.S. Navy Tracking Team of Roosevelt Roads Naval Base for location. Upon chotce of a suitable location, the vessel returned to the site and the anchor (attached to the floating, deployed mooring string) was released. It came to rest at the site labeled "A" on Figure 4. This actual resting site was somewhat deeper than originally planned, due to the presence of the rough, uneven terrain.

On 8 January 1979 the second mooring, "B" was cancelled due to navigational problems and malfunction of the precision depth recorder.

A schematic of the mooring "A" is shown in Figure 5.

The mooring was to have a subsurface buoyancy module about 20m bélow the surface. Aanderaa current meters, Model RCH-5 were to be located at depths of 100, 200, 400, and 800 m, Also, stretched between 200 and 400 m were two thermister strings, with temperature sensors every 10 m. The final configuration was different in that the thermister string was not used and each element of the entire array was 115 m deeper because the actual depth of 1215 m was 115 m deeper than design. The current meters were set to record every 10 minutes. Of this entire array, only the subsurface float and the upper two meters were recovered on 11 February 1979, and the results of the recovered data is presented in Section

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19°09"

10°02

= 10°00

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Fig. 4 - Bathymetry of the area surrounding

the location of the first current meter

woring, "A" (sounding in meters).

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Fig. 5 -Schenatic representation of current meter mooring "A",

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On 14 February 1979 a second mooring was implanted at Station "F", This station was favored over "B" as tt is very flat (41m over about 1 km radius circle). This flatness was confirmed by a bathymetric survey of "F" prior to mooring deployment. As the area is so flat immediately surrounding "F", no purpose would be served to include the bathymetric chart of this small area, therefore, an isometric drawing 1s included to show the bathymetric comparison between "F" and the Benchmark area, Station "8" (Fig. 6). Again, the "anchor last" depolyment method was used, and the mooring schematic for mooring "F* ts shown in Figure 7, The major dtfference

was the depth and inter-meter spacing. The depth at "F* was

1970 m, whiJe that at "AY it was only 1215 m. Mooring "Fr1"

was to be recovered in April 1979, but the attenpt proved

unsuccessful. As of Novenber 1979, the mooring had sti11 not

been recovered.

2.4 Water Density

The values of density of the sea water were calculated

using the above measured temperatures, fron the reversing

thermometers, and the Niskin bottle-sampled salinity deter-

minatfons (Knudsen, 1901). These values were substituted

into the following equations:

7 Tet (Go + 0.1328) (1-Ay + By (o9-0,1324))

2

Fee. ((tegg8)*, tezas.

2 = -0.069 + 1.4708C2 - 0.00157¢e2 + 0.0000398c83

Ay = (4.7867 - 0.09815 + 0.0010843t7) 1079.

= (18.03 - 0,8164¢ + 0.01677) 10

03

S = Salinity of the sample (°/ee)

t= Temperature of the s:

uu

ple (°C)

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Fig. 6 - Bathynetry of the Punta Tuna area, including the

Tocation of the mooring buoy and the second current

ring *F".

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Fig. 7 - Schematic representation of current meter mooring "F".

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2.5 Dissolved Oxygen

Dissolved oxygen samples were taken from the Niskin water-sampling bottles during the Hydrocast stations. The Subsamples were collected using a 300 ml glass bottle, after suitable rinsing, and carefully drawing the sample to avoid air entrapment. The analytical procedure used is that described for use during the International Indian Ocean Expedition (Menzel, 1962). The procedure, shown in Appendix H, is a modification of the standard Winkler techniques, and is followed as soon as possible after the subsampels are collected.

Repetitive laboratory sampling and analysis of standards using this method yielded a repeatability of + 0,13 mg/2,

2.6 Chlorophy!] Analysis

Analysis for concentration of chlorophyll a, the main photosynthetic pigment and for phaeophytin a, its immediate degradation product were carried out fluorometrically following the guidelines established by Strickland and Parsons (1972). Samples of marine plankton on Millipore or glass fiber filters were stored at -5°C in air tight containers with silica gel dessicator. Samples were routinely protected from exposure to strong light, For extraction of pigments, the filters were placed in screw-cap test tubes with 90% spectrophotonetric grade acetone (20 ml), shaken vigorously and stored for 24 to 48 hours at 5°C in the dark. Prior to fluorometric analysis, the samples were centrifuged at 5000 rpm for 5 min, decanted and allowed to come to room temperature. The extracts were quantified using a Turner 110 filter fluorometer equipped with filters, door and photomultiplier recommended by the above authors, For phaeophytin a analysis, the above extracts were treated with two drops of 1 N HCl, allowed to react for 5 min and then read again on the fluorometer.

Calibration of the fluorometer was achieved comparing the response to pigments to that of a Beckman DU spectro-

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photometer equipped with the Gilford up-dating electronic array. Twenty-one liters of sea water obtained from waters offshore of La Parguera (Fig. 3), were filtered onto Whatman No. 3 filters and extracted in 90% acetone. Absorbance at 665 nm was measured using 10 cm path length cuvettes and pigment concentrations were calculated using the formulae provided by Strickland and Parsons (1972), Door factors for the fluorometer were then computed from data on fluorometer response to known dilutions of the primary standard.

2.7 Zooplankton

Zooplankton sampling was carried out either by vertical, horizontal or oblique hauls. For vertical or oblique hauls, the 202 micron (silk size #8), 3/4 m diameter opening net is secured to a double trip mechanism and lowered to the desired dcpth, ?The closed net is then ratsed, and a messenger is sent down the cable, activating the first portion of the double trip mechanism to open the net at the desired depth. As the open net ascends and approaches the upper limit of the fishing depth, a second messenger is lowered again activating the double trip mechanism, this time to close the net, When the vessel was at the mooring, the haul was almost vertical. If the vessel was drifting, the path of the net became oblique due to the ship's motion. The dpeths sampled were: 1000 m-© m, 1000 - 800 m, 800 m- 200 m, 200 m- 07m, Finally, to achieve a 25 m deep horizontal haul, or tow, the net was lowered in the closed position while the vessel was steaming at or less than 1.5 m/sec, The actual net depth for these horizontal tows was computed, based on the wire angle from the vertical. At the desired depth, messengers are lowered - to open and close the net at the appropriate time interval.
In all cases a flow meter was mounted at the net entrance and was read to indicate the water volume passing through the net.

The collected samples were hosed with sea water into a container, where they were preserved in a 4% buffered formaldehyde solution for future laboratory analysis.

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In the laboratory, after sorting and cleaning to remove foreign particles, a subsample is drawn using a 1 mi stempel pipette. (If the number of copepods did not reach 300-400, subsequent subsamples were drawn and added to the first). Under a stereo-zoom binocular dissecting microscope, the animals were keyed to species (copepod) when possible or family (others). All the animals were measured for length.

2.8 Nutrients

Water samples were analyzed for nitrite, nitrate, phosphate, and silicate. Originally, the samples were filtered through a Nuclepore filter then treated with hydrochloric acid, Subsequently, chloroform replaced the hydrochloric acid and the filters were changed to Millipore membrane filter (45 um mesh). The plastic bottles in which the subsamples were stored were acid washed.

During the first four cruises, the subsample of water to be drawn and filtered on board was drawn with an acid washed, twice sample-rinsed poly-bottle. After filtering, the sample was returned to the plastic bottle and treated with preservative. As a precaution against unfiltered contamination, a twice-rinsed transfer bottle was used on the last two cruises to carry the water to the filtering apparatus. Only after filtering, was the sample placed into a clean, acid-washed storage bottle and preservative added. On all occasions, after preservation samples were stored at 4-5 °C until the analysis was completed. Analysis procedures were virtually identical to those provided by manufacturer of the Technicon Autoanalyser (Technicon, 1972; Technicon, 1973; Technicon, 1973a).

2.9 Horizontal Light Transmission

The horizontal light transmission was measured using 2 Hydro Products, model 912-5 transmissometer system, The unit reads both percent of light transmitted over a 1 meter path length and the instrument depth (Hydro Products, 1974). The

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instrument was read at convenient intervals, usually about 15 m, both while descending and ascending through the water column, The two readings from each depth were averaged.

The instrument never functioned properly throughout the field measurement period, even after factory recommended repairs and a trip back to the manufacturer.

2.10 Meteorological Data -

The meteorological data, taken during the cruise, consisted of air temperature, wet and dry bulb thermometer, barometric pressure, sea state, wind speed and direction, and cloud cover. As the methods for these data are adequately reported, (U.S. Navy, 1968), they will not be reported here. Also included in this report are some analysis of data taken at the Coast Guard Station at Punta Tuna Light and the NOAA Climatological Data from San Juan. The Punta Tuna Light date are taken every 3 hours (on week days) from 0800-1700 hr. The San Juan data are from hourly observations, as well as monthly averages, dating back to 1941,

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3.0 RESULTS AND INTERPRETATION

The following sections describe the results of the data acquisition program during the period from August, 1978 through June, 1979, Preceeding the discussion of these results, a summary of historical information is included that will help to describe some of the physical, biological and chemical characterisitics of the area.

3.0.1 Summary of Historical Results

3.0.1.1 Climate, The Commonwealth of Puerto Rico, associated with the United States by bilateral agreement, consists of a main island and several smaller islands. ?These islands are all located along the Antilles Chain

of islands, extending almost from Florida, USA to Venezuela, South America (see Fig. 1). Puerto Rico is approximately half way along the Chain, about 1700 km from Miami, Florida. The nearest large land mass to Puerto Rico is the island

of Hispafiola, about 130 km to the west. The Chain sepa~ rates the Atlantic Ocean and the Caribbean Sea. As Puerto Rico is situated along an east-west axis, the Atlantic washes its north coast, and the Caribbean, its south coast. At the latitude of about 18°N, Puerto Rico ts in the trade wind belt, with both the winds and oceanic currents generally moving east to west past the island.

The main island of Puerto Rico is roughly rectangular in shape, about 180 kn east to west, and about 60 km north to south. The island is @ mixture of mountains, rolling hills, and broad flat plains, In general, where the plains meet the sea, the climate is typically tropical marine (except along the semi-arid southwestern coast), That is, during the day as the land mass heats up, a convection cell is devoloped, causing the winds to move landward from the sea, bringing moist sea air inland. In the evening as the

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land cools, the convection cell reverses and the winds blow offshore. Due to the numerous hills and mountains on the island of Puerto Rico, the moist sea air is frequently cooled to saturation while still over the land mass. This causes considerable rainfall, almost daily over some parts of the island.

3.0.1.2 Wind Regime. The sixth edition of the U.S. Coastal Pilot, Area 5 (U.S. Dept. of Commerce, 1967), summarizes the wind regime on the coast of the island as follows:

?The prevailing winds over Puerto Rico are the easterly trades, which generally blow fresh during the day. The center of the Bermuda High shifts a Little north in summer and south in winter changing the direction of the winds over that island from north-northeast in winter to east in sumer.

Factors which interrupt the trade wind flow are frontal and easterly wave passages. As the cold front approaches, the wind shifts to a more southerly direction, and then as the front passes there is a gradual shift through the southwest and northwest quadrants back to northeast. The easterly wave passage normally does not bring a westerly wind but is usually characterized by an east-northeast wind ahead of the wave and a change to east-southeast following the passage.

Over most of the ocean near Puerto Rico the strength of the winds increases in midsummer, with Tighter winds in the spring and autumn seasons. There are also somewhat higher average winds in the northwest part of the area in the late autumn and winter.

Mean winds speeds over the Atlantic in this area range from 9 to 10 knots (4.5 to 5 m/sec) during the autunn to 2 high of 12 to 15 knots (6 m/sec) in smidsurmer

3.0.1.3 Water Masses and Circulation. The water masses in the Caribbean have been discussed by many authors (Must, 1963; Atwood et al., 1976; Craig et al., 1978; Lee et al., 1978), but for completeness they shall be mentioned again

in this report as the source, depth location, movement, and characteristics of the water masses are important to the understanding of the data described in the following sections.

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The cold water intake pipe of an OTEC plant in Puerto Rico waters would probably extend from near the surface to. about 1000 m deep. With the intake opening at 1000 m depth, the intake water would come from approximately 50-100 m above and below that depth. Therefore, for the purposes of this report, the water masses in the upper 1100 m of water in the northern Caribbean will be considered.

The upper water mass is called the Tropical Surface Water (TSW). The origin of this water is under the equatorial atmospheric trough (low), which is a tropical rain belt located to the northeast of South America. The TSW is influenced both by heavy precipitation in that area and by runoff from the Amazon and Orinoco Rivers. This water mass is driven by wind and the earth's rotation 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 predominent easterly winds, the water moves northwest toward the Yucatan, By the time it reaches Puerto Rico, the temperature and salinity of this upper water mass has been further affected by the general and local climate of the area through which it has passed, Additional precipit tion and runoff, (although slight), or evaporation from wind and insolation could further influence both the temperature and salinity, In the TSH, salinity generally ranges from 33-36 °/ee, and 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 geostrophic subsidence as the water moves westward. The local depth of the water mass, may be influenced more by atmospheric pressure and its variation, Normally, atmospheric pressure ?changes little, with changes of 3-6 mm of mercury in a month being considered large. However, as a tropical pressure trough moves through the Caribbean, the pressure is severely reduced, causing the water level to be raised, pushing the upper water mass to the side, and upwelling the cooler, more saline water

ass below. This upwelling would occur during a hurricane and, to a lesser degree, during a tropical wave or a tropical

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storm. This atmospheric effect on an operating OTEC plant would be to severely reduce its thermal efficiency,

The water mass directly beneath the Tropical Surface Water is called the Subtropical Underwater (SUM). This lower water mass originates directly beneath the Bermuda atmospheric high pressure zone. The Bermuda ?High is the atmospheric downwelling component of the Hadley cell which gives rise to the Equatorial Atmospheric Trough, which in turn is related to the origin of the Tropical Surface Water discussed above. The air under the Bermuda High is generally warm and dry. Due to the lower relative humidity, evapora tion is great and salinity is increased, making this water mass the most saline in all the Caribbean. The SUM descends to form the upper portion of the thermocline in the Caribbean. The salinity within the SUW does not vary much (36.8-37.2°/ because the water rarely comes into contact with any diluting agent. During conditions of low atmospheric pressure, this water 1s drawn upward, as evidenced by the very high salinity seen at or near the surface.

The temperature range within the SUW is 20°C-24°C. Due to thermal conduction, the temperature does not remain as invariant as the salinity, The density difference between the Tropical Surface Water and the Subtropical Underwater is large enough that they remain two distinct water masses. The SUK moves southward fromthe higher latitudes near Bermuda and enters the Caribbean through passages along both the north and east. From these passages, the water moves generally southward or westward, or both to spread throughout the entire Caribbean beneath the TSW.

As the SUW moves westerly into the Caribbean, it is seen to dilute somewhat to about 36.5°/.0-36.6°/oo in the Yucatan Strait. Near Puerto Rico, the water enters the Caribbean southward through both the Anegada and Mona Passages.

The core of this water mass generally lies at about 125-150 m depth in the Puerto Rico are

Below the SUM lies a transition zone of indistinct

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characteristics. The transition zone contains the lower portion of the thermocline, and extends into the definite area

of the cold water zone. This transition water is a mixture of North Atlantic Central Water and diffused and diluted Mediterranean Water. The salinity ranges about 36.8°/eo, from the water mass above it, down to about 35°/e,. The temperature ranges from 20°C to about 7°C. This transition zone reaches from about 200 m to 600 m depth. 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 both southward and westward.

The Antarctic Intermediate Water (AIM) is found just below the transition zone (600 m-800 m). This water is formed at the Antarctic Convergence Zone, about 45°-55° south latitude. The water tends to be low in salinity, as it 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 Hispafola. These latter deep sills may also forma path of departure from the Caribbean for the AIW that has entered through the Lesser Antilles 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 east (entering through the Windward Passage) or even north and east or west (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 1s no longer the 34°/ce of its origin, but rather about 34.8°/0. The temperature is 6-7°C.

From 800 m down to 1000 m, between the Antarctic Intermediate Water and the North Atlantic Deep Water, (NADW) lies

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another thin transition zone. From about 1000 m depth and deeper the water mass found in the Caribbean Sea has most of the characteristics of the North Atlantic Deep water. This water is formed in the high northern latitudes, and while descending both in depth and latitude, entrains some of the Mediterranean water, thereby increasing its salinity, density, and depth. This water enters the Caribbean only through the Windward and Anegada Passages. The water moves mainly westward from the Windward Passage, but south and west from the Anegada Passage to fill all the deep basins in the Caribbean. This water is characterized by 4-5°C temperatures, and a salinity of 35°/eo. After this water mass moves into the Caribbean, it is virtually trapped, with only 2 small passage out through the Yucatan Strait. The water remains in the Basin and is slightly different in silicate content from its origin, the NADH, found outside the Caribbean Basin, For this reason, some people choose to call this deep, cold water the Venezuela Bottom Water. In some portions of the Caribbean Basin, this water mass is over 3000 m thick.

3.0.1.4 Tides

The tides on the Caribbean coasts of Puerto Rico are generally of the mixed diurnal type, with a small semidiurnal component. An amphidromic (nodal) point of the principal lunar semidiurnal (Mj) tidal constituent lies near Punta Tuna (Atwood et al., 1976; Dietrich, 1963; Defant, 1961). The nearness to the node implies minimal tidal motion. In addition, as Punta Tuna fs on the somewhat exposed eastern side of the island, the tidal system affecting the North Atlantic (with its anphidromic east of Newfoundland) may also affect our site. The result could be @ moderately confused tidal current over our area of interest.

The tidal currents in the Punta Tuna area are expected to move generally east and west, west during the flood tide and east during the ebb tide. The actual result of this tidal motion on the prevailing water motion at Punta Tuna is still unknown.

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3.0.1.5 Productivity. Productivity, which can be defined as the rate at which biological organisms store energy, usually decreases from the coastal margins to the open ocean (Davis, 1973). In general, tropical ocean waters have low productivity and show little variation with changing seasons of the year. Raymont (1963) states that two compounds, phosphate and nitrate (together with nitrite and ammonia to a lesser extent) are clearly of extreme importance to marine plant growth. In general, values of both these essential nutrients in the upper photosynthetic zone, which is the only zone directly concerned with primary productivity, are low and fairly constant in sub-tropical and tropical waters. It would appear, therefore, that the tropics and subtropics would have low productivity. However, the overall productivity in tropical regions, considered on a yearly basis, may be much greater than would first appear, since the nutrients are recycled rapidly in the warm tropical water and thus pass through several cycles during the course of a year. In tropical seas around the world, the standing phytoplankton crop tends to be low at any one time, but the thickness of the photosynthetic zone is considerably greater in tropical seas due to the lower turbidity, than in other waters (Riley, 1939). The portion of the water column with sufficient sunlight to photosynthesize is called the euphotic zone (Duxbury, 1971). It reaches down to about 100 m in depth. At the OTEC plant site the euphotic zone corresponds closely with the Tropical Surface Water (TSW). This water mass may have a thickness of up to 100 m and its characteristics have been discussed previously in Section 3.0.1.3 in this report. Almost all phytoplankton activity takes place in the first 100 m of depth off Punta Tuni

3.0.1.6 Zooplankton. In the Caribbean, the most common groups of zooplankton are, in order of numerical importance, copepods, chaetognaths, and pteropods. Approximately 450 species of oceanic calanoid, harpacticoid and cyclopoid copepods have been reported from the Caribbean. Although the

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number of calanoid species is far greater than that of cyclopoids, the latter nearly equal calanoids in total number of individuals. The most numerous cyclopoids, Farranula carinata and Qithona plumifera are more than twice as abundant as the top ranking calanoids, Clausocalanus furcatus and Mormonilia minor. Harpacticoida, the smallest group of planktonic copepods, includes the third most numerous form Microsetella rosea (Michel, Foyo and Haagensen, 1976).

There are 18 species of chaetognaths prevalent in tropical oceans, five rare bathypelagic forms, Bathybelos typhlops, Eukronia hamata, E. proboscidea, Sagitta megalopthalma and S. planktonis, and two neritic species which are sometimes swept into oceanic waters, S. helenae and S. hispida. The most common pteropods encountered around Puerto Rico are: Limacina inflata, L. trochiformis, Creseis acicula, Styliola subula, Diacria trispina, Cavolina inflexa and Desmopterus papili

3.0.1.7 Dissolved Oxygen. The dissolved oxygen concentration throughout the Caribbean water column varies little throughout the year. Dissolved oxygen in surface waters generally ranges from 4 to 5 ml/l. This is a highly saturated condition. From this high, mixed layer value, there is a steady decrease, caused by both the length of time since the lower waters have been oxygenated?at the surface and the depletion of the available of oxygen by decomposition of descending dead and detrital matter. This oxygen minimum occurs at about 500-700 m depth, and has an oxygen concentration of around 2.5-3.2 ml/1. Below the oxygen minimum, the concentration increases, due to the high oxygen carrying capacity of the cold, less saline North Atlantic Deep Water. The values at about 1000 m may rise to about 3.5-4 ml/1, and at 2000 m, the dissolved oxygen concentration may rise to as much as 5.5-6 ml/1 (Atwood et al., 19765 Wust, 1964),

3.0.1.8 Nutrients. Tropical surface waters, such as the Caribbean, are usually deficient in many of the nutrients

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necessary for phytoplankton growth. The photosynthetic processes remove the nutrients from the upper, photic zone. As there is little land mass to produce organic runoff, the replenishment is very poor. Furthermore, nutrients are lost to the upper water column as detritus and dead organisms sink below the photic zone and continue to the bottom. Therefore, generally, the Upper Mixed Layer nutrient concentrations are quite Tow in (these) tropicel and subtropical seas and remain Jow to at least about 200 m depth. Below this depth, the concentrations are seen to rise to maximums at depths of 600 and below. Typically, the ratio of maximum values to mininun values may be about 15:1 for phosphate, 10:1 for silicate, and about 25:1 for nitrate. Although these ratios are by no means fixed, they are typical of what is measured in Caribbean waters (Atwood, et al, 1976).

3.1 Temperature Results

During each cruise, an attempt was made to collect at least four sets of discrete temperature data at the Punta Tuna benchmark site, Station "BY, Usually the four sets consisted of two Hydrocasts (to about 1000 m) and two Biocasts (to about 400 m). On all the cruises, except the first, several xBT's were taken at the Benchmark station, as well as other stations in the nearby area. Figures 8-13 show temperature versus depth profiles for each of the six hydrographic cruises. The profile shown in each figure is the average temperature, as measured with the reversing thermometers, from the four casts at the Benchmark station during that particular cruise. There is a moderately strong seasonal thermocline seen during all but the June 1979 cruise. The April data shows some reduction in the thermocline strength over that seen during the rest of the year, but during June, no thermocline was observable at all. Thermal variations with depth are also present through-out the year, but the next set of figures are used to show this variation more clearly

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?TEMPERATURE (°C)

DEPTH (ml

Fig. 8 ~ Tenperature profile at Punta Tuna using average reversing thermometer values for the cruise of August, 1978,

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?TEMPERATURE (°C)

DEPTH (end

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Fig. 9 - Temperature profile at Punta Tuna using average reversing

themoneter values for the cruise of October, 1978.

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DEPTH (ml

Fig. 10 -

?TEMPERATURE (°C)

Temperature profile at Punta Tuna using average revers~

?ing thermoneter values for the cruise of December, 1978,

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?TEMPERATURE (°C)

DEPTH (m)

Fig. 11 - Temperature profile at Punta Tuna using average

reversing thermoneter values for the cruise of

February, 1979,

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?TEMPERATURE (°c)

DEPTH mn)

Fig. 12 - Temperature profile at Punta Tuna using average

reversing thermoneter values for the cruise of

April, 1979.

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?TEMPERATURE (°c)

DEPTH (ml

t

Fig. 13 - Temperature profile at Punta Tuna using average

reversing thermoneter values for the cruise of

dune, 1979.

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Figure 14 shows a time series of the temperature at the Benchmark site (as taken from the reversing thermometer averages) throughout the year. The temperature of the upper waters was about 29°C during October 1978, over 27°C from August to December 1978, and again in June of 1979. During February and April 1978, the upper water temperature was about 26.4°C. Although there is some experimental error in both the depth determination and the temperature determination, there still appears to be a slight rise of the 26°C isotherm during April and June. Also, there appears to be a vertical migration of the 6°C isotherm throughout the year, however, an error in the December value alone could account for much of this cold water variation.

Finally, Figures 15-20 show the time series of tempera-ture during each cruise. Each of these figures are made by using all the XBT and all the reversing thermometer data made during each respective cruise. Usually there are at least four thermometer sets per cruise and at least eleven XBT casts. The reversing thermometer data correspond to the four aforementioned casts at the Benchmark site and one additional cast at the Vieques station. The XBT casts were taken at the Benchmark station, Vieques, and a few nearby locations, seen in Figure 3. Exceptions to this general trend are the first cruise, which was terminated early due to the equipment problems, and had a nonfunctioning XBT recorder, the fourth cruise, which was terminated early due to a collision at sea, and the last cruise, which has many other stations shown. A further description of the last (dune 1979) cruise will be shown in Section 6.0. In these thermal time series displays (Figs. 15-20) the thermometer data are shown as dashed lines and the XBT data are shown as solid lines. The intention in showing these figures are to give the reader our actual temporal variation of the water temperature during the cruise. Also, an easy comparison is possible between the XBT values and the much more accurate thermometer values, AS to be expected, the X8T values show a much greater variation than the thermometers, pointing out a potential hazard in

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Fig. 14°- Tie series of average reversing thermometer results

at Punta Tuna from August, 1978 to dune, 1979.

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Fig. 15 - Time series of reversing thermoneter results at Punta

Tuna during the cruise of August, 1978.

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Fig. 16 - Time series of reversing themoneter and XBT results

during the cruise of October, 1978.

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Fig. 17 - Time series of reversing thermoneter and Y8T results

during the cruise of Decenber, 1978.

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Fig. 18 - Time series of reversing thermometer and XBT results

during the cruise of February, 1979.

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Fig. 19 ~ Time series of reversing thermoneter and XBT results

during the cruise of April, 1979.

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Fig. 20 - Time series of reversing thermoneter and X8T

results during the cruise of dune, 1979.

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relying on the XBT results alone. Although the average results of both series are similar, the variation of the indiyidual Xx8T values should be viewed in the proper perspective,

3.1.1 Thermal Resource

Figure 21 shows a tenperature vs. depth profile based on all the thermometer data during our measurement program, In this figure, the ranges of all thermometer values are also shown at each depth as well as the standard deviation from the mean for depths down to 100 m, The average profile exhibits a thermally mixed layer, with an obseryable thermo- cline, The range of observed values were about 27,572 C. at the surface but the spread increases considerably at about 125 m depth to 23°32 £5. From this depth, the spread of values generally decrease to less than 0.2 C*. The standard deviation from the mean in the upper water is about +1 c*.

Also shown in Figure 21 is a conversion from actual temperature to usable temperature-difference (Thermal Resource). vom the bottom auxiliary axis, the Thermal Resource can be easily seen to exceed 20 C* from 50 m to 1000 n.

Figure 22 is a time series of the Thermal Resource at the Punta Tuna Benchmark site, as it affects the OTEC plant. The Thermal Resource is that temperature difference that can be used by a plant to actually run the thermal engine and produce power. Usually the Thermal Resource is considered as the temperature difference (in Centigrade or Kelvin degrees) between the surface water and the water at 1000 m depth. As these results may be used to formulate design criteria, Figure 22 contians not only this information, but also the difference from the surface to 900 m depth. As can be seen in the figure, the difference in using 900 m over 1000 m reduces the Thermal Resource about 0.5 C' Realistically, some depth other than the surface should be used for the warm water intake value. In the case of this Puerto Rico data, the only change that would result would be a decrease in the available Thermal Resource with depth below the surface in

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Fig. 21 - Temperature profile of the average thermometer data

taken at Punta Tuna for all cruises, from August, 1978

?to June, 1979, (The maximum and minimum temperatures

at each?depth are also shown).

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June (due to the aforementioned lack of thermally mixed layer at that time), and a somewhat reduced effect in April. The loss of Thermal Resource in June could be as much as 0,4 C* in 20 m depth.

With regard to the actual variation of the Thermal Resource, the figure clearly shows a minimum in late winter (our February cruise), and @ maximum in early Autumn (or late summer), These results are similar to those seen in the literature, and our values serve to help confirm the histor-ical data (Wolff, 1978), The Thermal Resource varied from 20.8-23.4 C* (1000-0 m case), with a mean of 22.1#1.0 C*, and 20.3-23.0 C* (900-0 m case), with a mean of 21.541,0 C*.

3.2 Salinity Results

During each cruise an attempt was made to collect at least four sets of water samples for subsequent salinity determination as a function of depth. As with the temperature data, the four sets consisted of two Hydrocasts (to about 1000 m) and two Biocasts (to about 400 m). Also, when pos~ sibles extra casts were taken either at the Vieques station, or Station *F" or both. Figures 23-28 show vertical profiles of salinity for each of the six hydrographic cruises, In each figure, the salinity displayed in the profile fs the average of the four casts, when possible. All the profiles show the same general shape, with a variable upper water salinity, a salinity maximum of about 37°/se at 125-150 m, and a gentle salinity decrease to about 34.9-35.0°/c, at about 700 m and below. In cases where the spread in the salinity determination during a particular cruise exceeded. +0,02°, at a given depth, the data spread 1s also shown in the figure.

Figure 29 1s a time series description of the salinity profiles throughout the year, These values were made using the salinity averages for each cruise, as were the previous figures. The noteworthy points in this figure are the large saTintty yartations in the upper water throughout the year, and the lack of variation elsewhere in the water column.

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SALINITY (%e)

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Fig. 23 - Average salinity profile at Punta Tuna for the cruise

of August, 1978. (Naximun and minimum observed

salinity values are shown at each depth).

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SALINITY (%o)

DEPTH (m)

Fig. 24 - Average salinity profile at Punta Tuna for the cruise of

October, 1978. "(Maximum and minimum observed salinity

values are shown at each depth).

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SALINITY (%0)

DEPTH (m)

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Fig. 25 - Average salinity profile at Punta Tuna for the cruise

Of December, 1978. (Maximum and minimum observed

?salinity values are shown at each depth).

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SALINITY (%e)

DEPTH (mi

Fig. 26 - Average salinity profile at Punta Tuna for the cruise of

February, 1973. (Maximum and minimum observed salin{ty

values are show at each depth).

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SALINITY (%e)

DEPTH im)

Fig. 27-- Average salinity profile at Punta Tuna for the cruise

of April, 1979. (Naxinum and minimum observed salinity

values are shown at each depth).

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SALINITY (%0)

DEPTH (m)

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Fig. 28 - Average salinity profile at Punta Tuna for the cruise

of June, 1979. © (Maximum and minimum observed salinity

values are shown at each depth).

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Fig. 29 - Time series of the average salinity values observed at Punta Tuna from August, 1978 to June, 1979,

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The salinity of the upper water is seen to vary from about 34.7°/o0 in October to 36,2°/.. in April, As the depth of the salinity maximum yaried Tittle, the salinity/depth gradient was quite high during the autumn and early winter, the period of lowest surface salinity, The remainder of the water column seems to be experiencing only small changes in salinity throughout the year, and these changes may be a result of error in depth determination, rather than salintty. These results compare well with the temporal salinity variations discussed by Froelich et al,, (1978), in which they point out the strong functional relationship between the fluctuations in the Caribbean surface water salinity and the fresh water discharge from the Amazon and Orinoco Rivers,

Figure 30 shows the average vertical salinity profile for all the data taken at the Benchmark Station during our 6 cruises frem August, 1978 to June, 1979, Although the average salinity izself is not important, the observed spread of values shovs the entire range seen throughout the program, As expecte:. the spread is greatest in the upper water waters, covering 35.5')'3°/ee. In the vicinity of the maximum hato-cline, the annual salinity variation even exceeded the surface values, bu: again this may be a result of our inability to accurately determine the exact depth of the water sampling bottle in zis rapidly changing environment. In the vicinity of a large vertical gradient of salinity, a small error in depth of only @ few meters may appear to be large salinity excursion. With increasing depth, the observed data spread éecreased =nsiderably fron about #0,15°/,, at the salinity maximum toTess than £0,02°/., at depths greater than 800 m.

3.3. Density Results

Tee dasity of any water particle in the water column is prinariy @ function of the temperature and the salinity of that pacicle. The relative density of that particle, compared t 211 others, will determine the vertical tocation of that paticle within the column.

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SALINITY (%e)

DEPTH im)

Fig. 30 - Average salinity profile observed at Punta Tuna for all

eruises from August, 1978 to June, 1979. (Maximum and

isin observed saltnity values are show at each

depth).

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Figures 31-36 show the average vertical density pro-

files for each of the six hydrographic cruises. In all, but

the last cruise (June,1978), a thick isopycnic layer is

clearly defined at the surface, Just below this uniform layer

lies a relatively sharp pycnocline of about 2 sigma-t units

within Tess than 100 vertical meters. As the normal wind

field develops over the Caribbean, the mixing intensifies, enhancing the presence of a strong pycnocline. In the absence of mixing, the isopycnic layer may decrease to almost nothing.

Figure 37 is a vertical profile of the average density including a11 the data from this program. The average pro- File also shows an isopycnic layer at the surface, and a sharp pycnocline directly beneath it, Also shown, in this figure are the ranges of the density values determined for each depth during the sampling period. As usual, the maxinum variations are found in the upper, near-surface waters, with generally decreasing variations down to about 300 m, Below this depth there is less than +0,1 sigma-t units change at each depth throughout the year. This figure, and the preceding density profiles, combined with the temperature and salinity profiles can be used to make estimates of the density change due to heating and cooling of the water pumped through an OTEC power plant. Subsequent predictive models can be developed for ultimate depth determination of the effluent waters, relative to the existing ambient water column.

3.3.1 Mixed Layer Depth

The water intake for the evaporation of an OTEC plant, would draw the heat from the upper water layers of the ocean. As mentioned previously, the uppermost layer is usually in a state of vertically stable equilibrium, and is isothermal,

isohaline, and therefore, isopycnic (constant density) for

many meters down from the surface, It is important for the

uniformity of the intake water to know the depth of this

uniform layer.

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DENSITY (o;)

DEPTH im)

Fig. 31 - Average density profile observed at Punta Tuna during

the cruise of August, 1978.

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DENSITY (Gj)

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DEPTH Im)

Fig. 32 - Average density profile observed at Punta Tuna during

the cruise of October, 1978.

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DENSITY 1)

DEPTH im)

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Fig. 33 - Average density profile observed at Punta Tuna during

?the cruise of Decenber, 1978,

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DENSITY (c;)

DEPTH(m)

Fig. 34 ~ Average density profile observed at Punta Tuna during

?the cruise of February, 1979.

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DENSITY (oj)

DEPTH Im)

Fig. 35 - Average density profile observed at Punta Tuna during

the cruise of April, 1979,

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DENSITY (op

DEPTH im)

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Fig. 36 - Average density profile observed at Punta Tuna during

the cruise of June, 1979,

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DENSITY (0%)

DEPTH Im)

£ .

Fig. 37 ~ Average density profile observed at Punta Tuna for ali

cruises, from August, 1978 to June, 1979, (Maximum and

minimum values are shown at each depth).

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A variety of definitions for the Mixed Layer Depth (MLD), haye been put forward, but usually they al] determine about the same depth value, The reason being that the upper layer is usually well mtxed, and immedtately below this untform upper layer, the temperature, salinity, and therefore, the density all experience such a large vertical gradient, that almost any reasonable definition will yield about the same depth for the bottom of the mixed layer as it would mark the depth beginning of the gradient. An example of this uniformity of definition is seen in Table 1, For the Table, the MLD is determined supposedly, for each of our cruises, using a ten- perature criteria, a salinity criteria and a density criteria, all independent of each other, The temperature criteria is- that depth when the change from the surface temperature equals 1 C*5 this is shown for both the thermometer data as well as the average XBT data. The salinity criteria requires--a change of 1°/o5 from the surface value. The density criteria uses--a 1 sigma-t unit change from that of the surface. As seen in the Table, when the criteria can be applied, as in most of these cases, the results are quite similar for all the criteria. With only a few exceptions, the difference in values for all the criteria was less than 10 m depth. The non-comply- ing cases occur when the salinity was quite high already

(April) and was less than 1°/.. different from that value at the salinity maximum, and in June, when there was no uniform upper layer. Another interesting point to note from the Table is the MLO difference that would be calculated by using the XBT averages, as opposed to the thermal values, the salinity values, or the density values, all of which are much harder to compute and collect than are the XBT values, Gerierally, the average XBT results are close.

Using the results of Table 1, Figure 38 shows a time series display of the MLD throughout our measurement period. In general, the MLO remains greater than 50 m throughout the year, except during the early summer, where it moves quite close to the surface. The comparison between our results and

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Fig. 38 - Time series of the Mixed Layer Depth at Punta Tuna

from August, 1978 to dune, 1979. (Average historical

values. are a10 shown).

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the most probable historical values are also seen not to

differ considerably,

3.3.2, Temperature/Salinity Relationships

Although temperature and salinity are riot necessarily controlled by the same mechanisms in the ocean, there do exist rather reliable interrelationships between the two, Figure 39 shows the temperature/salinity, or T/S diagram for the six cruise averages. Although the cruises were taken during separate times of the year, many T/S characteristics remain quite constant during this time. The Tropical Surface Water (TSW) ts the most vartable, as seen by the scatter in the upper portion of the Figure, The Subtropical Underwater (suW). is relatively constant tn its characteristics, and the vertical range of this water mass, not easily seen in this Figure, {s usually only affected by severe weather conditions, The two deeper water masses, the Atlantic Intermediate Kater (ATW), and the North Atlantic Deep Water (NADH) have Tittle seasonal variation.

Another T/S relationship can be seen in Figure 40, This is a time series of the upper 40 m for temperature, salinity, and density during the time of our measurement program, From this type of display, one can easily note the inverse yari-ation between the temperature and the salinity throughout the year. Another easily discernible relationship is the matching of the density with the salinity, not the temperature, as might be expected. In the density determination, the salinity is seen to be a much stronger functional force than is the

temperature. The results of a figure such as this must be

used to determine effluent mixing and dispersal depth,

3.4 Mater Current Results

During each cruise a set of water current profiles were

taken at least 4 times while at the Benchmark station, Also,

during the program year, 2 current meter moorings were

implanted near the Benchmark,

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SALINITY (%e)

TEMPERATURE (°C)

Fig. 39 - Temperature/Salinity diagram of all data observed at

Punta Tuna from August, 1978 to June, 1979.

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Fig. 40 - Tine series of sea surface-water characteristics at

Punta Tuna observed from August, 1978 to June, 1979,

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3.4.1 Current Meter Profiles

On the first cruise, current profiles were taken while the vessel was drifting. Starting with the October 1978 cruise, the measurements were made with the vessel secured to the mooring. The results of the initial measurements were strongly influenced by the drift of the vessel. An error analysis using the best available estimates for the instrument accuracy, the instrument readability, and the vessel position finding capability (the largest error of the three) produced possible errors in excess of +10-15 cm/sec and entire quadrants of direction. Also, it is possible that our meter might be adversely affected by being pulled through the water by the drifting vessel, and having the plane of the Savonius rotor of the meter not necessarily in the same plane as the water flow. During the program, the current meter was upgraded to increase the readability by expanding the scale 3-fold. This did not necessarily change the precision of the meter, but increased our ability to read the speed values in the 0-10 cm/sec range considerably.

To compliment the current profiles, the north-south components of the geostrophic current have been calculated using the data taken at both Punta Tuna (Station "B"), and Vieques (Station "V"). These calculations have been made for October and December, 1978, and April and June, 1979. Geostrophic current calculations are most accurate outside the influence of surface meteorological forcing, away from boundaries (such as land), and at mid latitudes, In spite of these shortcomings, the results of the calculations, shown in Table 2, compare well with the north-south component of the current profiles. In the calculations, the Tevel of no motion is assumed to be 800 m deep. This assumption is based soley on the maximum measured depth, not on any physical observation.

Figures 41-52 show modified stick-type diagrams of the current profiles for each cruise, as well as time series current patterns in N-S and E-W component form for each cruise.

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TABLE 2

North-South Components of Calculated Geostrophic Currents

Between Punta Tuna and Vieques

(tH signifies North, Speed in ca/sec)

Cruse Cruise Cruise Cruise

DEPTH Oct. 1979 Dec. 1978 Apr. 1979 June 1979

30 -19 22 8 22

50 -13 ?14 3 12

5 -5 -7 +2 10

100 -1 -6 +5 12

125 -3 -5 4 12

150 74 -4 41 10

175 -3 -3 -1 9

200 -3 -3 a 9

250 -2 -3 +1 10

300 ° -3 +2 12

400 0 -3 42 10

500 +1 -3 a 10

600 +2 -3 a 10

700 o -2 o 7

s00 ?0 noe non nom

900 ° ?1

1000 1 24

Assumed Level of No Motion

fs 800 m

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el drifting

taken at Punta Tuna

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Fig. 42 - Time series of the water current profiles taken at

Punta Tuna during the cruise of August, 1978.

(Estimated tidal condition and current is also shown).

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Fig. 44 - Time series of the water current profile taken at

Punta Tuna during the cruise of October, 1978,

(Estimated tidal condition and current is also shown).

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Fig. 46°~ Tine series of the water current profile taken at

Punta Tuna during the cruise of Decenber, 1978,

(Estimated tidal condition and current is also? shown),

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Time series of the water current profile

taken at Punta Tuna during the cruise of

February, 1979. (Estimated tidal condition

and current s'also shown).

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Fig. 50 - Time series of the water current profile

faken at Punta Tuna during the cruise of

April, 1979. "(Estimated tidal condition

and current? is also shown).

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Each of the stick-type diagrams has both the speed and direc-

tion of the measured water flow at each sampled depth for the

profiles measured during that respective cruise.

The speed scale of the first cruise, August 1978, is

1/2 that of the other cruises. The scale difference is due to the high speed indicated during the measurements. These higher speeds were probably due to the aforementioned errors induced by vessel drift. The results of these measurements are seen in Figure 41. In this figure, alone, the vessel drift vector is also shown for comparison. As seen in Figures 41 and 42, most of the water current results from this cruise were probably influenced quite a bit by the drifting vessel. However, from the lower portion of Figure 41, the effects of flood or ebb tide may still be seen in these results. The first two profiles were measured during periods of flooding tidal current (to the west), the third was measured during the ebbing tide. This tidal shift may explain the westerly to northerly shift in the upper water.

Figures 43 and 44 display the current profile results of the 2nd cruise, in August 1978. During this cruise, as in all subsequent operations, the vessel was moored during the current profile operations. The stick-type diagram (Fig. 43) shows the surface water mass (TSW) shifting from westerly to easterly,, both at 10-15 cm/sec. The westerly movement is seen during both the flood (first) and ebb (last) periods.

The next lower water mass, identifiable as the Subtropical Underwater (SUK), is also seen to change from easterly to westerly and back, with speeds of about 10 cm/sec. Unfortunately, the timing of the profile measurements was not necessarily optimum for determining the tidal effects. The water in the transition zone between the SUW and the Antarctic Intermediate Water (AIW), between 250-500 m, moves generally westerly at about 5 cm/sec (Fig. 43). The results of Table 2 confirm the predominantly southerly flow.

Figures 45 and 46 show the results of the current profile measurements for the December 1978 cruise. Again, considerable current reversal is seen, but either the time (first profile),

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was not ideal, as it corresponded to a projected slack tidal current period, or the speed indicator did not function, as in the third profile. In any case, there is a definite westerly motion down to depth of about 300m in the second profile, which should correspond to an ebbing tidal flow (easterly). The directions shown for the third profile are nearly all easterly for the upper 300 m. This is estimated to correspond to a flood tidal flow. All the speeds were about 10 cm/sec, even for the deeper waters. In all cases, during this cruise, the 500 m water was seen to move westerly, with @ strong northerly flow seen at 750m. The tine series displays show E-W oscillations in the upper 200 m. The southerly component is also seen in Table 2 as in Figure 46,

The February 1979 cruise results can be seen in Figures 47 and 48, There are reversals at virtually all depths, but the upper water seen to move westerly during the flood tide and easterly during the ebb. The transition zone between the Subtropical Underwater and the Antarctic Intermediate Water (200-700 m) has speeds of 5 cm/sec and also has direction reversals, but opposite to those of the upper waters. Water at the 700 m depth varied from southwest to northwest with speeds of about 5 cn/sec.

The April cruise resulted in only 1 current profile, seen in Figures 49 and 50. Throughout most of the water colunn the flow was westerly except at 700 m, were the direc tion was almost due east. The upper waters, the TSH and the SUN, down to about 150 m, showed speeds of 10-20 cn/sec, while the lower water moved at 5-10 cm/sec. The time of the measurement should have corresponded to a strong ebb current flow. The geostrophic calculations seen in Table 2 show similar north-south component distribution as seen in Figure 50.

The final, or June 1979 cruise, had a full complement of 4 current profiles, and they were all timed specifically correspond to ebb or flood tidal current periods, The ebb period (first two profiles) of Figures 51 and 52 show much

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of the upper water moving generally easterly. This easterly flow is also seen during the flood tide periods. Almost all the water below 200 m is moving easterly or northerly, except the first profile, which shows a northwest component. The northerly components are also seen in Table 2.

Figure 53 shows the frequency of occurence of the water current within compass octants (current rose) for 4 depth ranges at Punta Tuna. The depth ranges that are considered are: 25-50 m (Tropical Surface Water), 100-150 m (Subtropical Underwater), 250-500 m (Transition Zone), and 650-750 m (Antarctic Intermediate Water).

The TSW appears to have a definate bimodal distribution of water current directions. About one-half of the observa- tions had westerly or northerly flow. This is to be expected with the predominant easterly winds. However, about one-third of the observations showed an easterty flow, directly opposing the winds. Although these reversals have been seen by others (Lee et al., 1978) it was not expected, as the ves- sel never moved east of the mooring, only west. The tidal motion in this area is expected to be E-W in character, and this also could help to explain the large number of easterly observations.

?The observations taken from within the SUW showed a dominant westerly flow more than one-third of the time, with a weaker easterly component and a mixed distribution between these two. This bimodal distribution may also be a reduced tidal oscillation, as above. However, as this water mass is thought to come from the Bermuda area, North of Puerto Rico, and moye into the Caribbean through the various passages (i,?., Mona to the West, Anegada to the East of Puerto Rico), the water could be expected to have components of W, SW, S, SE, and E. Unexpected directions would be N and NE. Both of these directions were seen. Also, there were no southerly directions observed. As this water mass, and below, may contain an OTEC plant discharge (mixed cold and warm together), this confusion must be cleared up.

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Fig. 53 ~ Current roses of water current direction using all the current profile data taken at Punta Tuna from August, 1978 to June, 1979. (Four vertical depth bands are considered).

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The water in the Transition Zone is seen to be moving with a very strong predominance toward the West, as this water is a mixture of the SUW above, and the AIM below, it may be entering the area from either the North as mentioned above, or from the East through the passages of the Lesser Antilles. Therefore, almost any water direction might be possible,

and that is what is seen.

Finally, the AIW direction appears to be generally northerly (NE, NW). As this water is thought to enter the Caribbean through the Lesser Antilles and move generally westerly and northerly, the dominant directions are explain-able, with the water moving past Punta Tuna towards either the Yucatan to the West or the Jungfern Sill to the northeast.

The other directions almost appear as slight ?notse" in the measurenents.

In general, the results also indicate that at least the north-south component of the water moving past Punta Tuna may be somewhat characterized by geostrophic flow in the mid-to-deep water.

Figure 54 shows the frequency distribution for the observed speeds in the same four depth ranges seen in Figure 53; 25-50 m, 100-150.m, 250-500 m, and 650-750 m. The TSW (upper depth range) has a distribution tending toward the higher speeds, with an average speed of about 10 cm/sec. The SUW (100-150 m) shows a slight shift toward the lower speeds, averaging about 8 cm/sec. As expected, the two lower depth bands show decreasing speed with increasing depth. At the 250-500 m depth, the average speed is about 7 cm/sec, and at the 650-750 m depth, the speed averaged only about 5 cm/sec.

3.4.2 Water Current Mooring

The description of deep water circulation is based on the velocity data retrieved from in-situ meters recovered from depths of 215 and 332 meters at Station A, Bottom depth at this station was approximately 1216 meters. The sampling

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Fig. 54 - Frequency of observed speeds using the current profile

data taken at Punta Tuna fron October, 1978 to dune,

1979. "(Four vertical depth bands are considered).

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rate of both meters was at 10 minutes intervals; the records

recovered extend from 6 January to 10 February, 1979. Data

points from the first and last days in the records were dis-
carded in order to prevent the inclusion of spurious effects caused by deployment and retrieval operations of the meters.

Conventional methods of current flow analysis were employed to describe and determine circulation patterns and their variability. These included resultant velocity vectors statistics, histograms, stick plots, progressive vectors diagrams, and vectorial components graphs in order to smooth out superimposed water flow oscillations, Energy spectral analyses could not be performed as programmed owing to persistent malfunction of the computer at the last: stages of the analysis.

The analyses revealed the following general statistical results:

1. Currents flow, direction and speed, are highly variable at both monitored depths. Direction statis-
tics indicate that the flow is almost equally distrib-
uted around the compass rose.

2. Average current speed at a depth of 215 meters is about 7 n/sec. Resultant direction angle is 8.2 degrees azimuth (NNE). Average resultant current stability is 93.9%, with speeds ranging from 1 to 60 cm/sec (Fig. 55).

3. Average current speed at a depth of 332 meters 1s approximately 5,3 cm/sec. flowing in a NNE (12 degrees azimuth) direction. Average resultant current stab{1-

ity 18 94%, with speeds ranging from 1 to 30 m/sec

(Fig. 55).

4, Tidal, inertial and longer period oscillations

(days and weeks) are superimposed in the current

structure.

The discussion of the graphs, diagrams and statistical

tables that follows demonstrate these general results,

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Fig., 55 - Currents resultant-vectors rose.

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Table 3 tabulates the data points velocity statistics

for the 215 meters-depth current meter. Record length is for 786 hours or a total number of 4704 observations, The speed range at this depth extends from 1 to approximately 70 cm/sec (one data point) with a direction distribution covering the whole compass rose. Statistics indicate that the highest percentage, 41.3%, of current speeds lie within the 1 to § cm/sec ranges the average speed for the whole record length was 7.13 cm/sec as shown in Table 4. Current direction statistics indicate that flow is almost equally distributed among each quadrant; the highest cumulative Percentage occurs from 45 to 135 degrees azimuths (N to ESE) with another peak at the 270 to 300 degrees (NW quadrant) interval. The highest direction relative frequency percent-age was 5.8% at the 75-90 degrees (E) interval. Average current flow direction (Table 4) is at an angle of 8.24 degrees T (NNE) with an average speed of 7.13 cm/sec. The histograms for the data in Table 3 are shown in Figure 56; the cumulative frequency curve shows that 80% of the current speed values are below 10 cm/sec.

Current velocity statistics for 1 hour averaged data Points at a depth of 215 meters are shown in Tables 5 and 6. The total number of observations was reduced to 784 through the averaging and velocity resultants calculations, The average stability of current flow for an average speed of 7.13 cm/sec and an average resultant velocity of 6.90 cm/sec flowing in a 8.24 degree azimuth (NNE) is of about 93.9%, the values ranged from 99.99 to 8.47%. Direction relative

distribution percentage is 6.3% in the 270-285 degrees range

interval (WNW); the dominant azimuths are still between 60

and 120 degrees (? quadrant). Figure 57, the histograms for

12 hours averaged data points, illustrate that the two

directions peaks become more apparent in the averaging

Process.

The statistics for the data points recorded at a depth

of 332 meters are shown in tables 7, 8, 9 and 10; and the

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TABLE 4

Current's data-based statistics for

the 215 meters depth level.

Number of Observations... 4,708

Average Speed (cm/sec)... 2... 7,23

Average Direction (deg)... .- . . - 008,24

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Fig. 56 - The 215 meters depth level direction, speed, and

cumulative speed distribution histograms,

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TABLE 6

One hour current's resultant vectors:

Data-based statistics for the

215 meters depth level

Average Velocity (cm/sec)... 2... 7,13

Average Resultant Velocity (cm/sec). . 6.90

Resultant Direction (deg)... . . . . 008.28

Average Stability (%).-....... 93.91

Stability Range (2):

Maximum 2... . 99,99

Minimum. 2... 8,47

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Fig. 87 - Direction, speed, and cumulative speed distribution

histograms for 12 hours averaged data points from the

215 meters depth level.

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TABLE 8

Current's data-based statistics for

the 332 meters depth level.

Number of Observations... . 4 5 4,695

Average Speed (cm/sec)... .. 5.28

Average Direction (deg) . - 1... 012,13

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TABLE 10

One hour current's resultant vectors:

Data-based statistics for the

332 meters depth level.

Average Velocity (cm/sec). . . .

Average Resultant Velocity (cm/sec)

Resultant Direction (deg)... . .

Average Stability (%) . .

Stability Range (%):

Maximum.

Minimum .

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Fig. 58 - The 332 meters depth level direction, speed, and

cumulative speed distribution histograms.

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histograms of Figure 58. Table 7 indicates that a higher percentage (48.22) of current speeds Iie at the 5 to 10 cm/sec interval. The histogran in figure 58 shows the slight differences that were found between the results of the 215 mand 332 m depths; 96.1% of all speeds at the 332 m are below 10 cm/sec against 80% at a dépth of 215 meters. Current directions at the 332 m level are scattered over the compass rose with a dominant relative frequency percentage of 19.5 between the 75 to 120 degrees azimuths (E quadrant); the highest percentage, 7.1%, is found in the 75-90 degrees interval (ENE to £), The average speed (Table 8) is of about 5.3 cm/sec in a NNE (12.13 degrees) direction; current stability ranged from 8.9 to 100 percent, with an average stability of 94.02, when calculated for 1 hour current velocity resultants at an average speed of 5.29 cm/sec and an averaged resultant velocity of 5.09 ca/sec as shown in Table 10. Table 9 indicates that 97.6% of the 1 hour inter-vals speed averages are bleow the 10 cm/sec speed range.

Circulation patterns and variability at the monitored depths are evident in the velocity time series graphs

(Figs. 59 to 63), the stick plots (Figs 64 to 68) and the progressive resultant velocity vectors diagrams of Figures 70, to 81. All diagrams reveal a pattern of flow mostly dominated by tidal variations when compared with the pre-dicted tidal curves for Puerto Maunabo (Punta Tuna) as shown in. Figure 69.

In Figures 59 and 60, velocity variation curve at the 215 and 332 meters level respectively, two relatively con stant variations tendencies can be observed: (1) with few exceptions minimum speeds usually occur at the time of low tides (2) when compared with the tidal fluctuations of Figure 69 the highest speeds are encountered during the monthly spring tides periods. Higher speeds coincide with flood tidal stages; low-low tides consistently occur around midnight hours. These observations become more evident in the 6 and 12 hours averaged speeds graphs of Figure 61 and 62,

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Other periodic fluctuations that are superimposed on the record prevent exact tidal correlations.

The current velocity-tidal fluctuations correlations is more apparent in the stick plots of Figures 64-68. Observe that greater speeds (vector length) occur in three distinctive periods of the record length: the first from the 8 to 12 of January; the second from the 25 to the 30 of January; and the third from February 5 to 9. Figure 69 indicates that these periods coincide with monthly spring tides. In general, the changes in direction closely correlate with the ebb and flood stages of the tides. Ebb flow direction is toward the southern quadrants (SE, S, SH), while flood directions are mainly toward northern azimuths (NW, N, NE). Figures 65 and 66 show this ebb and flood flows directions through the 6 and 12 hours resultant vectors diagrams at the 215 meters level. Similar current vetocity-tide general correlations can be observed in the stick diagrams of Figures 67 and 68, the resultant vectors plots for the 332 meters level, Tidal forcing seems to be the dominant process affecting the speed and direction of water flows at the monitored depths. Tides along the south coast of Puerto Rico are mainly diurnal with a semi-diurnal component superimposed (mixed tides) as shwon in Figure 69.

Progressive resultant vectors diagrams (Figs. 70 to 81) illustrate much better the effects of tidal forcing in the circulation at the 225 and 332 meters depth levels. Super-imposed periodic fluctuations-other than tidal- can also be surmised from these diagrams. For example: in Figure 70, the progressive resultant vectors diagram at a depth of 215 meters, there is a trend of variation in speed and direction every 6 to 7 hours (semi-diurnal tide component) and a larger one from 12 to 13 hours (diurnal tide), Larger loops are also apparent at intervals of approximately 37 to 40 hours. The calculated inertial currents periods for Tatitutde 18°N, the location of the Punta Tuna Site, is of about 36.9 hours. Thus, it seems that inertial currents

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Fig, 70 ~ Progressive current vectors dfagran:_ 1 hour

J intervals resultant vectors for the 215 meters

depth level,

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Fig. 70a - Progressive current vectors diagram: 1 hour intervals resultant vectors for the 215 meters depth level (continued).

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Fig. 706 ~ Progressive current vectors diagram: 1 hour

intervals resultant yectors for the 215 meters

depth level (continued).

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Fig. 70¢ - Progressive current vectors diagram: 1 hour

intervals resultant vectors for the 215 meters

depth level. (continued).

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Fig. 70d - Progressive current vectors diagram: 1 hour

intervals resultant vectors for the 215 meters

depth level. (continued).

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Fig. 70e - Progressive current vectors diagram: 1 hour

intervals resultant vectors for the 215 meters -

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Fig. 70f

Progressive current vectors diagram: 1 hour

intervals resultant yectors for the 215 meters

depth level (continued),

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Fig, 709 - Progressive turrent yectors diagram: 1 hour

intervals resultant yectors for the 215 meters depth Tevel (continued).

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Fig. 71 ~ Progressive current vectors diagram: 6 hours

intervals resultant vectors for the 215 meters

depth level.

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Fig, 71a ~ Progressive current vectors diagram: 6 hours

intervals resultant vectors for the 215 meters

depth level. (continued).

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Fig. 72 - Progressive current vectors diagram: 12 hours

intervals resultant vectors for the 215 meters

depth level.

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Fig. 73 ~ Progressive current vectors diagram: 24 hours

intervals resultant vectors for the 215 meters

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Fig. 74 - Progressive current vectors diagram: 36 hours

intervals resultant vectors for the 215 meters

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Fig. 75 - Progressive current vectors diagram: 48 hours

intervals resultant yectors for the 215 meters

depth level.

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Fig. 76 ~ Progressive current vectors diagram: 1 hour

intervals resultant yectors for the 332 meters

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Fig. 76a- Progressive current vectors diagram: 1 hours

intervals resultant vectors for the 332 meters

depth level. (continued) .

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Fig. 76b- Progressive current vectors diagram: 1 hours

intervals resultant vectors for the 332 meters

depth level. (continued).

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Fig. 77 - Progressive current vectors diagram: 6 hours

intervals resultant vectors for the 332 meters

depth level.

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Fig. 78 - Progressive current vectors diagram: 12 hours

intervais resultant vectors for the 332 meters

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Fig. 79 - Progressive current vectors diagram: 24 hours

intervals resultant vectors for the 332 meters

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Fig. 80 - Progressive current vectors diagram: 36 hours

) intervals resultant vectors for the 332 meters

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Fig. 81 -

Progressive current vectors diagram: 48 hours

intervals resultant vectors for the 332 meters

depth level,

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are also affecting the circulation pattern at the monitored

depths, Smoothing out the velocity data by averaging

demonstrate that after the tidal cycle have been "averaged

out" higher period oscillations are still present; see

Figures 71 to 75, which {}lustrate the resultant circulation

at the 215 meter level after averaging the 6, 12, 24, 36,

and 48 hours resultant vectors, respectively, Observe that

even after 48 hours there are higher periodic variations

ranging from about 4 to 12 days.

The above discussion of the 215 meters level progressive resultant vectors diagrams apply to Figures 76 to?81, the circulation diagrams at a depth of 332 meters.

To determine the higher periodic, superimposed variations on the general circulation, which they might not be immediately apparent in the smoothed-out progressive vectors diagrams, the vectorial components of the resultant vectors were plotted as in Figures 82 to 87. The north and east vectorial conponents of the smoothed-out resultant vectors for 24, 36, and 48 hours were plotted against time at both depths. Figures 82 and 83 illustrate the vectorial components after the 24 hours oscillations (tides) have been smoothed-out. The inertial component is still present: there are periodic fluctuations of. approximately 36 to 40 hours (2 1/2 days intervals) with some longer oscillations of several days periods. After the 36 hours components have been averaged out (Figs, 84 and 85) oscillations with periods ranging from 4 to 12 days, which also appeared in the 24 hours curves, remain in the record. It is not Known why the east-west component smoothed-out more readily than the north-south component which, even after 48 hours, still con tians large periodic variations (Fig. 87). It can only be Surmised that eddy movements with periods ranging from days to weeks are also present superimposed in the general circualtion, Much more data than what {s now available is

needed to determine the source of the longer period oscil-

lations; only the small scale flow and fluctuations can be

interpreted at the moment.

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Fig. 86 - 215 m depth level 48 hours ?intervals vectorial components (cont.)

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It should be noted that resulting drift from 33-days current meters record 1s not necessarily representative of all currents measured during that time, Not only are currents of tidal and inertial periods present, but longer-period oscillations that are variable, steady, strong and/or weak at irregular intervals on the record cafi be present. These types of oscillations make interpretation of a current meter record questionable in terms of resulting flow.

Various investigators have reported east flowing currents at the Punta Tuna Site area (Atwood et al., 19765 Metcalf, 1976; Stalcup et al., 1975). Circulation patterns description at depths below the surface levels have been determined by geostrophic flow calculations. Sturges (1970) and Stalcup et al., (1975) reported that marked variations in both speed and direction at frequencies including seiche Periods, semidiurnal and diurnal tidal periods, and longer Periods of the order of days or weeks have been measured on the southern part of the Jungfern Passage, which encompasses the Punta Tuna Site area.

Metcalf (1976) describes the 200 to 400 meters water layer at the southern end of the Jungfern Passage as the 18 °C water where there is an oxygen maximum. It can be considered, according to Sverdrup (cited by Metcalf, 1976), as Tropical Atlantic Central Water having @-S characteristics intermediate between the more saline North Atlantic Central Water and the less saline South Atlantic Central Water. Circualtion at this layer supposedly is toward the Caribbean Sea, coming from the Atlantic through the Anegada Passage (Metcalf, 1976).

The present data suggest that the effect of several dynamic and submarine morphological forcing factors should be investigated in order to determine the long-term circilla-tion vartablility. These are as follows:

1. The action of tidal funnelling effects through the

Vieques and Jungern Passages,

154

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o

2. Presence of long-term Ekman's circulation effects at deeper. layers,

3. Effect of the submarine morphology in the are

4, The presence of seiches periods fluctuations and

5. The presence of long-period eddies,

To determine these forcing factors comprehensive, long-term currents measurements at deeper water levels and several locations in the area are necessary, Resultant water flow might possibly be in an opposite direction in deeper waters (east) to what is generally thought of at Present (westerly).

155,

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3.5 Dissolved Oxygen

During each cruise, samples for dissolved oxygen (D.0.) determination were taken at both day and night periods except for the first cruise (August 1978), which was terminated early with only the day-time samples being taken. The samples were usually taken around noon and midnight. The depths sampled extended from the surface to about 1000 m deep. Figure 88 shows the result of all the collected data, combining both the day and night results for all six data sets. This figure is included to show the general trend and scatter of the 0.0. data the the Benchmark station throughout the year. Generally the 0.0. level remained above 4 nl/1 from the surface downward below the pycnocline, and below the Subtropical Underwater. At, or near the core of the Antarctic Intermediate Water, 600-800 m deep, Ties the 0.0. minimum of 2.7-3.2 ml/1. The D.O. values then rise to almost the surface values (3.5-4 mI/1) at 950-1000 m. This general curve is well documented for the Caribbean (Must, 1964).

These 0.0. values indicate a high degree of saturation of oxygen at the surface (about 70%). The percent of saturation at the oxygen minimum depth is only about 30%.

Figures 89-94 represent the 0.0. profiles for each of the six cruises, consecutively. For each cruise (except August, 1978) both the day and the night values are shown. Generally, the night values average slightly higher than the day averages, but by only 0.1-0.2 al/1, as seen in Figure 95. This difference is not important biologically or chemically, when compared to the typical values of 3-4 mI/1. At two depths, nearly al1 the night values were higher than the day values. At the 50 m depth, 100% of the night values exceeded the values measured during the daylight hours. At about:

250 m depth, 80% of the measurenents showed night values higher than day values. Both of these depths may be important to an OTEC plant, and the reason for the day/night difference should be investigated. The 50 m depth frequently lies near the upper portion of the pycnocline, or the boundary between

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DEPTH Im)

DISSOLVED OxYGEN(?N)

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Fig. 88 - Dissolved oxygen profile for all data collected at Punta Tuna from August, 1978 to June, 1979,

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DISSOLVED 0x:

YoeN(?n)

DEPTHIm)

Fig. 89 - Dissolved oxyg

collected at P

cruise of Augu:

158

en profile for data

?unta Tuna during the

st, 1978.

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DISSOLVED oxyGeEN(?Ni)

DEPTH im)

Fig. 90 - Dissolved oxygen profile for data

collected at Punta Tuna during the

cruise of October, 1978.

---Page Break---

DISSOLVED oxyGEN (mln)

DEPTH im)

Fig. 91 - Dissolved oxygen profile for data

collected at Punta Tuna during the

cruise of December, 1978,

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DEPTHim)

DISSOLVED OxYGEN(?!)

Fig. 92 - Dissolyed oxygen profile for data collected

at Punta Tuna during the cruise of February,

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DISSOLVED OxYGEN(?N1)

DEPTHim)

Fig. 93 - Dissolved oxygen profile for data

collected at Punta Tuna during the

cruise of April, 1979,

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DISSOLVED oxyGen(?!1)

DEPTHim)

&

Fig. 94 - Dissolved oxygen profile for data

collected at Punta Tuna during the

cruise of June, 1979.

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DISSOLVED OxYGEN Im")

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g .

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DEPTH im)

Fig. 95 - Average dissolved oxygen profile for

all data collected at Punta Tuna from

?August, 1978 to June, 1979.

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the Upper Mixed Layer and the Subtropic Underwater. The

250 m depth is near the depth that a mixed discharge may

rest, at least temporarily during some temperature/salinity

conditions during the year.

Figure 89 shows a nearly constant 0.0. value throughout the Upper Mixed Layer. At the depth of the salinity maximum (about 150 m from Fig. 23), an oxygen maximum is also observed during the August 1978 cruise. From here downward, the 0.0. is seen to slowly decrease to 3.5 ml/1 between 450-550 m depth. Below this depth a sharp 0.0. discontinuity occurs, with a very low value of 2.7 m1/1 occurring at about 575 m. By 800 m the value has risen again to over 3.0 ml/1. uring the October 1978 cruise (Fig. 90), again an unusually high 0.0. value is seen at the salinity maximum depth. At this time, both the salinity maximum (Fig. 24), and the 0.0. maximum were closer to 100 m deep. During this cruise, the 0.0. values seem to have a more smooth and continuous decrease to the oxygen minimum of about 2.7 ml/1 near 600 m deep.

Figure 91 shows the high (4.1-4.3 ml/1) values of 0.0. throughout the upper 200 m. This occurred in spite of only 270m deep MLD. From-these high values, the 0.0. decreased smoothly (except for the night value at 470 m possibly a measurement error) to about 575 m. During this cruise the sampling missed the oxygen minimum depth, but it was probably between 575-750 m. The D.0. during February 1979 (Fig, 92) was 4.0 ml/1 or higher from the surface to about 300 Again, from this depth downward to about 575 m the 0.0. decreased smoothly. The oxygen minimum was located about

750 m deep at this time.

During the April 1979 cruise (Fig. 93), the upper 100 m had virtually constant 0.0. values throughout, with only a small decrease at about 150 m (4.5-4.3 ml/1). However, at 190 m, a sudden decrease is seen to almost 3.8 m1/1 during both the day and night sampling. Selow this depth the values rise to more typical values of about 4 m1/1 and slowly decrease downward as seen on the previous cruises. Neither

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temperature (Fig. 12) nor salinity (Fig. 27) show any abnor-malities at or near this depth that could be related to the high oxygen consumption, However, Figure 102 (which will be discussed in Section 3.6) shows abnormally high chlorophy11 values, about 5-10 times normal, at slightly more shallow depths of 100-125 m, As the chlorophy11 were seen in greater quantities at night only, apparently the large numbers of Phytoplankton were able to reduce the available oxygen by a measureable anount,

The June 1979 crutse (Fig. 94) had very high and very uniform 0.0, values (4.6-4.3 m1/1) down to about 300 m, The only exception was a slightly high value again seen at 100 m.

This was very close to the depth of the salinity maximum (Fig. 28). During this cruise there was almost no Upper Mixed Layer, except as seen using the 0,0. values, The remainder of the water column appeared typical at this time,

Figure 96 and 97 represent the time series of the day and night dissolved oxygen values respectively during the measurement program, Both figures show a general trend toward increasing values of D.0, throughout the measurement period in the upper 200 m, The upper water temperature was warmest in October (Fig, 14), corresponding to the low upper-water 0.0, as saturation of oxygen decreases with increasing tenpera-ture. The low October D,0, may be explained as maintaining the same percent of saturation (70%), but able to hold less gas. As the temperature decreases through February and April, 0,0, increases in the upper waters. The D,0, values deeper ?than 500 m do not appear to change much throughout the year. Between 200 and 450 m, a change in the D.0. 1s seen, However, it is in this depth range that the day-night values are dif-fering, and most of time series differences at these depths may correspond to specific bioactivity during the measurements, as opposed to overall annual trends.

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DEPTH(m)

Bor 802

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360

400

600

700

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800

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JULY AUG SEPT OCT NOV DEC JAN FEB MAR

978 7im78

Fig. 96 - Time series for dissolved oxygen data collected during,

daylight at Punta Tuna from August,

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1978 to dune, 1979.

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DEPTH (m)

300

490

600

900

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seve 3073

Fig. 97 - Time series for dissolved oxygen data collected during

nighttime at Punta Tuna from August, 1978 to June, 1979,

168,

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3.6 Chlorophyll a Results

During each cruise, samples were taken to determine the concentration of live flora (chlorophyl1 a) at discrete depths down to about 400 m. These samples were taken both during a noon Biocast and a midnight Biocast, except during the first cruise, which was terminated before the night Bfocast could be made. .

Figures 98-103 show the chlorophy11 a profiles vs, depth for both the day and night casts for each of the 6 crutses, Also, shown on each ftgure is the water density profile for comparison,

By studying the figures of the six cruises, the following points can be seen, First, during the August 1978 cruise, (Fig, 98), improper filter paper was used for chlorophyl1 analysis, and the results were poor, Many of the values were not reproducible, and this data should probably be discounted,

Starting from the second cruise, a pattern may be visible, From ftgures 99-103, it appears that the day and night chlorophyl1 values seem surpressed somewhat by the pycnocline, The number of viable cells seen in each sample were generally higher below the pycnocline than above, This implies difficulty in passing through this strong density gradiant. This same depth gradiant was seen by Beers, et aly, (1988),

During the April 1979 cruise (Fig. 102) the chlorophy11: a values were 5-10 times higher at the 100-125 m depths than the values seen at any depth during the other cruises, Typical values at this depth were 0.1-0,3 ug/1, but during April the values were 0.9-1.5 i9/1 during the night sampling, This type of anomalously high value might normally be attributed ?normal patchiness", however, it also corresponded to an easily mea surable dfssolyed oxygen decrease at about the same depth throughout the day, (Please see Fig, 93), This high concen- tration of phytoplankton may possibly have been present during the other cruises and may have been missed by our dis~ crete sampling procedure, however, the dissolved oxygen

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DEPTHIm)

DENSITY Ie 4

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Fig. 98 - Chlorophy11 "a" profile observed at Punta

Tuna during the crufse of August, 1978.

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DEPTHim)

CHLOROPHYLL?

(ya)

Fig. 99 ~ Chlorophyl1 "a" profile observed at Punta

Tuna during the cruise of October, 1978,

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DEPTH(m)

DENSITY (oj)

CHLOROPHYLL? a? (39/1)

Fig. 100 - Chlorophyt1 "a" profile observed at Punta

Tuna during the cruise of December, 1978,

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DEPTH(m)

ST PIITT TIT

CHLOROPHYLL ?a (y9/1)

Fig. 101 ~ Chlorophy11 "a" profile observed at Punta

Tuna during the.cruse of February, 1979,

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DEPTHIm)

» DENSITY (65)

CHLOROPHYLL?a? (39/1

Fig. 102 - Chlorophyll "a" profile observed at Punta

Tuna during the cruise of April, 1979.

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DEPTH Im)

DENSITY (6%)

CHLOROPHYLL a? (y9/1)

Fig. 103 - Chlorophyll "a" profile observed at Punta, Tuna during the cruise of June, 1979.

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concentration would probably have been surpressed if that were the case, Unfortunately, the nutrient data taken during this program was not refined engugh to help explain the exception~ ally high chlorophyl1 a values for April 1979, In fact, this chlorophy!1 a maximum corresponded temporanily with the highest surface salinity values (Pig. 40). According to Froelich, et al., (1978), the salinity of the Caribbean surface water is strongly influenced by the fresh water run-off from the Amazon and Orinoco Rivers. Therefore, when the salinity ts lowest, the river's influence fs highest, and the available nutrients might be expected to be above normal, During April the surface salinity was highest of all our crutses (Fig. 29), and therefore the rivers? influence would be expected to be minimal, With less river runoff as might be the terrestrially derived nutrients, which control the chlorophyl1 production in the sunlight-rich Caribbean Sea, would also be at a minimum, Therefore, this bloom may have been a temporal and spatial anomaly.

Figures 104 and 105 show the time series of the chloro~ phyl1 a values for the day and-night periods, respectively, The upper waters had minimum {n December 1978 and June 1979 and maximums in October 1978 and February 1979 during both the daylight and the night periods, The higher values through- out the water colunn are easily seen as occurring in October 1978 and April 1979, The highest overall values were seen in April, at 125 mas mentioned before, Beers, et al, (1968) also found his highest surface values during the late autumn and winter at Jamaica (specifically October), and during late autumn and winter (specifically February) at Barbados, At neither location were the peak values found as deep as 125 m,

Figure 106 shows: the normalized day/night-average int grated chlorophyll a resulting from all samples taken down. to 200 meters for each cruise. Relative peaks occur in August, October, and April. Also, in the figure are the values of surface salinity during each of the cruises. According to Froelich et al., (1978), the lower salinity values are due to perfods influenced by the Amazon and Orinoco Rivers. These

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DEPTH (m)

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Fig. 104 - Time series of chiorophyl1

UL AUG SEP OCT Ov DEC JAN FEB MAR APR way aw abe

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" values measured

during daylight at Punta Tuna from August, 1978

to June, 1973,

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DEPTH (m)

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ML AUG SEP CGT MOY OC UN FEB MAR APR MAY UN aR

1970 1

Fig. 105 - Time series of chlorophyll? "a" values measured during

nighttime at Punta Tuna from August, 1978 to June, 1979,

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801 802803 804 805 806

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SALINITY God)

SURFACE

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CHLOROPHYLL? (ug/!)

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o. x r Tt

JULY AUG SEPT OCT NOV OIC JAN FED MAR APR MAY JUN JULY

3978/1979

Fig. 106 - Time series of surface salinity and integrated chloro-

phyl1 "a" from the surface-to 200 m measured at Punta

Tuna from August, 1978 to June, 1979.

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waters of lower salinity should carry with them the more rich river waters, with possibly more available nutrients than other times of the year. Therefore, an inverse correlation might be expected between the two curves shown in Figure 106. Except for the extremely strong peak in April, this appears to be the case, however more information is needed before this relationship is actually confirmed. As mentioned earlier, the nutrient information collected during this program is inadequate to support the chlorophyll data. Beers et al., (1968), found peaks in gross primary productivity in June, September and October in Jamaica and July, February and May in Barbados. Their peaks in productivity appeared to match their peaks in nutrients, as expected.

Finally, it might be pointed out that these chlorophyll values were taken from discrete samplings at about every 25 m depth. There may be much more vertical structure to the chlorophyll profiles that have eluded this study due to to the few chosen sampling depths. The phytoplankton tend to be patchy in both the horizontal and the vertical directions as well as with time, These factors may influence any distortion of the chlorophyll seen in this report.

3.7 Zooplankton Results

On each cruise, zooplankton samples were taken. When Possible, one sample was taken at each of the following depths:

25 m Horizontal tow (day)

25 m Horizontal tow (night)

200-0 m Vertical tow

800-200 m Vertical tow

1000-800 m Vertical tow

1000-0 m Vertical tow

The tow covering the entire water column (1000-0 m) was not sorted as part of this work, but was sent to the Lawrence Berkeley Laboratory of the University of California, for analysis. The following portion of this section describes the results of the laboratory and statistical analysis of the remainder of the samples, and the interpretation thereof.

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3.7.1 Size Frequency Analysis

The data summarized in Figure 107 present the percent of total copepoda analyzed throughout the year (frequency) versus their size class expressed in mm (magnitude). Plankters were collected towing a 202 p net, which explains why so few individuals represented in the <0.5 mn size class interval. A finer mesh net captures those members that would seep through a 202 y net and will increase the number of individuals represented in the <0.5 mn size class interval.

Of the copepoda represented in this histogram those included in the 9.5-0.9 mm size class interval are the most abundant. If we assume there is no clogging problem and that the size of copepoda is normally distributed, a 202 » net is useful to collect those plankters bigger than 0.5 mn.

3.7.2 25 Meters Day vs. Night Tows

ANl data for all tests were log transformed from #/m?,

A series of t-distribution tests were applied to the following data groups to test for any significant difference between the day and night surface tows:

~ Total Copepoda

= Dominant Species

~ Clausocalanus. furcatus.

= Oithona plumifera

= Galocatanus pave

Results for each of the t-distribution tests conducted

are presented in Table 11, All of the values calculated are

not significant (N.S.) at the 0.05 level.

It {5 a well-known fact that during the night some zoo-

plankton vertically migrate to the surface waters (the reasons

for such events are not part of this exposition). Therefore,

we could expect much or at least higher concentrations of

plankters on the surface waters at night. This might be the

case, but variability is so ample that the differences are

not statistically significant.

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TABLE 11

Results of t-distribution tests on three zooplankton

species collected at Punta Tuna to determine the day/night

Significance for 25 m deep horizontal tows.

Total Clausocalanus ?_Oithona_?Calocalanus

Copepoda? furcatus plum fera avo

tho 0.311 0,952 0.285 0.541

0.05 >.05 N.S, >05 NS. >.05. NS. >,05 NLS.

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Dominant species were selected after construction of a rank order species list. The three most abundant species were chosen for the test.

Of the three species of copepoda subjected to the test, none were significant at the 0.05 level. But this could very well be that they are non-migratory species, or that there is not enough data (replicates) to reject the null hypothesis.

Season Depth Distribution

Two way analysis of variance tests were applied to the following data groups to test for any significant difference between season and depth:

= Total Copepoda

= Dominant species

~ Oncaea venusta

= Oithona plunifera

> Clausocalanus. furcat

For total copepoda (Table 12) there is slight evidence that their abundance varies with month, i.e. seasonal variations. If water masses of different temperature, salinity, and/or nutrients would go by the Punta Tuna site, variations in the planktonic population covld or should be detected. Therefore, seasonal variations are expected.

Dominant species were selected after construction of a rank order species list. The three species most common for ail months were chosen for the test.

Of the three species conpared in the test, only 0. venuste shows any significance at the 0.05 level. If we compare all copepoda and the three species chosen for this test none of the data group show any relation with depth at all,

Throughout the year @ species list was constructed for the copepoda found in the waters of the Punta Tuna site.? ATT identified species are listed in Table 13.

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TABLE 12

Results of tests for significance of depth and seasonality

for total copepoda and three zooplankton species collected

at Punta Tuna from August, 1978 to June, 1979.

?Sum of Degrees of Mean Variance Probability

Squares ?Freedom Square Ratio

(Ss.) (DF) (MS) (FD (r)

?TOTAL COPEPODA

YONTH 5.861 5 L172 5.586 0.05

DEPTH 41534 2 2.268 (2.887 NS.

ERROR 65.467 10 6.547

TOTAL 75.862 v7

ONCAEA. VENUSTA

WONTH 0.262 5 0.0524 6.471 0.05

DEPTH 0.831 2 0.4155 0.8161 NS.

ERROR 3.391 10 0.3391

TOTAL 4.484 7

OTTHONA PLUNIFERA

?MONTH 1.822 5 0.3664 3.957

DEPTH 1.369 2 0.6865 2.107

ERROR 14.419 10 1.482

TOTAL 17.610 v7

CCLAUSOCALANUS FURCATUS

wONTH

2.726 5 0.542 2.465

DEPTH 5.088 2 21526 0.532

ERROR 13.444 10 1344

TOTAL 21.218 a

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TABLE 13. List of Spectes - Copepoda

Acartia spinata Lucteutia {taviconnis

A, Heeb ebongez fecgrocena cts

S EiLejebongt cena cbaus

A: dana Netridia brevceaudaca

A. negtégens Méckosetetea nonvegien -

Acrocatanus Longiconnis Meraeéa eggerata -

Aetideus armatus Meraciz minor

Catanus tenuiconnis Worondtta minor

Candacéa béspinosa Nanmocabanus minor

©. pachydacceea

©. packongémana

Catocatanus pavo

©. pavonicus

Chausoentanus arcuiconnis

Ciytomestaa scutettata

4

opetie quadhata

Cr miaabetes

C. Speedosus

ai

©. typécus

Lirbatus

C. Zatus

Eucatanus attenuatus

tubbockéa acuteuta

L. squietinana

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3.7.3 A Comparative Study of Copepod Data Reported from Around the Puerto Rico Area

The Copepoda make up the largest group (ca 70-853) of the planktonic organisms sampled ?in our waters. Consequently, quantitative studies of their occurrence constitute an excellent tool for the understanding of distributional patterns of our zooplankton. Further, when inshore and offshore (pelagic) systems are compared, major differences are evident; some species being restricted to some areas and others to others.

In addition to these observations we find some species which are always present, others are commonly present, and stil] others exist but are extremely rare. Similar observ tions in the past led Preston (1948) to write the classic ecological paper ?The conmonness and rarity of species.? This is clearly indicative of the concern of traditional ecologists for this type of observation and their relevance for the establishment of basic concepts in ecology.

Anonymous (1978) made an analysis of copepod populations from off the south coast of Puerto Rico based on data generated by Wood, et al. (1975, 1975c) and presented a scheme that fits the overall pattern observed in our marine waters. An examination of copepod lists provided from other deep water areas around Puerto Rico, (Youngbluth, 1974, 197: Nutt, 1975, and Nutt and Yeaman, 1975), reveal that the species present are indeed in comnon with those from similar areas discussed above. Anonymous (1978) and Michel et al. (1976) found similar results off the southeast of Puerto Rico and Vieques, respectively. Coker and Gonzélez (1960) reported on spectes restricted to inshore waters. Examination of their list on Table 2, p. 18 reveals how some species such as Acartia tonsa, Paracalanus crassirostris, and Qithona simplex are found in larger numbers in embayments like Phosphorescent. Bays; then become less abundant in open bays (Montalva) and offshore, while others increase in abundance. See for instance the distribution of Corycaeus americanus, Centropages furcatus, and Temora turbinata. See also Tables 14-18 for reference in this discussion.

---Page Break---

TABLE 14, A list of the copepod spectes identified from the

Punta Higuero collections (after Nutt and Yeaman, 1975).

COPEPODA SPECIES

Aeantia 4)

Acartia Leetjebonget

Conyeaeus sububatus

onjaans gteabrachte

onyoaeus pace cus

Conyeaeus ages

Conyeaeus spectosus

Conyeneus angtieus

Conyeaeus clause

Sonpeneus Laut

famanita SpA

Undonuta vi

Narnocatanus: minor

Centropages gurcatus

Cakoeatanus pavo

Lucteutia slaviconnis

Catanopéa anerieana

Nachosetetia gracilis

Méerosetetea nonvegcea

Acaacalanus Langiconnds

wndacke pachy

Euchaeta mina

Eucatanus ef. attenuatus

Labidocera spp,

Wiracta eggerata

Euterpina acuti (rons

---Page Break---

TABLE 15. Spectes of copepods found at sampling stations in the

vicinity of Vieques Island (after Michel et al., 1976):

COPEPONA SPECIES

Actocatanus Longdeonnis

Euchaeta marena

Luceweda gLaviconnts

Hatoptdtua Longiconncs

Wormondtea minor

Nacnosetetta gracilis

Meerasetetta rosea

ther harpactiend

Conaea gaacceis

Famanuta caninata

P. gnacitis

Oithona plum gera

Qneaea medé

0, venasta

Other ?cyclopoids

189

---Page Break---

TABLE 16, Analysis of the copepod populations from Punta Verraco and Cabo Mala Pascua Sites, (After. Anonymous 1978).

Table 16-A Copepod population observed at Punta Verraco.

yecies usually most numerous

Tndtviduals

stan pe

Paracatanus sop. (P. acukeatus, P. crassirostris, P. parvus)

remain

tom 6

sie ae

\. Like feborgii

Tenona turblnats

Species commonly present

(observed on 5 oF Bore SeapT Ina periods

Conycaeus spp. (C. géesbrechti, C. pactgicus, C, speccousus)

Eutexpina aciitignons

Catanopia averieana

Undinuta vutgarcs

Spectes occasionally present

Euchaeta marina

Conyeaeus spp. (C. pavo, C. pavoninus)

Pscudodiamptomis coherd

Nannocatanus minor

Catocatanus spp. (C. pavo, C. pavonénus)

yes spp. (C. furcatus, C. cardbbeanensis)

Sentech ae

Labédocena spp. (L. scott, L. spp.)

Candactn pachycactsta

Mecynocera clausé

deroeatantuLengicomcs

Eucazonut 4pp.

lecentin feavcconnta

Tenona siylifena

Source: Wood, E. D., M. J. Youngbluth, P. Yoshioka, and M. J,

Canoy. "1975. ?Punta Verraco Environmental Studies.

Puerto Rico luclear Center, Mayaguez.

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(cone. }

THLE 16, Analysis of the copepod populations from Punta Verraco

(DieA) and Cabo Yala Pascua Site, Puerto Rico (IX-8).

(After Anonymous 1978).

Table 16-8 Copepod populations observed at the Cabo Mala Pascua Site.

Species usually most gunerous

See inaiviaats/ey

Ctausocatanus furcatus

Paracatanus spp. (P. acuteatus, P. crassirosinis, P. parvus)

Famanuta graciis

Octhona spp. (P. acuteatus, P, crassirostris, P. parvus)

Aeantla spinata

tunbinata

Catanopia anerceana

Species commonly present

(observed on5 oF more SeapT Ing Her fods)

Conyeaeus app. (C. giesbrechté, C. paccgious, C. spectosus)

Undénuta vubgares

Tenona stytifers

Species ocassionally present

Oncaea spp. (0. gas et, 0. venutta, 0. app.)

?onyeaeus spp. (C. subsLatus, C. spp.

Pseudoddaptonis cobert

Catocatanus pavonénus

Scotectthnix: danae

Wood, E. D., M. J. Youngbluth, P. Yoshioka, M. J. Canoy. 1975.

Cabo'Maia Pascua Environmental Studies. Puerto Rico Nuclear

Center, Mayaguez.

---Page Break---

TABLE 17, Zooplankton species distribution, abundance,

and diversity in the vicinity.

Conyeacus ap.

Euaetideus gieabrechte

COPEPODA

SPECIES

L. ctowsti

Maorosetetta gracitis

Mecynocena elausiz

Microsetetta norvegcea

Nanrocatanus minor

Odthona. plumé fora

0. sémptex

0: hebes

0. sp.

0. nana

Oncaea 4p.

Oneaea venusta

0. redétemanea

Paracatanus acuteatus

Pa enasacrostnis

P. parwus

P. bp.

Phaenna spinégera

Pewromama gnacitis

Rhinecatanus connutus

Tenora stybigena

T, tutbinata

lindénuta? vutgancs

Unidentified Copepodtes

Unidentified Catanoid Copepods

---Page Break---

TABLE 18. Zooplankton from Tortuguero Bay (after Nutt 1975).

coPePons:

Calanoids:

Nonpoentanus minor Seatelthads dena

a vubgaris Tomona stybigera

Eucatanus attenuatus Temona turbinata

Acroeatanus Longicornis Peewronanma gracceis

Acroeatanus andersont Centropagues furcatus

Paraeatanus acuteatus Lucceutéa (Laviconnis

Paraentanus parvus Candacéa pachydactyea

Catocatanus pavo Paraemdacia bispinosa

Mecynocera clausci Catanopia americana

Clawsocatanus urcatus Labédocera 4p.

Euchaeta marina Acaxtia spinata

Harpacticoids:

Miracta efgerata Ocutosetetta gracctis

Wackosetetea gracitis Euterpina acutignons

Cyclopoids:

Odthona peumigera Coiyeneus (Agetus) typious

Oéthona setigera Conyeneus (Urocoryeneus) Lautus

Oéthona ooukata Conyeaeus lonychocoryeaeus) giesbrechti

Saphirelta tropica Conyeaeus lonychoconyeneus) agitis

Copitia mirabitis Oncaea mediterranea

Copétia quadrata Oncaea venus ta

Conyeaeus (Coryeneus} spectosus Saphirina sp.

Conyeaeus (Coryeaeus) clause Farranuba gracceis

Conyeaeus (Agetus) <taceus

---Page Break---

Upon studying carefully the Punta Tuna data, it is found

that the diversity of the species is much higher than in all other sites mentioned above. This is apparently due to the fact that net tows were made down to a depth of 1000 meters (a large number of species reported here are deep water species), and were spaced out throughout the year. This offered a greater opportunity to catch organisms that undergo seasonal fluctuations in addition to stragglers from other regions.

The information obtained confirms previous observation of the distributional patterns of copepod species, but correlations with other parameters are not evident or can not be carried out because the data can not be tested statistically for that purpose.

Because the diversity of species found in the Punta Tuna site is considerably larger than in any other site explored before, it was believed proper to make a more extensive survey devoted exclusively to the study of pattern of the pelagic plankton populations. This will ensure that a dissection of vertical stratification of species and the overall plankton structure of the pelagic environment could be understood.

?The presence of Acartia tonsa, an inshore species, in the pelagic environment off Punta Tuna is of no significant consequence. However, the ongoing study may be able to add further insight on this observation.

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3.8 Nutrient Results

During each cruise an attempt was made to collect samples from throughout the water column down to 1000 m for Subsequent nutrient analysis. Shipboard handling and laboratory problems resulted in acceptable results not being available until the Sth cruise. Although the results of the last two cruises are much more meaningful than those preceeding, the results of all the cruises shall be represented, but special emphasis should be given to the April and June 1979 cruises.

In Caribbean surface waters, the low nutrient concentrations in the photic zone is the primary cause for the generally low primary production. In areas of upwelling, where traditionally nutrient rich deeper waters are moved upward into the photic zone, the primary production, and the entire food web is enhanced, both in species and in numbers.

3.8.1 Nitrate/Nitrite Results

Figures 108-112 show the average values of the nitrites and nitrates for each of the last 5 cruises respectively.

The values seen for the October 1978 (Fig. 108), December 1978 (Fig. 109), and February 1979 (Fig. 110) cruises for the concentration of nitrate and nitrite in the water are inconsistant, both among themselves and relative to literature values. The nitrate values seen during October (Fig. 108) were quite high at the surface, decreased with depth to about 200 m, then showed fairly constant values downward.

The nitrite values for this same cruise showed irratic high and low values. The values of nitrate concentration seen during the December cruise (Fig. 109) is very low until the 200 m depth is reached. From that depth downward, the values generally increase. The nitrite concentration for this same cruise is shown to be virtually zero throughout the water column, The nitrate values for the February cruise (Fig. 110) are quite low near the surface, but then increase to extremely

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Fig. 108 - Profile of the average values of the various nutrient

concentrations measured at Punta Tuna during the

cruise of October, 197:

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a Fig. 109 - Profile of the average values of the various nutrient

concentrations measured at Punta Tuna during the

cruise of Decenber, 1378,

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Fig. 110 - Profile of the average values of the various nutrient concentrations measured at Punta Tuna during the cruise of February, 1979.

198,

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peat

Fig. 111 - Profile of the average values of the varfous nutrient concentrations measured at Punta Tuna during the cruise of April, 1979,

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Fig. 112 - Profile of the average values of the various nutrient C

concentrations measured at Punta Tuna during the

cruise of dune, 1979,

200

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high values (about 140 ug-At/1) at about 500-900 m. It is

quite possible that the samples were contaminated during the

water collection period. The nitrite concentrations during

this cruise were quite irratic.

April 1979 (Fig. 111), and June 1979 (Fig. 112) had similar nitrate profiles. Generally, during these cruises the concentration is very low at the surface and throughout. the photic zone. Betow this level, there is a trend toward increasing nitrate concentration as depth increases. The nitrite concentration is virtually unchanged throughout the water column in both of these cruises, except for a peak near 400 m in April 1979. The typical values of nitrite concentration is almost undetectable in April, but almost 0.2 ug-At/1 in June, showing a possible systematic offset during the handling and/or analysis during the last cruise.

Normally, the upper waters of the Caribbean are quite low in nitrites and nitrates (Atwood et al., 1976; Beers et al., 1968). Typically, nitrate values of less than a few ug-At/1 are seen in the literature throughout the photic zone. Only below this level do the values usually rise to significant levels, Putting our emphasis and confidence on the nitrate values of the April and June cruises of 1979, the typical values would be low throughout the upper 100 m, and start to rise gradually as the bottom is approached. Significant changes in the surface and upper water nutrient concentration levels could occur if an OTEC plant would be permitted to produce an artificial upwelling of these nitrates and nitrites. The increase could be as much as 10-50 times the present values.

3.8.2 Phosphate Results

The profiles of phosphate concentrations vs. depth for each of the last 5 cruises are also shown in Figures 108-112. The above mentioned problems encountered with the samples before the April cruise also apply to the phosphate concentrations.

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April (Fig. 111) concentrations showed not much vertical structure, and simply varied from 1-3 ug-At/1 throughout the entire water column. These values do not appear reliable. During the June cruise (Fig. 112), the phosphate concentrate remained between .5-1 ug-At/1 down to about 300 m. Below 300 m, the concentration steadily increased to almost 3.5 ug-AT/T.

In summary, the concentration of phosphate generally showed Tow values near the surface, increasing with depth below the photic zone. However, many of the data seen to display systematic errors which at times either inhibit higher values or overshadow the lower values.

3.8.3 Silicate Results

The concentration of reactive silicate for the Punta Tuna waters is shown in Figures 108-112, covering the period from October, 1978 unti1 June, 1979. The samples from the cruises of October and December, 1978 (Figs. 108-109), and February and April, 1979 (Figs. 110-111) all suffered from extended time delays between collection and chemical analysis. The October, December, and February samples also suffered from possible contamination of the samples due to improper handling at sea. These factors may account for the unclear results.

The October, 1978 results (Fig. 108) shows a surprising peak at mid-depth and a considerable decrease at 400 m. The December, 1978 (Fig. 109) values are surprisingly high in the upper 250 m, but appear to increase smoothly with depth below 4-0 m. The February, 1979 (Fig. 110) concentrations of silicate display either a peak at 400 m or a dip at 500 m, depending on the interpretation, but the values appear usable otherwise. The upper water values (0-300 m) show a relatively uniform, but moderate concentration in April, 1979 (Fig. 111). Below this depth, the values appear consistant with the other months. The values for June, 1979 (Fig. 112) are quite low in the upper 300 m, and steadily increasing

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with depth below this. The values for June, 1979 appear to most closely follow those concentration envelopes seen in the literature (Cummings et al., 1979).

The average concentrations are shown in Figure 113. Although the early data appears unrealiable, the general curve form is nota typical,

3.8.4 Nutrient Summary

In summarizing the nutrient results, the following items can be addressed: relative nutrient concentrations, present data quality, and expected OTEC impacts.

In general, normal Caribbean offshore nutrient concentration levels are very low at the surface, and rise to relative maximum near the core of the Antarctic Intermediate Water, about 700 m depth (Atwood et al., 1976). This typical

Profile applies to those specific nutrient species measured during this program, namely silicate, phosphate, nitrate and nitrite. At times there are slight increases seen near or at the surface, but the shape of the profile does not seem to vary much. :

The "average" profiles for nutrient concentration are seen in Figure 113. These "average" values, together with their standard deviations are also shown in Table 19.

The nitrate values all show standard deviations greater than the mean, implying lack of reliability of the data or much greater variation than normally seen. Also, the concentration profiles vs. depth for nitrite is seen to have many relative maximums and minimums.

The phosphate concentrations are not consistant near the surface waters, but seem to improve with increasing depth. Although the standard deviations are not quite as large, (relative to the mean) as with the nitrites; the spread of data is still quite large compared to expected sampling variations for this species, as seen in the litera~ ture (Cummings et al., 1979; Lee et al., 1978; Wood et al., 19753 and Wood and Asencio, 1975). As seen in the figure,

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Fig. 113 - Profile of the average values of the varjous nutrient

concentrations measured at Punta Tuna during all

cruises from October, 1978 to June, 1979,

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TABLE 19

?Average values of nutrient concentrations in the water

?at Punta Tuna from October, 1978 to June, 1979

(and standard deviation of measurenents)..

oman. PO, NO, No S105

() (ugm-AT/2) (ugm-AT/2) ? (ugm-AT/2) (ugm-AT/2)

0 O.78t 49 0.10F 17 LOt 16 © 5.46.3

50 OSS 144 015+ 28 3.84 9.1 © 4.64 3.0

100.94 540.15 18 Ls 47 © 2.6 2 2.3

150-079 .34 0104.13 232 44 © 31234

200 «1.96 £1.01 0.08 +14 3.94 30 © 3.62 3.1

2000 «1.83 21.38 0.134.146 85213 6.327.5

3000.79 30 0.23 4.28 13.22190 5.47.7

400-110 410.15 +20 20.7 413.4 7.5 25.8

500 «LIZ t 91 0.08 4.13 28.32 44.8 © -7.525.8

600 «1.33 £1.05 0.08 + 413 50.2455.8 13.14 9.5

800 6.744134 0.08 113 55.14 78.9 22.6 + 9.8

1000 1.49 £1.01 0.05.10 22.3413.3 30,1 + 2.3

---Page Break---

the average values oscillate between relative maximum and relative minimums down to about 300 m. Below this depth, there appears to be a single maximum value at about 750 m depth, in agreement with historical observations (Atwood

et al., 1976).

The average nitrate profiles show very low surface and near surface values, increasing steadily from about 200 m to the deep waters. These values also show very high (mean vs. standard deviation) ratios, indicating considerable variation in the results.

On the figure, the average silicate concentrations show moderate levels near the surface, a decrease below the mixed layer, and a fairly steady increase with depth below that. The reliability of most of the values is in question, however, as the standard deviation exceeded the mean value in almost all cases.

Table 20 is included as a comparison in Table 19.

Table 20 shows the average nutrient concentrations and their deviations from the mean for only the last two cruises,

April and June, 1979. These cruises employed optimum shipboard handling procedures, and probably any significant variations in these results are due to either our preservative, any delays between the collection and the measurements, or the laboratory handling and analysis. The values in Table 20 are not necessarily similar to those in Table 19. The phosphate values range from about 1-3 ugm-AT/2, with the higher values seen below 500 m. The deviations from the means are a smaller fraction of the mean than seen for the phosphates in Table 19. The nitrite values are irratic, with high standard deviations from the means. Nitrate con

centrations are generally lower near the surface and high in

the deep water. However, the progression from one realm to

another is not necessarily smooth, with frequent high devia-

tions. The silicate values show quite constant, moderate

levels, from the surface to 300 m, However, the deviations

from the mean quite often almost equal, or exceed the mean.

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TABLE 20

a Average values of nutrient concentrations in the

water at Punta Tuna during April and June, 1979

{and standard deviation of the measurements).

OMA PO, No, NO S103

(HM) (ugm-AT/2) ? (ugm-AT/2) ??(uigm-AT/2) (ugn-AT/2)

0 1,004 .30 015+ .18 0.49 30 2,93 # 1.32

500.982 117 O17 +20 0.92 = 673.26 + 2.67

100 «L1L4 67 0.18 + 16 1.08 + 452.85 + 3.08

1500.86 40 0.17 4.15 0.66: 524.00 + 4.11

20000 «1b 2 1.08 0,202 173.56 + 603.81 + 2.71

250 1.05 + 20 OBS .13 3.31 F 1.60 3.13 + 2.32

3000.91 .28 O18 616 413s 2.77 3.48 + 2.58

400 150+ 15 0.28 4.25 8.2 218.7 7.77 + 4.38

500 2.02 .42 0,08 + 14 = 9.83 + 7.65 10.2 + 4.69

600 2.41 43 0,004.00 20.1 412.8 18.4 + 9.36

800 3.12 17 0.07 + 1322.4 + 5.7 28.0 + 7.79

1000 2.40 .90 0.084 16 19.6 + 9.2 © 29.7 + 4.86

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The concentration at depth fs generally high. In most cases in the table, the deviations from the mean are high relative to the mean, again indicating low reliability of the results.

In general, the nutrient concentrations tend to be higher in the deep waters than in the near surface waters. This trend. suggests confirmation of the potential situation that may be common to an operating OTEC plant in any tropical waters. If the plant were to draw into its cold water intake these nutrient rich deep waters, and exhaust then into the nutrient poor photic zone, a totally unnatural Situation could be created in the open Caribbean waters.

However, this scenario seems highly unlikely. Should the cold water system remain separated from the warm water system, the exhausted cold water would quickly descend to its deep final resting place. If the plant were to use a mixed effluent, the resultant mixture would also probably descend below the photic zone within a matter of a few hours after leaving the plant. This nutrient rich effluent could only be expected to impact on nearby (or downstream) submerged structures which may diverst some of the flow upward into the photic zone. It is these nearby shallow or shelf structures that could be subjected to an artificial "upwelling" of this newly created water mass.

3.9 Meteorological Results

The meteorological and climatological observations were made for two purposes during this program. The first purpose is to note how the weather varied during our measurement Period as opposed to the normal, long-term climatological averages. This may account for any observed abnormal physical characteristics. The second purpose was to compare the mete-erological data taken while on board the research vessels during their occupations of the Benchmark station, with the recorded meteorological data observed at the Punta Tuna Coast Guard Light Station, about 3 km northwest of our mooring.

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3.9.1 Comparison with Historical Data

Figure 114 shows comparison of the long-term meteorological averages of temperature and wind speed with those mea sured during the year of our measurement program. As the island is only about 60 km (N-S) by 180 km, and San Juan is located on the coast (although the north coast, as opposed to the south coast for the Benchmark station), and because there 1s historical data for San Juan weather, the comparison of the historical data versus that seen during 1978-1979 will be done using the San Juan data files.

The upper portion of Figure 114 shows the temperature comparisons. The circles represent the historical average monthly temperature data from all the reporting stations in the San Juan area during the period from 1941-1970 (NOAA, 1979), These monthly averages are compared with the monthly average temperature measured from June, 1978 to June, 1979 at the San Juan Natfonal Weather Service Forcast Office (NOAA, 1978-1979).

In general, the present values are higher than the historical averages, and this is probably due to the specific weather reporting location within the city. Throughout the year (1978-1979), the data averaged about 1.3 C°-hfgher ?than the historical data, with the standard deviation being about 40:3 0%. The exceptions to this trend occured in January, February, and June, 1979, when the difference was almost 1.5 times as great, and March, 1979, when the difference was about 0.7 times. This probably indicates that the air temperature was slightly warmer during the first half of 1979 than can be normally expected. Another interpretation might be that 1979 may be the more typical year, and the later half of 1978 may actually be slightly cooler than the average. In either case, the sea surface may react to this difference from the mean, by either producing slightly cooler than nor= mal surface temperature values during August, October, and December, 1978, or slightly warmer than average values during February and June, 1979. The actual comparison of the

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Fig. 114 - Tine series of air temperature and wind speed at. San Juan, Puerto Rico from June, 1978 to June, 1979. (Historigal averages are also shown).

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historical sea surface temperature (ODSI, 1977) with measurements taken during 1978-1979 are shown in Figure 40. The results indicate that most of the recent data seems cooler than normal with only the February cruise data showing above normal sea surface temperatures. This would correspond to the interpretation of the historical/present meteorological data, that says that January and February of 1979 had above average air temperatures.

Another type of comparison of the historical versus the recent meteorological data is to evaluate any difference in the observed wind speed. The lower portion of Figure 114 shows the historical San Juan monthly average wind data compared to the monthly averages during 1978-1979. Although there 1s considerable variation between the two sets, the average difference is only about 0.2 m/sec, with the recent data showing the slightly lower wind speed. Again, this difference may be due to the actual sensor location within the city. If this small negative difference is taken into account, the periods of major differences occured during our August cruise, when the average wind speed was greater than the historical average, and during our December and April cruises, when the average wind speed was lower than the historical values. This suggests better wind mixing during the August cruise, and poorer mixing during the December and

April cruises. Figure 38 shows the comparison between our measured data for the MLD (Mixed Layer Depth) and the historical averages (00ST, 1977). Our August cruise saw a sonewhat more developed mixed surface layer, so the depth was slightly greater than the average. The MLD during December was not much different than the historical value. Finally, our April cruise data indicates a somewhat shallower MLD than the historical average, for that time period.

This all indicates that the local meteorological conditions can, and do influence the hydrographic parameters relatable to an OTEC plant.

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3.9.2 Comparison with Shipboard Data

Table 21 shows the comparisons between two typical sets of shipboard meteorological data and those data observed at the Punta Tuna Coast Guard Light Station which takes observations at 800, 1100, 1400, and 1700 hours, week-days only. These two shipboard data sets were chosen as they represent considerably different measurement capabilities aboard the research vessels. The set from the BA-804 cruise (February, 1979) was observed and recorded by the crew of the USNS BARTLETT (T-AGOR-13). These data, with the exception of the wave height values, are measured using remotely located instruments, some set on the superstructure, and the anenon-eter and wind vane on the ship's mast. The second data set was observed and recorded by the crew of the R/V CRANFORD, using hand-held instruments in all cases. These latter observations were made usually against the superstructure and as such are also closer to the sea level and in 2 more restricted air passage.

The table reflects the locations of the instruments and the observers. In general, if we assume that all the instru-ments are within calibration (which is probably a poor assumption), the wind speed sensor aboard the BARTLETT, by being higher above sea level (wind speed generally increases with height above the sea surface), and less obstructed should give @ higher reading than the value seen on the CRAWFORD. This higher elevation seems to be the case, with the wind speed values observed from the BARTLETT even higher than those from the Light Station, as well as higher than ?the CRAWFORD. The speeds observed from the CRANFORD were usually lower than at the Light Station. This could also be an artifact of the above mentioned calibration.

In all cases, the wind direction was more southerly

from the shipboard observation than seen at the Light

Station, The most probable cause of the difference is that

the Light Station is sitting at the base and to the south

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ant 1+ 20+ - 11-8/908-89

° se sv0+ 9° ot-8/908-u9

° ee oLo+ 9° 6-9/908-¥9

° a oso+ e y-9/908-¥9

° oF oso+ I- £-8/908-¥9

0 oe ogo+ ze 2-8/908-¥9

ate e ost+ - 01-8/908-v8

ate 9° sto+ a 9-a/908-¥8

at ae - sto+ ? $-a/v08-va

ate e szo+ se -a/908-Va

ate s+ ogo+ ae 1-8/v08-va

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of a 400-500 m high hill, which would deflect any southern component of wind.

The difference in air temperature is as yet unexplained and is probably due to poor instrument calibration or solar exposure to the thermometers.

Finally, as the wave height observations are taking place fron a lower deck aboard the CRANFORD than from the BARTLETT, it is expected that the wave height observations from the CRANFORD may be more direct, and less remote, with less of 2 vertical error involved in the observation. However, it is truly impossible to estimate the wave height in open sea from the Light Station, located about 20 m above sea level, and about 1/2 km inside an energy breaking reef.

Overall, it appears that the infrequent meteorological observations at the Punta Tuna Light Station may be reason=ably suitable for short-term observations, but for long-term trends, and averages, the meteorological data taken from the San Juan station (hourly over many years) may be more practical. On board measurements are still necessary, but care must be taken to insure quality measurements.

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4.0 COMPARISON BETWEEN PUNTA TUNA AND PUNTA VACA, VIEQUES AS POTENTIAL OTEC SITES

4.1 Introduction

Throughout the measurement program, from August 1978 until June 1979, a series of measurements were made to test the hypothesis that "there is no significant difference between Punta Tuna, Puerto Rico and Punta Vaca, Vieques from an OTEC siting standpoint, as far as environmental and thermal resource variables are concerned." This investigation was not designed to consider socio-economic condition, cable costs, or land-based support. The criteria that were evaluated were available thermal resource, temperature/salinity /density structure in the water column, Mixed Layer Depth, chlorophy1 and dissolved oxygen.

Punta Vaca, Vieques is a small point of land on the southwest part of Vieques jutting into the Caribbean Sea. Much as Punta Tuna sticks out from the main island of Puerto Rico, Punta Vaca is about 40 km ENE from Punta Tuna (Fig. 115, Station "V"). Both points face southward, and are in areas of significant terrestrial mountains. Also, both are located only 3+3.5 km from the 1000 m depth contour. The bottom topography off both points is quite similar, with very rough and uneven bottom during the descent. With these similarities described, the evaluation must be made as to what, if any, are the basic differences. Punta Tuna lies in the windward path of the southeast winds and seas moving to the northwest. Punta Tuna is also exposed to northeast winds and their associated seas, as this point is virtually exposed on the southeast corner of Puerto Rico. Punta Tuna is also located about 1/2 km east of the mouth of the Maunabo River, which brings silt, nutrients, and fresh water into the oceanic area, although in small amounts.

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Fig. 115 ~ Map showing Vieques in relation to Puerto Rico,

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Punta Vaca, however, is relatively protected. This point Ifes directly northwest of the island of St. Crofx. This location tends to protect Punta Vaca from some of the strong southeast winds and their effects. Also, as Punta Vaca lies in the southwest side of the island of Vieques,

it is protected quite well from activities to the north, Such as North Atlantic Storms. There are no major rivers or streams flowing into the ocean near Punta Vaca, and further-more, as Vieques is a small island, any runoff would be even less significant than at Punta Tun:

The measurements made and samples taken at Punta Vaca were similar to those taken at Punta Tuna. The major dif-ference was that the ship was allowed to drift while on station, as there is no fixed mooring buoy at the Vieques location. This results in unusually less deep hydrocasts, due to the considerable wire angle.

During the measurement period, six cruises were conducted to the area of interest. However, on two occasions, the cruises had to be terminated before reaching the Vieques

Station. Comparative data is available only for the cruises of October and December 1978, and April and June 1979.

4.2 Results

4.2.1 Temperature Results

Reversing thermometer data of Vieques was compared with the average reversing thermometer temperature results determined at Punta Tuna. These profiles, both the Vieques values and the Punta Tuna values are seen in Figures 116-119, representing each of the 4 usable cruise results. The October 1978 results (Fig. 116), show a surprising departure from the Punta Tuna data near the surface. Apparently, near-the Vieques Station there was a very shallow mixed surface layer at that time. This may have been due to the protection from the southeast winds, as Punta Vaca lies in the lee of St. Croix. This would have reduced the wind mixing, thus reducing the MLO.

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?TEMPERATURE (°c)

DEPTH (m)

Fig. 116 ~ Temperature profile of average reversing thermone-

ter values at Punta Tuna (Station "B") vs. revers~

?ing thermometer values taken at Vieques (Station "V")

for the cruise of October, 197

218

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Fig.

117 - Temperature profile of average reversing thermome~

ter values at Punta Tuna (Station "B") vs. revers~

ing thermometer values taken at Vieques (Station

"V") for the crufse of Decenber, 1978,

219

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TEMPERATURE (°c)

z

5

8

Fig. 118 - Temperature profile of average reversing thermone-

ter values at Punta Tuna (Station "B") vs. revers-

{ing thermometer values taken at Vieques (Statfon

"V") for the crutse of April, 1979.

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?TEMPERATURE (°c)

DEPTH im)

Fig. 119 - Temperature profile of average reversing themone-
ter values at Punta Tuna (Station "8") vs, revers-
ing thermometer values taken at Vieques (Station
?v") for the cruise of dune, 1979).

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Also, the water at depths greater than 600 m appeared slightly warmer at Vieques than at Punta Tuna. The direct temperature difference between Punta Tuna and Vieques can be seen in Figures 120-123. Figure 120 shows this difference observed during the October 1978 cruise. Punta Tuna water was warmer, by up to 1.2 C®, in the upper 80.m and cooler than Vieques below 500 m. During the December 1978 cruise (Fig. 117 and i2i), less temperature difference was seen between the two stations in the upper waters. In general,

_ the surface waters were about 0.1 C° warmer at Punta Tuna, and the mixed layer structure was similar between the two locations (Fig. 121). The deeper water (400-600 m) was warmer at Vieques by about 0.6 C*, but at 800 m, the Vieques water was cooler by about 0.8 C°. This latter value may be in error, as no other case exhibits such a strong difference reversal at these depths. The error is probably in the depth values, rather than temperature. During the April 1979 cruise, (Fig. 118), again the upper mixed layer was less pronounced at Vieques than at Punta Tuna. Also, the upper waters were warmer at Punta Tuna (Fig. 122) by as much as 0.5 C® at 50m. The deeper waters differed by less than 0.25 C°, with the Vieques waters being warmer, The last cruise, June 1979, (Fig. 119 and 123) showed almost no upper mixed layer structure at either of the two stations. In the near surface waters (0-30 m), the water at Punta Tuna was slightly warmer, but directly below this, the Vieques water was more than 0.5 C° warmer (at 100 m). In the deep waters, from 600-1000 m, the water at Vieques was as much as 0.3 C® warmer.

Table 22 shows a summary of the average temperature differences between Punta Tuna and Punta Vaca, Vieques. Near the surface, the water at Punta Tuna tends to be slightly warmer, but as deep as 30m, the difference was only 0.3.C%.

In the deep water, the average difference is even less, as

expected, but occasionally a large difference is seen, result-

ing in the standard deviation at 800 m being +0.22 C*.

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Fig. 120 ~ Tenperature difference between average tempera~

ture values at Punta Tune (sation 8") ang

values at Vieques (Station "V") for the crutse

of October, 1:

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Fig, 121 - Temperature difference between average

?temperature values at Punta Tuna

[Station "B") and values at Vieques

?Station "V") for the cruise of

Decenber, 1978.

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Fig. 122 - Temperature difference between average

?temperature values at Punta Tuna

?Station "B") and values at Vieques

?Station "V") for the cruise of

April, 1979.

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* Fig, 123 - Temperature difference between

average temperature values at

Punta Tuna (Station "B") and

values at Vieques (Station "v")

?for the cruise of June, 1979.

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TABLE 22

Average Temperature Difference

Between Punta Tuna and Punta Vaca, Vieques

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20 +002 + 05

20 +03 +07

50 +04 4.28

15 +0.3 +26

100 = 0.2 £15

12s = 0.2 + .08

150 = 0.2 09

175 =o. a9

200 ° at

250 +0.3 08

300 +0.2 a2

400 <1 20

500 = 0.2 ?3

600 = 0.4 09

700 = 0.2 a4

800 ° 22

900 = 0.2 05

1000 = 0.1 +07

(+ Signifies that Punta Tuna is warmer than Vieques).

227

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4.2.2 Thermal Resource Results

More important than the occasional variations in the temperature of portions of the water column is the actual difference in the available Thermal Resource that would be usable for an OTEC power plant. Unfortunately, during two of the four comparable cruises, no thermal data is available below 800 m depth. Therefore two types of presentation will be discussed regarding the Thermal Resource. In the first the discussion will involve looking at the temperature difference between the 20 m depth and the 800 m depth, the deepest temperature common to the four cruises. The second discussion will consider only the warm water resource, and assume the deep waters are virtually equal.

The first discussion assumes that the warm water intake WiTl be located 20 m below the surface and that the cold water intake will be at a depth of 800 m. As far as thermal efficiency is concerned for an OTEC plant in Puerto Rico waters, 1000 m depth is probably required, but the 20 m to 800 m difference must be used to allow use of all the available cruise data. The lower portion of Figure 124 shows this Thermal Resource for both Punta Tuna and Vieques. In October 1978, and April and June of 1979, there is a greater Thermal Resource at Punta Tuna than there is at Vieques (by about 1/2 C*), while in December 1978 there was an exception to this trend, and the Vieques station had the greater Thermal Resource by more than 1 C°. As mentioned above, the December deep water temperature for Vieques is suspect. Therefore, it appears that the Thermal Resource at Punta Tuna is higher than at Vieques, by almost 1/2 c*,

The second part of the discussion comparing the Thermal Resources between surface and 1000 m, assumes that cold water L intake temperatures equal.? This assumption also may not be valid, but it allows a second comparison, which may help validate the first. The upper portion of Figure 124 shows the change in surface water temperature for the two stations throughout the year. In every case where surface temperature

casi

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Fig. 124 - Compatison of surface waters and thermal resource

(20 between Punta Tuna and Vieques from

Ragust, 1998 to dune, 1979,

---Page Break---

was measured at both stations, the Punta Tuna station always

showed a higher temperature, by about 1/4 C°. If the deep

water intake temperature were the same, again the thermal

resource at Punta Tuna would be greater than at Vieques.

4.2.3. Salinity Results

The salinity/depth relationship at the Punta Tuna and Vieques locations is compared to try to interpret differences in water movement that may affect either the operation of an OTEC Plant or the path of a plant's effluent (Figs, 125-128). During the October cruise (Fig. 125), the salinity of the upper water was higher at the Vieques station down to about 200 m. Below that depth the salinities were fairly similar. As mentioned in the previous section discussing the temperature results, there was less evidence of good mixing in the surface layers at Vieques than at Punta Tuna. With less mixing, the local precipitation may not be carried down as far into the mixed layer, causing higher subsurface salinities. But this can not explain the salinity difference at and below the salinity maximum depths.

To explain this difference one must assume the Subtropical Underwater (SUM) is entering into the Caribbean from the North, it may mix and diffuse slightly with time. Vieques is closer to the source of this water mass (closer to the Anegada Pass), therefore the Vieques location would be more inclined to experience original higher salinity.

During the cruise of December 1978, (Fig. 126), the vertical salinity structure at Vieques was more nearly the same as at Punta Tuna than during October. The major differences seen during December were in the lower water column.

These small, but noticeable differences could be explained by

a snall error in depth determination.

During the April 1979, cruise (Fig. 127), the mixed

layer at Vieques was not as well defined as at Punta Tuna.

This is consistent with the temperature results for this

cruise. Otherwise, the salinities are similar, Ouring June

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DEPTH (md

SALINITY (90)

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Fig. 125 - Salinity profite of average values measured at

Punta Tuna (Station "8") and values measured at

Vieques (Station "V") during the cruise of

October, 1978,

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DEPTH (m)

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SALINITY (%e)

Fig. 126 - Salinity profile of average values measured at

Punta Tuna (Station "B") and yalues measured at

Vieques (Station *V") during the cruise of

Decenber, 1978.

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DEPTH im)

SALINITY (S60)

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Fig. 127 ~ Salinity profile of average values measured at

Punta Tuna (Station "B") and values measured at

Vieques (Station "V") during the cruise of

April, 1979,

233

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SALINITY (%o)

DEPTH im!

z .

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Fig, 128 - Salinity profile of average values measured at

Punta Tuna (Station "B") and values measured at

?Vieques (Station "Y") during the cruise of

June, 1979,

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1979, (Fig. 128), the upper waters appeared similar at both stations, but the core of the SUW was thicker at Punta Tuna than at Vieques, resulting in lower salinities in the 50-150 m depth range at Vieques. Other differences occur in the Tower water column, but these appear to be artifacts of measurement errors.

4.2.4 Density Results

The density profile of the water column is compared for the two locatfons, Punta Tuna and Vieques, only as it relates to a potential effluent depth. Figures 129-132 show density vs. depth profiles for each of the four comparable cruises, respectively, for both Punta Tuna and Vieques. There is almost no difference in the density/depth profiles between the two stations on the October and December cruises (Figs. 129 and 130). This indicates the effluent dynamics would be virtually the same at the two locations. The upper water during April 1979, was more dense at Vieques than at Punta Tuna, and this difference did not disappear until a depth of about 100 m. This indicates that a mixed (warm and cold water) effluent would seek a greater depth after discharge from an operating OTEC power plant at Vieques during these conditions. As a greater equilibrium depth for the effluent may. be an advantage, this could be considered a positive indicator. During June, however, although the density-of the upper 30 m was higher at. Vieques, from about 40 m to almost 200 m, the water at Punta Tuna was more dense than at Vieques. As this is the depth range where a mixed effluent would probably be found, the structure at Vieques during this period was less desirable,

4.2.8 Mixed Layer Depth

The warm water intake for an OTEC plant will be pumped into the evaporators from the upper mixed layer of the ocean. The depth of this layer, the variation of that depth, and its Physical characteristics are then important to plant operation.

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DENSITY (07)

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Fig. 129 - Density profile of the average values observed at

Punta Tuna (Station "B") and the values observed at

Vieques (Station "Y") during the cruise of

October, 1978.

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DENSITY (Gj)

DEPTH im)

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Fig. 130 - Density profile of the average values observed at

Punta Tuna {station "B") and the. values: observed

at Vieques (Station "V") during the cruise of

December, 1978,

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DENSITY (og)

DEPTH im)

Fig. 131 - Density profile of the average values observed

at Punta Tuna (Station "B*) and the values

?observed at Vieques (Station "V*) during the

cruise of April, 1979.

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DENSITY (j)

DEPTH Im)

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Fig, 132 - Density profile of the average values observed

at Punta Tuna (Station "B") and the values

Observed at Vieques (Station "Y") during the

the cruise of June, 1979,

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Also, the dynamics of the mixed layer will determine sone

of the plant discharge design characteristics and effluent

flow patterns. The time series description of the Mixed

Layer Depth (MLD) for Punta Tuna (both from this program and from the historical averages) and Vieques is seen in Figure 133. Other than the wind and open sea sheltering effects

at Vieques (by St. Croix), there are no apparent explanations for the differences in the MLD between Punta Tuna and Vieques. During October the MLD at Vieques was much more shallow than at Punta Tuna, however, during December, the opposite was

true. During April and June the two locations had about the same MLD (Table 23). Therefore, MLO can not be used as a criteria to chose between the two, although there may be differences.

4.2.6 Chlorophyl1 Results

Figures 134-137 give the chlorophyll ?a? profile for

both Punta Tuna and Vieques during each cruise, There were

no significant differences between the two locations. Figure 138 shows the time series description of the integrated chloro-phyl1 "a" values in the upper 200 m at both Punta Tuna and at Vieques. Also shown in this figure is the time series of the surface salinity throughout the year. If the theory of the Amazon and Orinoco Rivers being the major factor influencing the surface salinity (Atwood et al. 1976) is corrected, the Periods of lowest salinity have the greatest amount of river runoff and its associated nutrients. If that were the case, the chlorophy11 "a" might be expected to reflect a negative correlation to the salinity, The waters at Punta Tuna reflect this inverse relationship during much of the year, but. the large peak, in April, is directly opposed to the theory. The values at Vieques do seem to reflect the inverse relationship, even during April. This might be explained by having the aforementioned Maunabo River influence the productivity at Punta Tuna more than might be thought. If that were the

case, Vieques could be seen as amore representative ?open ocean"

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Fig. 133 - Values of Mixed Layer Depth seen in the

historical data (OSI, 1977) and those seen

at Punta Tuna and at Vieques during the period

fron August, 1978 to June, 1979.

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TABLE 23

Calculated Mixed Layer Depth (MLD) seen at

Punta Vaca, Vieques from October, 1978 to June, 1979.

Cruise Temperature Salinity Density ?ised

Thermometer 387

october "78 tn Sim Sn BAS

Decenber ?78 ns as no

Aoi) 179 se ar)

June 178 os

CRITERIA aT = 1° AS = 1%/o9 dog 1

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CHLOROPHYLL 2" (yo/1)

Fig. 134 - Chiorophy11 ?a® profiles observed at both

Punta Tuna and at Vieques during the cruise

of October, 1978,

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DENSITY (og)

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CHLOROPHYLL a? (39/1)

Fig. 135 ~ Chlorophyll "a" profiles observed at both

Punta Tuna and at Vieques during the cruise

of December, 1978,

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DEPTH Im

DENSITY (oj)

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CHLOROPHYLL a? (pa/1)

Fig, 196 - Chloropytt "a" prafsies observed st bots

Punta Tuna and at Vieques during the cruise

of April, 1979,

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DEPTH Im)

Dewsrry (a5)

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CHLOROPHYLL a? (y9/

Fig. 137 ~ Chlorophyll *a" profiles observed at both

Punta Tuna and at Vieques during the cruise

of June, 1979,

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Pag ess

erage (qe mateo

ues during the period from

August, 1978 to June, 1979.

00m measured at both Punta

in the upper 2

= Tine series of integrated chlorophyll "a

Tuna and at Vieq

Fig. 138

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site, with less terrestrial influence. Another explanation to the April peak could be the natural patchiness of the phytoplankton producing the measured values of chlorophyll

4.2.7 Dissolved Oxygen

Dissolved oxygen may be a limiting factor to the natural recovery of an ecosystem after it experiences a serious perturbation. It is thought that a large OTEC plant bringing

the deep water up to near the surface may have an adverse effect. Figure 139 has the average dissolved oxygen profiles for both all the Punta Tuna cruises and all the Vieques stations. The two locations have dissolved oxygen concentrates that differ by less than 0.1 m1/1 anywhere in the water column. As this represents a very small difference, which 1s probably at about the limit of the measurement error, it must be assumed that the area near Punta Tuna would act similarly, with regard to oxygen availability, as that near Vieques.

4.3 Conclusions

Both the influence of the environment on an OTEC plant and the effect of an OTEC plant on its environment were evaluated to determine if there is a significant siting difference between? Punta Tuna, Puerto Rico and Punta Vaca, Vieques. From the results of this comparative work, it appears that an OTEC

plant operating at Punta Tuna would have a slightly greater

Thermal Resource available throughout the year. This advantage

would result in slightly greater thermal efficiency. The pri-

mary reason for the greater Thermal Resource is the slightly

higher surface temperature at Punta Tuna. Vieques surface

water may be more influenced by the cooler North Atlantic

water than can occur at Punta Tuna.

Terrestrial runoff may influence the Punta Tuna site

whereas it is not nearly as important at Punta Vaca. Runoff

is high in nutrients. Usually more nutrients in the surface

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DISSOLVED OxyGEN (ml)

8 as

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DEPTHIm)

Fig. 139 - Dissolved oxygen profile for the average of all values measured at Punta Tuna and the average values measured at Vieques, (Station *v"),

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waters will produce more phytoplankton. These phytoplankton may either damage the evaporator plumbing of an OTEC plant, or attract more predators, which in turn may cause problems to the plant.

The density structure in the water column will ultimately determine the vertical fate of the effluent water. There seemed to be no systematic difference in water column structure between the two sites that would favor one over the other. Chlorophy!! concentrations as well as the dis-Solved oxygen levels are the same between the sites.

In conclusion, the only significant difference between Punta Tuna and Punta Vaca, Vieques is the available Thermal Resource. Measurements made during this period from August 1978 to June 1979 indicate that the Thermal Resource at Punta Tuna is consistantly 1/4-1/2 C* greater ?than the Thermal Resource at Punta Vaca, Vieques. This amounts to a potential difference of 2-3% of the net output power from @ large operating OTEC power plant.

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5.0 COMPARISON OF PUNTA TUNA WITH CABO ROJO AND PUNTA BORINQUEN

5.1 Introduction

Serious thought is being given to the advantages and disadvantages of changing the "Benchmark", or ?most suitable site? in Puerto Rico to a location other than Punta Tuna. The three prime choices (Fig. 140) are a site off Cabo Rojo {Station "c"), on the southwest corner of the island, a site Off Punta Borfnquen (Station "R"), on the northwest of the island, and a location designated Station "F" about 17.8 km southeast of Punta Tuna, and 14 km southeast of our current "Benchmark" mooring.

Although all three alternate sites are further offshore than the Punta Tuna mooring, one or more of these sites may have advantages that could outweigh the financial and logistical problems that are related to the greater offshore distance. Because the literature indicated the prevailing water currents are to the westward, the discharge from an OTEC plant off Cabo Rojo or Punta Borinquen would have little effect on the island of Puerto Rico. If the water did indeed move westward, then both the Cabo Rojo and Punta Borfnquen sites could possibly be located 140-160 km from the next nearest influencable shoreline. That would be the eastern shore of the Dominican Republic, located in the island of Hispaflola, and separated from Puerto Rico by the Nona Passage, which is about 160 km wide.

The third alternate being considered is Station "F". There are two advantages to this site over the present Punta Tuna site. First, as Station "F* lies 14 km further south of the fsland than the present mooring, it is hoped that the discharged effluent would have less chance to impact on the coastal ecosystem due to the greater distance offshore. Secondly, as can be seen in Figure 6 (previously shown), the

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Fig. 140 - Location of Stations "C", "R", and ?F relative to the

island of Puerto Rico and its? surroundings,

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bottom at the present mooring site is steep and uneven. The area around Station "F", although almost twice as deep (1950m), fs flat to within +2m over a circle of radius of about 1 km. Mooring an OTEC plant on this flat plane may

be considerably easier than using the uneven underwater hill-side at the present mooring site.

This section is devoted to a comparison of the 4 sites from an OTEC/Oceanographic point of view, without any regard for financial or logistic difficulties. The sites will be compared with respect to temperature, salinity, density, dissolved oxygen, chlorophyll, and any oceanographic insights learned during this measurement program. The data described and compared in this section was collected during the cruise of dune, 1979.

Throughout this section the four alternate sites will be compared, and in both the text and in the figures the stations will be referred to as:

"B" ~ Punta Tuna Benchmark site

"cM - Cabo Rojo site

"RY = Punta Borfnguen site (Rincén)

"FY ~ Station southeast of "8" (Flat area).

5.2 Results

Figure 141 shows the temperature vs. depth profiles for all four locations. The data for Station "B" is the average of all thermometer values. Data for the other stations is the result of a single hydrocast at each station. No thermo-cline is evident at any of the stations, and all have nearly the same temperature, about 28°C, at the surface. The variation in surface temperature for all the stations ranged from a low of 27.84°C for Station "B" to a high of 28.14°C at "F". The temperature at 50m had more variation, from 25.98°C at "BY to 27.00°C at "C", giving "C? the smallest thermal gradiant in the surface layer.

The deep water comparison must be made at 900 m because 1000 m depths were not achieved during the hydrocasts to give

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?TEMPERATURE ¢c)

DEPTH (n}

Fig, 161 - Temperature profiles cogparing thermoseter data

measured at Stations "C', "R", and "F" with the

average data measured at Punta Tuna ("B") during

the cruise of June, 1979.

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a full depth range. The 900 m depth value shall be used as a comparative for the Thermal Resource. The temperature at 900 m ranged from 5.7°C at "B" to 7.15°C at "R*. Using the surface and 900 m values the Thermal Resource values are as listed below:

Station "F* - 22.3 c°

Station "BY - 22.1 c%

Station "C* - 21.8 ce

Statfon "R* - 20.7 c°

This clearly shows that the Stations "8" and "F" are not only similar, thermally, but superior to the other two relative to thermal resource. There is no reason to suspect that the 1000 m temperature would reveal any significant difference. Site "R", and to a lesser degree, Site "C* are effected by Atlantic water, in which the Antarctic Intermediate Water is not quite as shallow as in the Caribbean, and therefore not as cold at 900 m.

Figure 142 has the salinity profite with respect to depth for the 4 sites. Again, Stations "B" and ?F" are very similar. Station "R" is most dissimilar (although it has the same shape profile), and "C" is intermediate.

Figure 143 contains the density vs. depth profiles for the 4 locations. There is little difference in the density between any of the stations.

Dissolved oxygen profiles for the 4 stations are shown in Figure 144, Stations "B" and "F" are again very similar throughout most of the water column. Stations "C" and *R" are similar to each other, but different from the other two to a depth of about 450 m. Below this depth the values for ?c* and "R" diverge considerably, with "C" remaining less than the "B"-"F" values, All the curves have similar shape, with an oxygen maximum near the surface, (another relative maximum at about 300 m), and a minimum at about 700 m, and a characteristic increase as depth increases beyond 700 a.

An estimate of the standing crop of an area can be made by evaluating the concentration of chlorophyll ?a* in the

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DEPTH (m)

SALINITY (%0)

Fig. 142 ~ Salinity profiles comparing values measured at

Stations "Cc", "R', and "F" with the average

data measured at punta Tuna ("B") during the

cruise of June, 1979,

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DENSITY (gj)

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Eg.

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5 Fig. 143 ~ Density profiles comparing values observed at

Stations "C", "R", and "F" at Punta Tuna ("B")

during the crujse'of June, 1979.

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DEPTHIm)

DISSOLVED OxYGENI?)

Fig. 144 - Dissolved oxygen profiles conparing values

observed at Stations "C", "R", and "F" with

the average data measured at Punta Tuna ("8")

during the cruise of June, 1979.

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water column. The profile of chlorophyl1 "a" is shown in Figure 145 for the four stations. Not only does Station "C* have a strong peak at about 50 m depth, but by integrating the values from the surface to 200 m depth, the amount of chlorophyll measured at Station "C* is about twice that at either Station "B" or Station "F". Station "R? is half that at Station "BY. As the sampling time varied from day to night, and the sampling was done at descrete depths, rather than over the continuous profile, the reasons for these differences are not entirely clear. The most probable reason is the land runoff supplying more nutrients from along the entire south coast. This nutrient rich water would be carried by the westward drifting surface water intensifying the nutrient concentration near the west coast of the island, in the vicinity of Station "Cc". The wide, shallow shelf at "Cc" would also help trap these materials in the photic zone. Along the north coast they would be carried out to sea, past Station "R". With respect to the variables measured, the only difference between stations is the smaller Thermal Resource at Station "R". The other comparative evaluations offer no preference of one location over another. One impor tant factor missing is information on water currents at the sites.

Generally, surface water has been seen to move westerly

from both Station "CY and Station "R" (Metcalf et al., 19775

Duncan et al., 1977; Bane, 1965). There are strong tidal

currents in the Mona Passage (Goldman et al., 1977; U.S. Dept.

of Commerce, 1977), that move the surface water north-south

at speeds often exceeding 50 cm/sec. There are many large,

living reefs in the Mona Passage, especially along the south-

western coast of Puerto Rico, extending 5-10 km from shore

(Goldman et a1., 1977). This reef area, as well as. the other

shallow shelf communities would certainly be affected by an

OTEC plant sited at "C* or possibly even at "R", because of

these tidal currents. Another consideration is the strong

bimodal east-west water flow at Station "B" (Fig. 53). Any

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DEPTHIm)

i CHLOROPHYLL'a? (g/t)

Fig. 145 ~ Chlorophyl1 "a" profiles comparing values observed at Stations "C", "

and "E" at Punta-Tuna ("8") during

the cruise of June, 1979,

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advantage of siting a plant at either Station "C* or "R" may be eliminated if this bimodal flow is also seen to occur along the West Coast. Also, such factors as the high sediment load (so prevalent on the west coast), and the "island wake" effect during winter at Station ?R" (waves and water moving westerly along the storm driven North Atlantic wrap around Punta Borinquen and strike the West Coast from the west) must be taken into account (Wood et al., 1975a; Wood et al., 19758).

5.3 Conclusions

In conclusion, based on this one cruise and the interpretation of the data collected during that time, the only alternative location that might be considered as good, or better than Station "8" from an OTEC siting point-of-view is Station "F". This is not due to any potential improvement in the plant operating efficiency, but rather due to its greater distance from land, and the possible associated advantages, as well as the flat submarine terrain.

At present, there is not sufficient information available to suggest any other conclusions related to this siting matter.

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6.0 COMPARISON OF SOUTH COAST STATIONS

6.1 Introduction

During the June 1979 cruise, hydrocasts were made at seven stations along the South Coast from Cabo Rojo Light (west) to southeast of the Benchmark Station (Fig. 146).

The purpose of this study was to determine what spatial variability, if any, might be encountered in either the placement of or the effluent from an OTEC plant along the south coast. Measurements of temperature, salinity and dissolved oxygen were made of each station. Samples were also taken for subsequent laboratory analyses of nutrient concentration and zooplankton, but results of these analyses are not available at this tine.

Figure 146 shows the location of the stations. The cruise design was to visit stations of approximately equal depth, and therefore, of equal interest with regard to OTEC plant siting. Some stations are located much further off-shore than others. This is because the shelf is wider south of the middle of the istand.

6.2 Results

Figures 147-152 show the temperatue, salinity, density and dissolved oxygen profiles for all the south coast stations visited. The depth at Station "F" was about 2000 m, and Station "60" had a depth of 1300 m.

The spatial temperature distribution along the south coast is shown in Figure 147. Along western half, there was no apparent temperature variations. The 27°C isotherm was about 25 m shallower on the western half. The actual surface temperature varied from 28.1°C at Stations "F* to 27.6°C at Stations "GO" and "MO". Although the difference 0.5 C° is important thermodynami¢ally, the 27°C isotherm of these 3 stations varied by less than 15 m in depth, indicating the

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ee

Fig. 146 - Location of stations along the south coast of Puerto

Rico during the cruise of June, 1979.

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Fig. 147 - Temperature cross section along the south coast

of Puerto Rico, measured during the cruise of

June, 1979.

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Fig. 148 - Thermal Resource for seven stations along the

south coast of Puerto Rico for June, 1973,

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Fig. 149 - Salinity cross? section along the south coast

of Puerto Rico, measured during the cruise of,

June, 1979,

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Fig. 150 - Density cross section along the south coast

of Puerto Rico, measured during the cruise of

june, 1979.

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(2) = Horne

Fig. 151 - Geostrophic currents calculated along the south coast: of Puerto Rico. (The level of. no motion is taken to be 800 hi, (+) signifies north).

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difference is possibly only a surface ?skin effect". Since the stations were not sampled simultaneously, this difference may or may not be real.

Except for a few anomalous values, the isotherms show little variation, especially the deepest isotherm, 6°C. There is a slight temperature rise from west to east at the 900 m depth. If this rise is real it supports the theory of the source of this deep water as coming over the Jungfern Sill (Must, 1964) and moving westward, cooling as it goes,

The Thermal Resource was calculated for seven south coast stations. The temperature at 900 m was used as the cold water resource tenperature, because 900 m is the maximum depth at which all the station had determinable temperatures from our measurements. (Note- An operating OTEC plant at any of these locations would probably use water from at Teast 1000 m in condensers but unfortunately the temperature at this depth was not measured at all of the stations, and uniformity of comparison is being stressed here, not the actual usable Thermal Resource). The Thermal Resource was calculated using both the actual surface temperature and the temperature at 20 m depth for the warm water resource. These results are seen in Figure 148.

For the 0-900 m case, the Thermal Resource is fairly constant, except for the low value at Station "MO" and the high value at Station "F*. There appears to be a general trend toward an increase in Thermal Resource while moving eastward. The values ranged from 21.39 C° at Station "MO" to 22.34 C° at Station "F". The average 0-900 m Thermal Resource is 21.88 C*, with a standard deviation of #0.31 C*.

If a more realistic warm water resource is used, the temperature at the results change somewhat. In general, the average Thermal Resource for the 7 stations is now 21.54 C*, about 0.36 C° less than the surface to 900 n value. However, these 20 m depth values are more uniform, with a standard deviation of only 20.21 C°, and no east-west dependency. As this 20-900 m value 1s probably more

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representative of the subsurface warm water intake of a full size OTEC plant, it seems that there 1s little if any, indication of preferential location along Puerto Rico's

south coast to maximize the Thermal Resource.

Another feature that can be seen in Figure 148 is the amount of thermal mixing in the upper 20 m at these 7 loca~ tions. As the cold water resource is the same for both the 0-900 m depth, and 20-900 m Thermal Resource for a station. The only difference in the Thermal Resource is due to the temperature difference from 0-20 m. From this figure, the 0-20 m temperature difference appears large at Stations "ct, "SO", "B", and "F", At Stations "G0", "NO", and "JO" the water is well mixed at Teast to the 20:m depth, Apparently these stations far from shore, more exposed to the southeast winds are well mixed. Station "SO" might be thought to fall into this same category, but it is actually protected from the winds and seas, by a small sub-shelf to the south and east, thereby minimizing the oceanic mixing.

Figure 149 shows the results of salinity measurements at stations along the south coast. In this case, salinity 1s no better an indicator of water movement than temperature.

Section 3.4.1 described that the SUM was moving eastward at Station "B". The eastward motion is not denied by the temperature or salinity structure.

The transition water mass between the SUW and the Antarctic Intermediate Water (AIH), appears to be moving northward past both Stations ?C* and "B", this is shown by the virtually level isotherms in Figure 147 and the upward tilt of the isohatine below 500 m from Station "C" to Station "SO". ?The expected isopycnal tilting also can be seen in Figure 150 below 300 m depth. If this water, and the AIW below it are moving northward, they must be coming. into the Caribbean through the deep passages of the Lesser Antilles, and then departing over the deep northern passages (Anegada, Windward) and through the Yucatan Straits.

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The deeper North Atlantic Deep Water (NADW), identift- able by a salinity of 34.9 °/s. is coming oyer the Jungfern Si] (in the Anegada Pass near Station "8") and spreading in all directions to cover the Caribbean Basin. This might explain the slight rise in salinity moving westward from station "a".

Figure 151 shows the calculated geostrophic currents using the data from this cruise. There are many shortcomings with these results, a few of which are: a) the stations are not much more than 20 km apart, which is a reasonable lower scale limit for geostrophic calculations, b) at the latitute of only 18° the geostrophic calculations are still weak, and c) these calculations assume no boundary effects, either bottom, side, or top. Furthermore, in the final result, a ?level of no motion" was assumed to exist at 800 m, This is not based on any measurements only a need to normalize the results.

Along the eastern portion of the island, the geostrophic results indicate the SUW and the AIW water moving northward, probably through the Anegada Passage. The NADM is seen to be moving southward, over the Jungfern Sill, as expected. However, along the western sector, the results are more confusing, showing the SUW and transition water moving southward into the Caribbean, as opposed to that seen along the eastern profile. Because of the low values seen, and the above mentioned sources of errors, any further attempts at analysis of these geostrophic resutls are probably futile.

Figure 152 shows the dissolved oxygen distribution along the south coast. In the upper waters the dissolved oxygen concentration is somewhat higher along the eastern portion of the south coast. These waters may be more exposed to wind mixing from the southeast and the northeast. In the deeper waters, the dissolved oxygen concentration changes little from east to west, but when it does, it seems to follow the isopycnal slope.

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6.3 Conclusions

In conclusion, it appears that any south coast location could be said to have virtually the same Thermal Resource. Furthermore, if the warm water discharge will be mixed with the cold, deep water, the resulting effluent will probably be found in the boundartes of the Subtropical Underwater.

If the results of this cruise are universal, it seems that such an effluent may have a high probability of moving eastward. If this were the case, an eastern location may be more preferable. However, the other water movement results of this study indicate that this water mass may change direction frequently, giving no advantages to either east or west,

Therefore, the conclusions of this work is that the criteria that will probably influence the. particular choice of a south coast location will be logistics distance to shore, and mooring considerations, rather than thermodynamic or biological considerations.

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7.0 SUMMARY OF RESULTS

Temperature measurements made throughout the year show that there 1s almost no seasonal change in the deep-water (1000 m) temperature at Punta Tuna. The surface water ten-perature does vary seasonally, yielding a Thermal Resource of about 20-23 C* and a mean value of 22.1 + 1.0 C*. During June this Thermal Resource did not vary along the entire south coast of Puerto Rico. The Thermal Resource off the norhtwest coast, near Punta Borinquen is smaller because of a 2 C° warmer deep-water temperature. The Thermal Resource off Punta Vaca, Vieques is about 1/2 C* less than that at Punta Tuna.

The Mixed Layer Depth was found to vary seasonally from a depth of as much as 90 m during the winter, when the weather 1s more rough, to virtually zero in the summer, when the weather is calm. Since the warm-water intake for a full size OTEC power plant will probably be at a depth of 20-25 m. it is possible that a plant off Punta Tuna might draw water from below the MLD during part of the summer.

Very Iittle is known about the water currents around Punta Tuna. During this program both diurnal and semi~ diurnal tidal components were seen moving east and west along the south coast. Also seen were a predominance of east-west

Movement at various depths down to about 500 m, however, other compass directions are not insignificant. Water motion at depths of 650-750 m usually is towards the northeast or northwest. This little knowledge is insufficient to predict dynamics of the intake and discharge from an OTEC plant,

Much of the temporal and spatial dynamics of the .chemical and biological interactions are stil1 poorly understood for the Punta Tuna area. The results of this program simply emphasizes the lack of depth of understanding of these systems and their interactions as they would affect and be effected by an OTEC power plant.

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8.0 RECOMMENDATIONS

AS a result of both the field program, discussed in this report, and the physical and biological oceanographic literature search conducted for the Punta Tuna area, under this same contract, the following recommendations are given. The purpose of these recommendations are to minimize the field work where there is now adequate information, and maximize the field efforts to emphasize the serious deficits ?in the present knowledge of the area. Those recommendations with two asterisks (**) should be given the highest priority. The recommendations with a single asterisk (*) should receive a moderate priority. The other recommended activities are important, but of a lower priority with respect to the future measurement programs at the Punta Tuna area.

1, Temperature

*4a) of the mixed layer, using thermometers, STD, or XBT (daily), when possible, for short-term variations.

12) to 200m, using recorded monitoring equipnent for upper water thermal structure during severe weather events. $

if

*c) in the water column to 1000 m, using thermometers STD, or XBT (monthly) for ecological Structuring and plant design purposes.

4) of the actual sea surface and the mixed layer, using thermometers, STD, XBT, and satellite (whenever the satellite data will be available) to correlate the ?satellite sea surface temperature monitoring with the mixed layer temperature.

e) of the mixed layer, using thermometers, STD,

and XBT (weekly), for ecological structuring.

2. Thermocline depth

ta) using X8T (daily, when possible, otherwise

weekly), to anticipate discharge dynamiese

3. Salinity

*2) to 200 m depth downstream, at discrete depths

or with STD (biweekly), to assess the density structure

for water discharge.

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*b) in the water column, at descrete depths (monthly

or bimonthly), for ecological structuring.

*c) to 200 m, using recording equipment, to deter-

mine vertical movement of water masses and salinity

structure (during severe weather events).

4) in the mixed layer, at the benchmark site, at

descrete depths, (weekly), to correlate with the rainfall in the surface water mass at its source area (the Amazon and Orinoco Rivers), for predictive purposes.

4. Mixed Layer Depth

+a) using STD or XBT (daily, if possible), for engineering design requirements.

*>) using recording equipment with thermister strings, to monitor thermal resource variation during severe weather events,

5. Internal waves

*a) at one site in the Caribbean and one in the Atlantic measuring both amplitude and period, by monitoring the temperature profile with recording thermister strings, to determine the effect of the variation of the horizontal thermal structure (due to large amplitude Tong waves) on intake and outlet.

6. Wave spectra-surface

a) at one Caribbean and one Atlantic site, using a recording wave rider, to determine the long-tern

wave spectra for plant and personnel safety.

7. Mater currents

*a) using current profiters, (4 per day on a weekl

basis), to supplement the moored dates with-eaphasts

during? the tidal periods.

**b) using moored, recording current meters at

déscrete depths, to determine the stress to the plant

mooring and deep water pipe, and to estimate the long

and short-term eulerian movement of water past the site

for intake and discharge.

8. Mater trajectory

__*a) using drogues above and below the thermocline,

(bimonthly for 2-8 days), to determine the trajectory

uston and plume dynamics of the plant discharge.

9. Zooplankton

a) at the site and downstream, using a suitable

mesh net, at descrete depth intervals, (hourly for 48

hours, bimonthly) to determine the patchiness of the zoopTankton population.

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*b) at the site and downstream, using a suitable mesh net, at descrete depth intervals (daily for a week, bimonthly) to determine the short-term varTations Yn the zooplankton population.

c) at the site and downstream, using a suitable mesh net, at descrete depth intervals, (weekly), to deterning the mid-term seasonality of the sooplankton population.

47d) tt the site and coynstrean, using a suitable mesh net, at descrete depth intervals, (monthly or bimonthly), to determine the seasonal patterns of the ZoopTankton population.

?**e) in all of the above zooplankton sampling cases, it is necessary to replicate each tow at least once (more often, if possible), replicate subsamples from each tow, and repeat the analysis on each final aliquot to determine the statistical nature of the zooplankton population.

10. Chlorophy11

**a) either at descrete depths or by pumping through-

out the upper 200 m (bthourly for 48 hours, quarterly), to determine the normal short-term tenporal variability.

*b) at the sites and downstream, at either descrete depths or by pumping throughout the upper 200 m (bimonthly), to determine the chlorophyll distribution for ecological structuring.

11. Phytoplankton

*a) at the sites and downstream, at descrete depths in the upper 200 m by net or bottle, (bimonthly), for counting and identification to determine the spatial distribution and species present for ecological struc-turing.

*#) at descrete depths in the upper 200 m (bihourly, terly), for counting and identification to determine Statistics related to patchiness.

12. Primary productivity

*a) at the site and downstream (weekly), to determine

the productivity rates for ecological structuring.

13. Deep Scattering Layer

a) at the site monitor the depth and thickness, and the components of the Deep Scattering Layer, (hourly for 48 hours bimonthly), to determine the vertical dynamics of the Ost.

14. Nutrients

*a) downstream along the 200 m isobath, at descrete depths, (bimonthly), to determine if normal upwelling exists, for ecological structuring.

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*b) downstream in the plume from the sites, at discrete depths throughout the water column, (monthly), for ecological structuring.

*c) at the benchriark site, at discrete depths (bihourly for 48 hours, quarterly) to determine temporal vartation-

15. Trace metals

*a) at the site near the surface and bottom and mid-
depths (monthly) to determine the background trace
metal levels tm the area.

*b) at the site and downstream, in organisms near
the surface and mid-depths to determine the background
trace metals and the fate through the food chain in the
area

16. Particulate matter
Ya) at the site, at 10-25 m depth (bihourly for 48

hours bimonthly) to'determine the extent, size distri-

Button, and components of potential intake matter.

17. Bottom sampling

*a) at and around the site (once) to determine the
smal] scale bottom materials and topography for anchoring
and turbulence effects.

18. Fish attraction

*a) in upper waters from a moored structure, to determine attraction effects of a floating pelagic structure.

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APPENDIX A

CRUISE REPORT AND DATA FROM OTEC CRUISE #1 (CR-801)

31 JULY - 3 AUGUST 1978

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CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

CRUISE REPORT

OTEC CRUISE #1 (CR-801)

31 July - 3 Auguct 1978

by

Gary C. Goldman, Chief Scientist

2e5

'NAILING AOONESS: CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, COLLEGE STATION, MAYAGUEZ, PUERTO RICO 00708

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CRUISE REPORT

OTEC Cruise #1 (CR-801) 31 July - 3 August 1978

Objective:

A. Measure oceanic parameters

at Punta Tuna, P.

B. | Measure the variability of the above parameters.

Cl Evaluate and develop techniques for measuring

these paraneters.

atable to "OTEC"

II, Research Vessel:

R/V CRAWFORD (University of Puerto Rico).

III. Supporting? Agency (ies

A. U.S. Department of Energy (LBL).

B. P.R. Water Resources Authority.

Cl UPR/CEER.

IV. Dates of Cruise:

31 July - 3 August 1978.

V. Cruise Plan:

See Appendix IE. (Not included)

VI. Scientific and Technical Personnel:

C, Bonafe -- Technician

D: Corales -- Technician

G! Goldman -- Shief Scientist

A. Horn -- Visiting Scientist (LBL)

?AL Nazario -- Technician

D! Pesante -- Biological Coordinator

J. Rivera -- Scientific Assistant

J. Sandusky -- Visiting Scientist (LBL)

M. Shafnacker -- Technician

VII. Station Locations:

See attached Cruise Plan, Appendix Hy (Not included)

VIII. Types of Sampling:

See attached Cruise Plan, Appendix IZ, (Not included)

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XI.

XII.

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Land Trave!

34 July 1978. All personnel and equipment were

transported to Magueyes. CEER vehicles (truck and Ramcharger) took most of the equipment from CEEE/ Mayaguez. Rental station wagon (LBL) brought Sandusky, Horn and Bullock (capt. of CRAWFORD) plus LBL equipment to Magueyes. CEER vehicles (Ramcharger and station wagon) transported remainder of personnel. All CEER vehicles were returned to Mayaguez and drivers (members of scientific/technician staff) returned to Magueyes in LBL station wagon,

3 August 1978. LBL station wagon used to transport some personnel to Mayaguez, then returned with CEER Ramcharger for remainder of personnel. LBL stat?an wagon remained at Magueyes for use by LBL personnel and equipment.

<4 August 1978. CEER Ramcharger and truck used to bring CEER equipment from Magueyes to Mayaguez.

Reasons for termination of cruise

Hydrographic separated, leaving apparently weakened

cable.

B. Starboard screw not getting power.

C. Potential tropical depression in next 12 hours.

D. Lack of ship's crew supplying winch operator,

?thereby overtaxing the scientific/technical personnel,

Accomplishments:

A. Collected much of data from stations B-1 to B-6.

B. Evaluated data collection techniques of staff

and equipment.

Changes to be effected:

A, Not take unnecessary equips

B. Correct transmissometer reading problem.

©. Correct XBT problem.

D. Install mooring at Station "B".

£. Use "Bucket" method for chlorophyl sampling from

Niskin bottles.

F. Minimize current meter underwater time.

G. Request UPR change cable, repair BT winch and stern

, $aPStan, and supply 24-hour winch operator.

+ Improve? transmissometer cable deployment.

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spauuetd se ?2-q Jo peoasur t-g 3e saT;yoag-ywauung AaeuoTseas a43 pardess ATTENIOV O--

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(Z 230N) S~GLs (3 930N) T-sueaL

(2 P30N) S-1GX(H ION)T~SVOOTA NiL?BSoLt MiT~9HoSY ?OOBT-GOT Ls BAY ZOU

(2 220N) h-dus

(2 ®30N) n-2ex e-auadang NBS oLT MES 0S ooso-cezo © BLy Baye asm

s+ Aysnpueg souep ?sq 90g vs-a 2

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(@ 230N) e-ais e-uoaquetg

(2 ®30N) E-LEX (1 P30N) Z-OUGAH NiB'LSoLT MizZS-0S0S9 ? OENO-GOZZ BL,BNV e-T HU,

(z 230N) Lax B-uOaNUETd NiE?LSoLTMZ*ES- 1905959 Gedz~Sz0Z Ls BOVE En

(2 230) é~aLs

(Z 230N) 2-4ax z-auasang NB°BSoLT Mo6'TS0S9 ? OUBT-OELT BL, BMY ET 2-B

(0 @30N) F-ausaang

(2 920%) T-aLs r-uoaXueTa,

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+yaon 30 PEP

sapaovas Jax *9Tqeadeoor ou sem pur ?ar yaeK ?HezaEH Sem YaID Aq peTTddns GIS

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August 7, 1978

Biological Report

Daniel Pesante

According to the plan of work, eight zooplankton samples

were to be obtained from the proposed site.

4) 25 m day.)

2) 25 m night)

3) 1200 m to SFC)

4) 1200 m to 800 m) Punta Tuna

5) 800 m to 200 m)

8) 200 mto SFC)

7D 28m)

8) 800 m to 200m) Vieques

Of the eight samples only four were gathered as, while making the fifth tow, the hydrographic cable broke and the net and complementary equipment were lost (included in

Dr. Goldman's report). Further use of the cable was cancelled as it proved to. be a big risk.

Getting acquainted with the zooplankton sampling gear was no problem, although extreme care had to be taken in rolling the net tightly to the D.T.M.

My-main concern at this point is that of knowing the exact depth at which the sampling gear is located. Due to nigh wire angles (60°) and to unknown subsurface currents, the position of net at sampling time could not be estimated accurately. For this reason a pinger should be purchased and coupled to the CRAWFORD ecosounder system. This will prove very useful, not only for the zooplankton sampling but also for all other sampling procedures where the exact depth of sampling has to be observed.

Included is a report on the biological organisms observed during this first cruise.

20

---Page Break---

0-79-78

Observations concerning biological specimens observed during

OTEC Cruise #1.

organ:

family and/or scientific name is

Tursiops truncatus

Fregata magnificens

Caranx

- Thalassia leaves ~

~ Sargassum natans -

Fluitans -

291

included.

were observed during day or night hours.

ugh the number of individuals could not be estimated, the

Porpoise

Blue Marlin

Terns ~

Jacks

white

Tigerillas

Cojinua

Boba

Flying fish

Trigger fish

Barracuda

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WEATHER CODE FOR DATA SHEETS

(ANI times are Atlantic Standard Time (AST) = GNT - 4 hours)

7 KT/130°, 91°, 47%, 1, 150°

7 KT = Wind Speed (kT)

130° = Wind Direction - from (Deg)

91° = Air Temperature (*F)

47% = Relative Humidity (5)

1 = Wave Hefght (m)

150° = Wave Direction - from (Deg)

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FE Bs Salb Bow

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SIZE CLASS SIZE IN MILLIMETERS

1 <0.5

2 0.5 - 0.9

3 1.0 - 1.9

4 2.0 - 2.9

5 3.0- 3.9

6 4.0 - 4.9

7 5.0 - 5.9

8 6.0 - 6.9

9 7.0 - 7.9

10 8.0 - 8.9

n 9.0 - 9.9

12 10.0 19.9

13 20.0 - 29.9

14 30.0 = 39.9

15 40.0 - 49.9

16 > 50.0

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DATE:

STATION NUMBER:

SHIP:

TINE:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPT!

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF Tow:

LATITUDE:

LONGi TUDE:

SEA STATE AND WEATHER:

1 August 1978

BENCHMARK.

CRAWFORD

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801-1

CONICAL 5:1

2024

0.75 m

HORIZONTAL,

25m

60m

60°-65°

26082

20 min

17° 57.8'N

65° 51.0'W

ss#1-2

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DATE:

STATION NUMBER:

surP:

Tame:

SAMPLE NUMBER:

TYPE OF NET:

NESH SIZE:

RINS SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

NETERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF TOW:

Lari tupe:

Losi TUDE:

SEA STATE AND WEATHER:

1 August 1978

BENCHMARK

CRAWFORD

2018

#2

CONICAL

202u

0.75 m

HORIZONTAL

25m

60m

55°-60°

026793,

046057

10 min

17° 58.3'N

65° 51.2'W

ss2

304

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DATE:

STATION NUMBER:

SHIP:

TIME:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF TOW:

LATITUDE:

LONGITUDE:

SEA STATE AND WEATHER:

2 August 1978

BENCHMARK #3

CRAWFORD

1:30

8

CONICAL 5:1

202u

75m

OBLIGUE

1,200 m SFC

1,300

50

106724

201189

47 min

17° 57.8''

65° 50.2'W

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APPENDIX B

CRUISE REPORT AND DATA FROM OTEC CRUISE #2 (JE-802)

10-14 OCTOBER 1978

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(CRUISE REPORT

OTE CRUISE #2 (JE-802)

10-14 October 1978

i by

Gary C. Goldman, Chief Scientist

314

a 70 Rico C0708

IAILING ADDRESS: CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, COLLEGE STATION. MAYAGUEZ, PUEE

---Page Break---

CRUISE REPORT

OTEC Cruise #3 (JE 802) 10-14 october 1978

I. Objectives:

A. Measure oceanic parameters relatable to *OTEC" at Punta

Tuna, P. Re

Measure the variability of the above parameters.

Evaluate and develop techniques for measuring these parameters.

Measure variability of the parameters at Punta Vaca.

Measure water currents at two other sites.

IT. Research Vessel:

RW Jean A (P.R, Department of

III. Supporting Agencies:

A. U.S. Department of Energy? (LBL)

B. P:R. Water Resources Authority

cc. UPR/cHER

IV. Dates of Cruise:

10-14 october 1978

cruise Plan:

See Appendix 1x (Not included)

VE. Scientific and Technical Personnel:

. Bonage ?- Technician

D. Corales ? Technician

G. Goldman ~~ chief Stientist

?Technician

Biological Coordinator

3. Rivera ~~ Scientific Assistant

M. Shafnacker ~~ Technician

VII. Station Locations:

See attached Cruise Plan, Appendix IT (Not included)

VIII. types of Sampling:

See attached Cruise Plan, Appendix IX (Not included)

315,

---Page Break---

x.

Land Travel:

--26 September 1978. A11 personnel and equipment were transported

to Magueyes. CEER vehicles took the equipment from CEER/Mayaguez.

After aborted attempt to depart on R/V CRAWFORD, all personnel

remained on board CRAWFOKD until the following sorning.

=--27 September 1978. Al1 personnel were transported to Mayaguez

using CEER vehicles. equipment remained aboard CRAWFORD.

=~ 9 October 1978. R/V JEAN A departed from San Juan to rendezvous

with scientific personne! in Mayaguez.

10 October 1978. ALL personnel were transported from CEER/

Mayaguez to Malecon port in Mayaguez using CEER vehicles.

14 October 1978. ALL personnel were transported from Malecon

port in Mayaguez to CEER using CEER vehicles.

Reasons for termination of cruise

Completed virtually ali planned operations.

Accomplishments:

AL Collected most of data from Station ?

transni seio

B, Evaluated data collection technigues and sample preservation

and processing.

©. Collected all data from station *P*.

D. Collected ali data from Station "A"

E. Collected all data from Station °V".

F. Did not get Bathymetric data for Station "B? and "A".

G. Seemed to take only necessary equipment (see last Report) .

H. > Corrected XBT problem (See last Report) -

I. Used mooring at Station "B* (see last Report) -

J. Tried and successfully used "Bucket Method" for chlorophyll

?sampling (see last Report)

= only missed

Changes to be effected:

A. ?Try transmissoneter cable deploynent.

BL Minimize current meter underwater time.

?. Find reliable, useable, available vessel of sufficient size.

D. Try to charge battery at "S* mooring.

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2o-minute horizontal tow at 25 m depth.

Cnty 900 m of hydrocable, therefore, only sampled to 800 x.

Vertical tow 800 m to 200 a.

Vertical tow 200 m to surtece.

only 900 m of cable, £0 no 1100 m plankton tow was possible.

?Tried 900 m to surface, but double trip mechaniam on net mal-

functioned repeatedly, and Finally lost the net.

Verticle (oblique) tow 800 - 200 m.

Verticle (oblique) tow 200 m to surface.

20-minute tow at 25 m depth during night.

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(CRUISE REPORT FOR BIOLOGY DIVISION OTEC, P. R.

During the dates of Uetober 10-14, 1978, the second field trip to

Punta Tuna and the first field trip to Vieques took place. Of the ciaht samples taken by using the Double Trip Mechanikm with the 200 plankton

nets, only three samples are representative of the stratums sampled.

?These are the 25 m at Punta Tuna ~ day, 25 8 at Punta Tuna ~ night,

200 m = SFC at Punta Tune,

Due to malfunction of the DTH and the fact that the R/V JEAN A had

only 900 m of hydrocable, no other samples could be obtained. On

arrival from the cruise, and through personal communication with per~

sonnel fron Gencral Oreanics, different alternatives were delincated in

order to increase the percent of access of the zooplankton sampling

Mechanicel malfunction at the level of the second phase of release

Of the not wax the main problem as the first messenaer, would actuate

both first and ancond phases of the sampling procedure, making it

Impossible ta cbtoin: the samples.

?The fact chat @ buoy was installed at the benchmark site at Punta

?Tune hes somewhat changed the environment in the sense that fish are

congregating around ang under the buoy

Poinhin Fish and sharks up fo 100 in number were renn at thie ty

Guring ditferent Limes of the day. As of this date the List of spucius of those animals found around the buoy 1s being worked out.

Sea States of SS # 2-3 were observed during this cruise.

319

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WEATHER CODE FOR DATA SHEETS

(ANI times are Atlantic Standard Tine (AST) = GHT - 4 hours)

7 xT/130", 91°, 47%, 1, 150°

7 KT = Wind Speed (KT)

130° = Wind Direction - from (Deg)

91° = Air Temperature (°F)

478

Relative Humidity (2)

Mave Height (m)

150° = Wave Direction - from (Deg)

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DEPTH To BoTTON __ ee, SwLE mR

(CRUISE _se.an2__ STATION 2.1 Bev DATE _15 Detonen 2020 WEATHER aora3s*, 70", 9st. 1.

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SIZE CLASS	SIZE IN MILLIMETERS
1	£05
2	0.5 - 0.9
3	1.0 - 1.9
4	2.0- 2.9
5	3.0 - 3.9
6	4.0- 4.9
7	5.0 - 5.9
8	6.0- 6.9
9	7.0 - 7.9
10	B.0- 8.9
1	9.0 - 9.9
12	10.0 19.9
13	20.0 - 29.9
4	30.0 - 39.9
15	40.0 - 49.9
16	> 50.0

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DATE: 11 October 1978

STATION NUMBE! BENCHMARK #1

SHIP: JEAN A

TIME: 0935

SAMPLE NUMBER: 5

TYPE OF NE CONICAL 5:1

MESH SIZE: 2020

RING SIZE: a4

TYPE OF HAUL: HORIZONTAL,

SAMPLING DEPTH: 2m

METERS OF WIRE: 63m

anste: 55°-60°

FLOWMETER START: 004459

FLOWMETER FINISH: 0036174

LENGTH OF TOW: 10 min

LATITUDE: 17° 57.6'N

Loni Tube: 65° 51.9'¥

SEA STATE AND WEATHER: go

The quantities in the following data sheets are #/m?.

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DATE: 11 October 1978

STATION NUMBER:

BENCHMARK

sup: JEAN A

TIME: 1543

SAMPLE. NUMBER: 6

TYPE OF NET: CONICAL 5:1

MESH SIZE: ay

RING SIZE: 202u

TYPE OF HAUL: VERTICAL

SAMPLING DEPTH: 800-200

METERS OF WIRE: 810

ANGLE: o

FLOWMETER START!? 0036827

FLOWMETER FINISH: 077330

LENGTH OF TOW: 17 min

LATITUDE: 17" 57.6"

LonsiTuoe: 65° 51.9%"

SEA STATE AND WEATHER: #2

The quantities in the following data sheets are #/m?.

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341

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DATE: 11 October 1978

STATION NUMBER: BENCHMARK

SHIP: SEAN A

TIME: 2205

SAMPLE NUMBER: 7

TYPE OF NET: CONICAL 5:1

MESH SIZE: 3/4m

RING SIZE: 202u

TYPE OF HAUL: VERTICAL

SAMPLING DEPTH: 200 SFC

METERS OF WIRE: 230

ANGLE: 0

FLOWMETER START: 077332

FLOWMETER FINISH: 089374

LENGTH OF TOW: 17° 57.6'N

LATITUDE: 65° 51.9'W

LonciTuve:

SEA STATE AND WEATHER:

The quantities in the following data sheets are #/m°.

342

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346

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DATE: 13 October 1978

STATION NUMBER: BENCHMARK

SHIP: EAN A

TIME: 0030

SAMPLE NUMBER: oy

TYPE OF NET: CONICAL 5:1

MESH SIZE: 202"

RING SIZE: 75m

TYPE OF HAUL: HORIZONTAL

SAMPLING DEPTH: 250

METERS OF WIRE: 65

ANGLE: 70

FLOWMETERY START: 102682

FLOWMETER FINISH: 142790,

LENGTH OF TOW: 10 min

LATITUDE: 17° 57.6'N

LONGITUDE: 65° 51.9'W

SEA STATE AND WEATHER: 42

The quantities in the following data sheets are #/n?,

347

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APPENDIX C

CRUISE REPORT AND DATA FROM OTEC CRUISE #3 (CR-803)

1-5 DECEMBER 1978

351

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CRUISE REPORT

OTEC CRUISE #3 (cR-803)

1-5 December 1978

by

Gary C. Goldman, Chief Scientist

352

MAILING ALIORESS: CENTER FOR ENERGY AND ENVIRONMENT RESEARCH COLLEGE STATION, MAYAGUEZ, PUERTO RICO 0708

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(CRUISE REPORT

Orec.cruise #3 (CR 803) 1-5 December 1978

I. Objectives:

A. Measure oceanic paraneters relatable to ?OTEC* at

Punta Tuna, P. R.

1B. Measure the variability of the above paraneters.

. Evaluate and develop techniques for measuring these paraneters.

D. Measure variability of the parameters at Punta Vaca.

B. Measure vater currents at two other sites.

II. Research Vessel:

R/V CRAWFORD (University of Puerto Rico)

IIT. Supporting Agencies:

A. U. 8. Department of Energy (LBL)

BLP. R. Water Resources Authority

cl UPR/cEER

IV. Dates of crui

1-5 Decenber 1978

VY. Cruise Plan:

See Appendix Ir (Not included)

VI. Scientific and Technical Personnel:

c. Bonafé ? technician

D. Corales -~ Technician

G. Goldman -- chief Scientist

B. Gonzitez ~~ Technician

A. Nazario ~ Technician

R. Noble ~- Visiting Contractor

D. Pesante ~- Biological Coordinator

J. Rivera =~ Scientific Assistant

M. Shafnacker -- Technician

VIZ. Station Locations:

See attached Cruise Plan, Appendix 1X (Not included)

VEIT. types of Sampling:

See attached Cruise Plan, Appendix IZ (Not included)

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x.

xr.

?travel:

w= 1 Decesber 1978. R/V CRANPORD departed from Magueyes to rendevout

with scientific personnel in Mayaguez at Malecon Port.

=-- 1 December 1978, ALL personnel were transported from CEER/

Mayaguez to Malecon Port in Mayaguez using CER vehicl

== 5 December 1978, All personnel were transported from Malecon

?RV CRANFORD

Reasons for termination of cruise:

Completed virtually all planned operations.

Accomplishments.

A. Collected all of data from Station "B".

Bvaluated data collection techniques and sample preservation

and processing.

Collected all data from station "P*.

D. Collected all data from Station "A".

B. Collected all data from Station "V".

F. Did not get Bathymetric data for Station ?B? and "A".

G. ?ried unsuccessfully to repair burned out Light on buoy.

changes to be effected:

Conbine our operations with those of recovering and

re-nooring current meters.

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356

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Notes

This cast would have been made for Dr. Sandusky, if he were on the ruts

Rotor bearing malfunction -- no speed record.

Bearing repaired, recorder malfunction

no record.

387

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CHUISE [FROM ZOOPLANKTON ?SUB-DIVISION

on this last cruise (CR-803), all zooplankton samples were collected.

?Through previous trial of the nets and:mechanien at the Mona channel, it

was possible to find out vhat was wrong with the mechanism. Correction

for the weight of the first messenger resulted in 1008 rate. of success

at all sampling depths, even in relatively rouh seas.

?The biota reported for the? last cruise (CR-802) is the sane for this cruise. A steady population of sharks is still present at the buoy.

Samples collected were practically devoid of particulate matter, a factor which will speed the processing of the data.

A prima facie observation of the samples revealed the présence of medusae land a leptocephallus which had not been collected before.

X am very pleased with the outcome of this last cruise.

Dev Sida

Daniel Pesante

Biological Coordinator

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WEATHER CODE FOR DATA SHEETS

(ANI times are Atlantic Standard Time (AST) = GMT = 4 hours)

7 KT/130°, 91°, 47%, 1, 150°

7 KT = Wind Speed (kT)

130° = Wind Direction - from (Deg)

91° = Air Temperature (°F)

47% = Relative Humidity (2)

1 = Wave Height (m)

150° = Mave Direction - from (Deg)

360

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SIZE CLASS SIZE IN MILLIMETERS

1 £05

2 0.5 - 0.9

3 10-19

4 2.0 - 2.9

5 3.0 - 3.9

6 4.05 4.9

7 5.0 - 5.9

8 6.0 - 6.9

9 7.0 - 7.9

10 B.0- 8.9

i 9.0 - 9.9

12 10.0 19.9

13 20.0 - 29.9

14 30.0 - 39.9

15 40.0 - 49.9

16 > 50.0

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DATE:

STATION NUMBER:

SHIP:

TINE:

?SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINIS

LENGTH OF TOW:

LATITUDE:

Lonsi uve:

SEA STATE AND HEATHER:

2 December 1978

BENCHMARK

CRAWFORD

1533,

#3

CONICAL 5:1

2020

75m

VERTICAL

800-200

810

299208,

324182

20 min

17° 57.3."

65° 52 W

SS #1-2

374

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375

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Ta SESS POUT

376

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44

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DATE:

STATION NUMBER:

SHIP:

TIME:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF TOW:

LATITUDE:

LONGITUDE:

SEA STATE AND WEATHER:

2 December 1978

BENCHMARK

CRAWFORD

1309

#138

CONICAL 5:1

202"

75m

VERTICAL,

1000-800m

1000

o

272933,

299208

8 min

17° 57.3.N

65° 52 W

ss#1-2

378

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381

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DATE:

STATION NUMBER:

SHIP:

TINE:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIR

ancte:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF Tow:

LaTiTuoe:

LonG1 TUDE:

SEA STATE AND WEATHER:

2 December 1978

BENCHMARK

CRAWFORD

1636

4

CONICAL 5:1

202y

75m

VERTICAL,

200-sFC

210

oO

324185

330980

17° 57.3.N

65° 52 W

SS #1-2

382

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383,

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385

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DATE:

STATION NUMBER:

SHIP:

TIME:

SAMPLE? NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF To!

LATITUDE:

LonGi Tube:

SEA STATE AND WEATHER:

3 December 1978

BENCHMARK

CRAWFORD

2:50

CR 803-15

CONICAL 5:1

0.75 m

202u

HORIZONTAL

25m

60

60°

331010

368064

10 min

17° 57.3%

65° 52.4

#1-2

386

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38a

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DATE:

STATION NUMBER:

SHIP:

TIME:

SAMPLE NUMBER:

TYPE. OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

NETERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF Tow:

LatrTupe:

LONGI TUDE:

SEA STATE AND WEATHER:

2 December 1978

BENCHMARK

CRAWFORD

2080

CR 803-16

CONICAL 5:1

202u

75m

HORIZONTAL

25m

60m

60°

379446

414005

10 min

17° 57.3.N

65° 52 W

390

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APPENDIX D

CRUISE REPORT AND DATA FROM OTEC CRUISE #4 (BA-804)

10-16 FEBRUARY 1979

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rN,

&) CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

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CRUISE REPORT

OTEC CRUISE #4 (BA~804)

10-16 February 1979

by

Gary C. Goldman, Chief Scientist

396

[MAILING ADORESS. CENTER FOR ENERGY ANO ENVIRONMENT RESEARCH, COLLEGE STATION, MAYAGUEZ, PUERTO RICO C0708

---Page Break---

CRUISE REPORT

OTEC CRUISE #4 (BA-804) 10-16 February 1979

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1.

Vv.

vr.

vir.

objectives:

A. Measure oceanic parameters relatable to OTEC AT

Punta Tun

B. Measure variability of these oceanic parameters

at Punta Vaca. -

. Measure water currents at 3 other stations.

0. Recover current meter mooring at a station.

E. Implant current meter moorings at 2 stations.

Research Vessel:

USNS BARTLETT (T-AGOR+13)

Supporting Agencies:

A. U.S. Department of Energy

B. Lawrence Berkeley Laboratory

C. PLR. Water Resources Authority

D. ULSIN.- Underwater System Lab.

EL UPR/CEER

Dates of Cruise:

10-16 February 1979

Cruise Plan:

See Appendix II (Not included)

Scientific and Technical Personnel:

C. Carmiggeit_- Visiting Scientist (LBL)

D. Corales - Technician (CER)

M. Commins - Visiting Scientist (LBL)

M. Fecher ~ Oceanographer (USNUSL)

G. Goldman - Co-Chief Scientist (CEER)

E! Gonzalez - Technician (CER)

T. Morgan - Scientific Assistant (CEER)

KI Nazario - Technician (CER)

R. Noble - Co-Chief Scientist (uswust)

D. Pesante - Biological Coordinator (CEER)

M. Shafnacker - Technician (CEER)

Station Locations:

See Attached Cruise Plan, Appendix II. (Not included)

---Page Break---

VIII. Types of Sampling:

A. See attached Crufse Plan, Appendix I

B. Botton sampling.

IX, Travel:

(Not included)

<-- 9 Feb. 1979. USNS BARTLETT arrived at Malecon Port, Mayaguez, P. R.| All above personnel (except Carmiggelt and Commins) "were assembled by that time, Flat bed truck, and Grane were used to move Mr. Noble's material from Guanajibo laboratory complex to Malecon and onto the vessel. CEER vehicles carried the rest of the materials.

10 February 1979. Al] personnel assembled on board and ship departed about 1300 local time.

z-- 16 February 1979. Flat bed truck and van were used from Mayaguez to carry the equipment from Roosevelt Roads Naval Base to Mayaguez. Equipment was transferred to vehicles b: hand and using USN supplied cranes. Vehicles left Roosevelt Roads area about 1430 and arrived Hayaguez about 2015 carrying T. Morgan and 0. Corales. Other CEER personnel were transported by taxi from Roosevelt Roads to'Ista

Verde airport, San Juan, from where, they travelled by

air to Mayaguez, and by CEER vehicle to the Guanajibo Lab. LBL people departed on'16 Feb. also. USNUSL people were to depart 17 February.

X. Reason for termination of cruise:

Vessel suffered collision at sea with USN submarine,

and suffered severe, but not fatal damage.

IX. Accomplishments:

A. Collected virtually all data from station "B*

(exception is nite horizontal plankton tow).

B. Collected al] data from Station *

?. Collected al1 data from Station "F*

D. Recovered mooring from "A-1".

E. Implanted mooring at "F-1".

F. Did not get to Station ?P*.

&. Did not get to Station ?V

4: Did not implant mooring "a2.

I. Did not collect any current meter profile data

while vessel was drifting.

398

---Page Break---

XII.

Changes to be affected:

A. Evaluate reducing volume of chlorophyll water

sample.

B. Evaluate separating mooring operation from

hydro operations.

C. Evaluate coring operation in area.

399

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BIOLOGICAL REPORT

Some difficultes encountered with the sampling of

Zooplankton due to floating debris. Howevers all sanples

were collected except the 25m deep horizontal tow at

Right. This tow was to have been taken after station

"VS, and the cruise was aborted before that time.

The samples collected were:

25m deep horizontal tow, day

1000-8008 vertical tow

800-200m vertical tow

200-0m vertical tow

1000-0m vertical tow

During the cruise, Marcie Commins; of LBL, was

aboard to oversee all zooplankton operations. ?Her main

interest {s to standardize sampling and analysis procedures.

Except for the fact that there were no sharks seen

on the cruise, all other plants and animals already reported

were sited,

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WEATHER CODE FOR DATA SHEETS

(ANI times are Atlantic Standard Time, (AST) = GMT - 4 hours)

7 KI/130°, 91°, 47%, 1, 150°

7-KT = Wind Speed (KT)

130°

Wind Direction - from (Deg)

91° = Air Temperature (°F)

47% = Relative Humidity (2)

1 = Wave Height (m)

150° = Wave Direction - from (Deg)

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SIZE CLASS SIZE IN MILLIMETERS

1 <0.5

2 0.5 - 0.9

3 1.0 - 1.9

4 2.0 - 2.9

5 3.0 - 3.9

6 4.0 - 4.9

7 5.0 - 5.9

8 6.0 - 6.9

9 7.0 - 7.9

10 8.0 - 8.9

n 9.0 - 9.9

2 10.0 - 19.9

43 20.0 - 29.9

uM 30.0 - 39.0

15 40.0 - 49.9

16 >50.0

416

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DATE:

STATION NUMBER:

SHIP:

TINE:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

?LENGTH OF Tow:

LATITUDE:

LONGITUDE:

SEA STATE AND WEATHER:

11 February 1979

BENCHMARK

USNS BARTLETT

1503

804-21

CONICAL

202u

?75.0

HORIZONTAL

25m

60m

55-60"

665576

711891

10 min

17° 34.91 6

65° 48.89 W

ss#1

a7

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ee

a8

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419

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Tr

ee

420

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DATE:

STATION NUMBER:

SHIP:

TIME:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

(FLOWMETER FINISH:

LENGTH OF Tow:

LATITUDE:

Lone1Tup

SEA STATE AND WEATHER:

12 April 1979

BENCHMARK

USNS BARTLETT

1310

804-23,

CONICAL 5:1

202

750

VERTICAL,

1000-800 m

1060

760067

798993

15 min

17° 57.5

65° 51.7

#2 Clear day no clouds

421

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Bote ta te as ee

423

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424

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425

---Page Break---

DATE: 12 April 1979

STATION NUMBER: BENCHMARK

SHIP: USNS BARTLETT

TIME: 1615

SAMPLE NUNBER: 804-24

TYPE OF NET: CONICAL 5:1

MESH SIZE: 202

RING SIZE: 75m

TYPE OF HAUL: VERTICAL,

SAMPLING DEPTH: 800-200 m

METERS OF WIRE: 860 m

ANGLE: °

FLOWMETER: START: 799105

FLOWMETER FINISH: 825357

LENGTH OF TOW: 20 min

LATITUDE: 17° 57.5

LONGITUDE: 65° 51.8

SEA STATE AND MEATHER: #2-3 CLEAR-CALM SUNNY DAY

426.

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wa

429

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DATE:

STATION NUMBER:

SHIP:

TINE:

SAMPLE NUMBER:

TYPE OF NET:

mesi SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPT!

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF TOW:

LATITUDE:

LONGITUDE:

SEA STATE AND WEATHER:

12 February 1979

BENCHMARK

USNS BARTLETT

1654

804-25

CONICAL 5:1

2020

0.75 m

VERTICAL

200-0 m

260

0

925143

934923

10 min

17° 57.52

65° 51.91

430

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DATE:

STATION NUMBER:

SHIP:

TIME:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISI

LENGTH OF TOW:

LATITUDE:

LONGITUDE:

SEA STATE AWD WEATHER:

13 February 1979

BENCHMARK

USNS BARTLETT

1624

804-26

CONICAL 5:1

202u

0.75 m

HORIZONTAL

25m

60

60°

280029

975100

10 min

17° 57.52

65° 51.91

ss#2

434

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APPENDIX E

CRUISE REPORT AND DATA FROM OTEC CRUISE #5 (CR-805)

19-23 APRIL 1979

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CRUISE REPORT

OTEC CRUISE #5 (CR-805)

19-23 April 1979

by

Gary C. Goldman, Chief scientist

439

"AIUNG ADDRESS: CENTER FOR ENERGY ANO ENVIRONMENT RESEARCH, COLLEGE STATION, MAYAGUEZ, PUERTO RICO 0078

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CRUISE REPORT

OTEC CRUISE #5 (CR-805)° 19-23 April 1979

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Vint.

Objectives:

?A. Measure oceanic parameters relatable to OTEC at

2) Punta Tuna.

B. Measure variability of these oceanic parameters at

Punta Vaca. :

C. Measure water temperature at three other stations.

Research Vessel:

R/V CRANFORD

Supporting Agencies:

U.S. Department of Energy

BL Lawrence Berkeley Laboratory

C. P.R. Water Resources Authority

DO: UPR/CEER

Dates of Cruise:

19-23 April 1979

Cruise Plan:

See Appendix II (Not included)

Scientific and Technical Personnel:

Bonafe, C. - Technician (CEER)

Gorales, 5. ~ Technician (GEER)

Goldman, G. - Chief Scientist (CEER)

Gonzalez, ?. - Technician (CEER)

Morgan, T. - Scientific Assistant (CEER)

Nazario, A. - Technician (CEER)

Pesante, 0. - Biological Coordinator (CEER)

Rivera, J. - Scientific Assistant (CEER)

Shafnacker, M. = Technician (CEER)

Steen, J. + Visiting Scientist (Gulf Coast Research Lab)

Station Locations:

See Attached Plan, Appendix II (Not included)

Types of. sampling:

A. See Attached Cruise Plan, Appendix II (Not included)

B. Yater Sampling for Foam OTEC Experiment

2 Chlorophyll sampling for LBL

440

---Page Break---

IX. Travel:

z-- 19 April 1979. R/V CRANFORD arrived at Malecon Port,

Mayaguez, P. 8. A11 personnel, except Mr. Morgan, were

assembled at CEER (Cornelia) Lab. All equipment and personnel

were transported from Cornelia lab to Matecon by CEER vehicles.

Nr. Morgan had separate transportation from Nain Lab. to Malecon

with his (Or. Kay's) supplies. Ship departed about 1530 -Tocal

ne.

<-~ 23 April 1979. R/V CRAWFORD returned to Malecon Port, Mayaguez about 0330. All equipment and personnel were removed from the vessel by 0700, as she was forced to vacate her berth to allow another vessel to arrive. Equipment and personnel were again transported to their respective laboratories by CEER vehicles. R/V CRANFORD returned to Magueyes.

X. Reason for termination of cruise:

AN] work was completed.

IX. Accomplishments:

A. Collected virtually a11 data from Station "8*

(exception transmission data, and some current data).

B. Collected temperature data from Station "F".

C. Collected temperature data from Station "A".

D: Collected temperature data from Station ?P*.

E. Collected all data at Station "Vv".

IIX. Changes to be affected:

A. Repair transmissoneter.

B. Consider increasing XBT stations.

?. Correct current meter intermittent malfunction.

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(? @30N) Isyo-#209

Puaess

(2 @30n) Ki6'LS059 N9*LSoLL Oly ?0860 GL, Lidy 12 oe

1659 Mi9'CSeLL??OoBO-0099 sus LIME LZ 8

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- (482) S-WOLMMTd ?Ms6°LS0$9 N9ZSeL ?$020-0E00 Ly LOY 22 6

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BIOLOGICAL REPORT

?This cruise was carried out without any hardship. Zooplankton

sampled from:

'1000-800m

'800-200m

200-sFC

1000-scF

25 meter horizontal-day

25 meter horizontal-night

Samples of organisms that live attached to the mooring b

obtained during a snorkling effort. These will be identified

later date.

No new fish were seen, although the same as previously reported

present.

Heavy overcast was present about 75¢ of the time.

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WEATHER CODE FOR DATA SHEETS

(AIL times are Atlantic Standard Time (AST) = GHT - 4 hours)

7 KT/130°, 91°, 47%, 1, 150°

7 KT = Wind Speed (KT)

130° = Wind Direction - from (Deg)

91° = Air Temperature (°F)

47% = Relative Humidity (x)

1 = Mave Height (m)

150° = Wave Direction - from (Deg)

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ZOOPLANKTON

SIZE CLASS	SIZE IN MILLIMETERS
1	<0.5
2	0.5 - 0.9
3	1.0 1.9
4	2.0- 2.9
5	3.0 = .3.9
6	4.0 - 4.9
7	5.0- 5.9
8	6.0- 6.9
9	7.0 > 7.9
10	8.0- 8.9
u	9.0- 9.9

12 10.0 - 19.9

13 20.0 - 29.9

14 30:0 - 39.9

15 40.0 - 49.9

16 >50.0

461

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DATE: 20 April 1979

STATION NUMBER: BENCHMARK

SHIP: CRAWFORD

TIME: 0800

SAMPLE NUMBER: 805-27

TYPE OF NET: CONICAL 5:1

MESH SIZE: 202u

RING SIZE: 0.75 m

TYPE OF HAUL: HORIZONTAL

SAMPLING DEPTH: 25m

METERS OF WIRE: 60m

ANGLE: 60°

FLOWMETER START: 975150

FLOWMETER FINISH: 1003240,

LENGTH OF Tow: 10 min

LATITUDE: 17° 57.52

LONGI TUDE: 65° 51.91

SEA STATE AND WEATHER: #2

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483

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464

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465

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466

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DATE: 20 April 1979

STATION NUMBE!

BENCHMARK

SHIP: CRAWFORD

5 TINE: 1305

SAMPLE NUMBER: 805-29,

TYPE OF NET: CONICAL

MESH SIZE: 202n

RING SIZE: 0.75 m

TYPE OF HAUL: VERTICAL,

SAMPLING DEPTH: 1000-800 »

METERS OF WIRE: 1060

ANGLE: 0

FLOWMETER START: 84577

FLOWMETER FINISH: 139257

LENGTH OF TOW:

LATITUDE: 17° 57,6'N

LONGITUDE: 65° 51.9°H

SEA STATE AND WEATHER:

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DATE:

STATION NUMBER:

SHIP:

TINE:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPT:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF TOW:

LATITUDE:

LONGITUDE:

SEA STATE AND WEATHER:

20 April 1979

BENCHMARK

CRAWFORD

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805-30

CONICAL 5:1

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0.75 9

VERTICAL

800-200 m

800 m

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209882

17° 57.6'N

65° 51.9'W

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Tae TTT

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DATE:

STATION NUMBER:

SHIP:

TIME:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF TOW:

LATITUDE:

LonGiTuve:

SEA STATE AND WEATHER:

20 April 1979

CRAWFORD

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805-31

CONICAL 5:1

202y

0.75 m

VERTICAL

200-SFC

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221091,

17° 57.66

65° 51.9'W

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DATE:

STATION NUMBE

SHIP:

TINE:

SAMPLE NUMBER:

TYPE OF NET:

Nes size:

RING SIZE:

TPE OF HAUL:

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF TOW:

LATITUDE:

LONG! TUDE:

SEA STATE AND WEATHER:

21 April 1979

BENCHMARK

CRANFORD

0205

805-32

CONICAL 5:1

202u

0.75 m

HORIZONTAL

25m

60m

60°

030190,

60860

10 min

172 57.6'N

65° 51.9'W

SS#1-2

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APPENDIX F

CRUISE REPORT AND DATA FROM OTEC CRUISE #6 (CR-806)

4-9 JUNE 1979

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Me) CENTER FOR ENERGY ANO ENVIRONMENT RESEARCH

CRUISE REPORT

OTEC CRUISE #6 (CR-806)

4-9 gune 1979

by

Gary C. Goldman, Chief Scientist

493

-MAIUNG ADDRESS: CENTER FOR ENERGY AND ENVIRONMENT RESEARCH, COLLEGE STATION, MAVAGUEZ, PUERTO RICO coro

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CRUISE REPORT

PLR. OTEC CRUISE #6 (CR-806) 4-9 June 1979

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Objectives:

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Measure oceanic parameters relatable to OTEC at Punta Tuna.

Measure variability of these oceanic parane- ters at Punta Vaca, Punta Borinquen, and Cabo Rojo.

Measure temperature at three other sites.

Measure variation of oceanic parameters as a function of distance from Benchmark and dis~ tance from shore at 10 stations.

Sample for water characteristics for foam OTEC program at 2 stations.

Research Vessel:

R/V CRANFORD

Supporting Agencies:

A

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D

U.S. Department of Energy

Lawrence Berkeley Laboratory

P.R. Mater Resources Authority

UPR/CEER

Dates of Cruise:

4-9 dune 1979

Cruise Plan:

See Appendix I1 (Not included)

Scientific and Technical Personnel:

Altschuler, S. - Biologist

Bonafé, C.'- Technician

Cabassa, P. - Technician

Carmiggelt,

= Visiting Sei. (LBL)

Corales, D: - Technician

Goldman, G. - Chief Scientist

Gonzalez, E. - Technician

Jones, X.

Morgan,

~ Visiting Sci. (LBL)

> Scientist Ass't.

Nazario, A. - Technician

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vir.

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xr.

Pesante, D. - Biological Coordinator

Rivera, Scientific Ass't.

Saddler, T. - Technicia

Shafnacker, M.'- Technician

Station Locations:

See Cruise Plan, Appendix II (Not included)

Types of Sampling:

A. See Cruise Plan, Appendix II (Not included)

B. Five Gallon sample at 10 m for Foam Experiment

C. Water samples for LBL

D: Phytoplankton net samples for L8L

Travel:

4 dune 1979. R/V CRAWFORD arrived at Malecén Port, Mayaguez, P.R. at about 1030 AST after leaving Mayaguez about 0600-0700. The personnel assembled at CEER, CORNELIA LAB, along with the equipment at that location, were transported to the vessel.

Other personnel and their equipment (Norgan from the main CEER LAB, and Carmiggelt and Jones from Hotel) arrived via CEER vehicles or rented vehicles. The ship departed about 1400 AST.

=~ 9 June 1979. R/V CRAWFORD returned to Malecén Port, Mayaquez about 0530 AST. Equipment and personnel were removed from the vessel by 0730-0800 AST, and were transported to their destinations by CEER vehicles. R/V CRANFORD returned to Mayaguez about 1100 A.S.T.

Reason for termination of cruise:

As neither the leased fathometer, nor either of ?the onboard fathometers were functioning, I determined the probability too great of loosing a string of hydrographic bottles and reversing thermometer if

we attempted to visit the inner stations scheduled for the return trip. These stations are located on

a sharp drop-off, and a slight navigation error could have put the vessel in too shallow water. All other work was completed.

Accomplishments:

A. Collected virtually all data from Station "B"

(except transmission data).

B. Collected all scheduled data from Stations "R",

"CY, and "F", three high-priority OTEC sites.

435

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c.

D.

Collected all data from Station *V".

Collected all scheduled data from Stations

"co", "Mo", "sO", "JO", all deep water stations

with OTEC Potential

486

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BIOLOGICAL REPORT FOR CRUISE 806

During the days comprising the fourth to the ninth

of June 1979 the following was accomplished:

--Al1 Zooplankton samples were effec-

tively collected. :

25 m horizontal day

. =-25 m hortzonta) night

--1000-sec-verticat

~-1000-800-vertical

~-800-200-vertical

--200-sec-vertical

while on station

As usual all ?the fish and organisms collected during

the cruise are being identified for the Final Report.

An inspection dive was conducted at the buoy in

which the state of the cable was checked down to 160 feet.

Organisms from the cable and rope were collected and will

be included in the Final Report.

Daniel Pesante

Biological Coordinator

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GL6T eunr G-F * (908-4) 9% BSTNYD DBI FOF OUTTHORAE

493

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WEATHER CODE FOR DATA SHEETS

(AI times are Atlantic Standard Time (AST) = GMT - 4 hours)

7 KT/130°, 91°, 47%, 1, 150°

7 KT = Wind Speed (KT)

130°

{nd Direction - fron (Deg)

91° = Air Temperature (*F)

?47% = Relative Humidity (%)

1 = Wave Hefght (n)

150° = Wave Direction - from (Deg)

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BLAS RAE RBH G29 BERS

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SIZE CLASS SIZE IN MILLIMETERS

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2.0- 2.9

3.0- 3.9

4.0- 4.9

5.0- 5.9

6.0- 6.9

7.0- 7.9

8.0- 8.9

9.0- 9.9

10.0 19.9

20.0 - 29.9

30.0 - 39.9

40.0 - 49.9

> 50.0

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DATE: 5 dune 1979

STATION NUMBER: BENCHMARK

SHIP: ?CRAKFORD

TIME: 0915

SAMPLE NUMBER: 806-35

TYPE OF NET: CONICAL 5:1

MESH SIZE: 202y

RING SIZE: 75.0

TYPE OF HAUL: HORIZONTAL

SAMPLING DEPTH: 2m

METERS OF WIRE: 60m

ANGLE: 55°

FLOWMETER START: 180124

FLOWMETER FINISH: 202841

LENGTH OF TOW: 10 min

LATITUDE: 17° 87.61"

LONGITUDE: 65° 51.9'W

SEA STATE AND WEATHER:

cloudy

The quantities in the following data sheets are #/m

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518

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520

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pate: 6 dune 1979

STATION NUMBER: BENCHMARK

SHIP: CRAWFORD a

TIME: 0930

SAMPLE NUMBER: 806-37

TYPE OF NET: CONICAL 5:1

MESH SIZE: 2020

RING SIZE: 75 0

TYPE OF HAUL: VERTICAL

SAMPLING DEPTI 1000-800 m

METERS OF WIRI 1060 m

ANGLE: °

FLOWHETER START: 271038

FLOWNETER FINISH: 317623

LENGTH OF Tow: .

LATITUDE: 17° 57.6°N

Loner tune: 65° 51.9'W

SEA STATE AND WEATHER: ss#1-2, 75% cloudy

The quantities in the following data sheets are #/n?,

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pate:

STATION NUMBER:

SHIP:

TIME:

SAMPLE NUMBER:

TYPE OF NET:

MESH SIZE:

RING SIZ

TYPE OF HAUI

SAMPLING DEPTH:

METERS OF WIRE:

ANGLE:

FLOWMETER START:

FLOWMETER FINISH:

LENGTH OF TOW:

LATITUDE:

LONGI TUDE:

SEA STATE AND WEATHER:

6 June 1979

BENCHMARK

CRAWFORD

1100

806-38

CONICAL 5:1

202u

?759

VERTICAL

800-200 m

810

317888

340354

17° 57.6'N

65° 51.9'W

The quantities in the following data sheets are #/m°,

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DATE:

STATION NUMBER:

SHIP:

TIME:

SAMPLE NUMBER:

TYPE OF NE

MeSH SIZE:

RING SIZE:

TYPE OF HAUL:

SAMPLING DEPT!

NETERS OF WIRE:

ANGLE:

FLOWMETER START:

_ FLONMETER FINISH:

LENGTH OF Tow:

LATITUDE:

LonerTuve:

SEA STATE AND WEATHER:

"6 June 1979

BENCHMARK

CRAWFORD

125

806-39

CONICAL 5:

202u

75m

VERTICAL

200 sre

200

349132

380590

17° 57.6'N

65° 51.9'W

ss#2, 50% cloudy

The quantities in the following data sheets are #/m3,

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534

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bare:

SvavtOn wunseR:

sme:

rine:

SaWPLE munsen:

TYPE OF NE

MESH size

a1ue size:

TYPE OF HAUL:

SAMPLING OEPTH:

NETERS OF MIRE:

ANGLE:

FLOWMETER START:

FLOWNETER FINISH:

LENGTH OF Tow:

LATITUDE:

LonciTuve:

SEA STATE AND WEATHER:

7 dune 1979

BENCHMARK

CRAWFORD

1335

cR-806-42

CONICAL 5:1

202u

75.9

HORIZONTAL

25m

60m

55°

490248

515730

10 min

17° 57.6"

65° 51.9%

The quantities in the following data sheets are #/m3

537

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VIE.

virt.

XI.

APPENDIX G ~ TYPICAL CRUISE PLAN

CRUISE PLAN CEER

Research Vessel R/V CRAWFORD

Supporting Agency U.S. DOE/PRNRA

Cruise Name and Number cr-805

Dates 19-23 April 1979

Total Days 5 (estimated)

Objectives:

Measure oceanic parameters relatable to OTEC at

Measure variability of these oceanic paraneters

at Punta Vaca.

Measure temperature at two other sites.

Personnel:

G. Goldman, Chief scientist J, Rivera, Scientific

D: Pesante, Biological Coordinator assistant.

ML Shafnacker, Technictan D, Corales, Technician

. Bonafé, Technician Morgan, Scientific

E. Gonzélez, Technician assistant.

AL Nazario, Technician Sctentist (unnamed)

Scientist (unnaned|

Stations:

"BY=Genchmark Station-

?KY-Augnented Statfon-

AnciTlary Station:

?Fa-Aneillary Station:

?y*-AneilTary Station:

17°57,6'N by 65°51,9'W-

about 18°02'N by 65°40'W

?about 17°55'N, by 66°00'W,

out 17°51,7"N by 65°46,9"W

bout 18°03'N by 65°32'H

See accompanying list.

Equipment:

Type of Samples:

Hydrocasts for temperature, salinity, dissolved

?oxygen, nutrients, chlorophyll, phytoplankton.

xeT

Current Profiles

Plankton Hauls (horizontal and oblique)

Transmissivity

Travel:

At mid-moring of 19 April, personnel shall trans-

port all equipment and personnel gear to the

CRAWFORD at Malecon port, Mayaguez, using all

---Page Break---

necessary vehicles. About mid-moring of April 23

Personnel and equipment shall be removed from

CRAWFROD at Malecon port, Mayaguez.

CRUISE SCHEDULE cR-805

DATE TINE EVENT

19 April 700 ?CRAWFORD depart Magueyes

1100 (CRANFORD arrive Malecon port, Mayaguez

100-1400 Transport personne? and equipment to CRAKFORD

1600 (CRANFORD depart Mayaguez for Punta Tuna,

Station "8"

20 April 0500 Arrive Punta Tuna, Station "6"

?Bm (0900-0930 xBr-1

Plankton-1 (25 m hortzontal-10 min)

(0930-1000 Secure to buoy

?B28 1000-1200 HYDROCAST=1

XBT-2

1100 WEATHER

: ?8-3 320-1600 FAMINE (1000 W-9 a}

PLANKTON-3 (1000 m-800 m)

PLANKTON-4 ("800 m-200 m)

PLANKTON-5 (200 m-0 m)

X8T-3

Run Oxygen Analysis

Filter Nutrient Samples

1400 WEATHER

1500-1700 Prepare for CURRENT

8-4" 1700-1830 CURRENT-1

xBT-4

1700 WEATHER

2000 WEATHER

2230-2300 Prepare for HYDRO, X8T

---Page Break---

20 Apri

"Bs" 2300-0130

yoROCAST-2

XBT-5

WEATHER (2300)

?CURRENT-2

21 April (0000-0200,

200

0500

600-9800,

800

0300-1000,

?o7 1000-1400,

1700

2000

2100-2200

21-22 Aprit

8-8 2200-0100

Run Oxygen Analysts

Filter Nutrient? Samples

WEATHER

WEATHER

CCURRENT-3

X8T-6.

WEATHER,

Prepare for BIOCAST, XBT, TRANSMISSION,

CURRENT.

BIOCAST-1

TRANSHISSION-1

xer-7.

CCURRENT-4

WEATHER (1100

WEATHER (1400

Filter for chlorophyll

WEATHER

WEATHER

Prepare for BIOCAST, XBT, TRANSMISSION

BIOCAST-2

xeT-8

TRANSMISSION-2

WEATHER (2300)

Filter for chlorophy11

22 Apri 0100-0130

"39" 0130-0200

(0200-0700

?0700-0730

rae 0730-0745

Release fron mooring

PLANKTON-6 (25 m-horizonti

X8T-9

10 min)

Remain in area

Steam to Station "

At Station "F*

x8T-10

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"pat

23 April

0745-0900

(0900-0915,

0915-1030

11030-1600

1600-1930

1930-1945

1945

0900

0900-1100

1100

1500

Steam to Station "A"

[At Station "A"

XBT

Steam to Station "Vy"

Prepare for HYOROCAST, PLANKTON, XBT, OXYGEN,

?CHLOROPHYLL, NUTRIENTS

At Station "y"

HYDRO/BTOCAST-1

xeT-12

PLANKTON-7 (25 m horizontal tow)

PLANKTON-8

PLANKTON-9

X8T-13

Run Oxygen

Filter for nutrients

Filter for chlorophy1

?Steam to Station "P*

Ae *p*

XBT-16

Depart for Mayaguez

Arrive at Malecon port, Mayaguez

Remove equipment and personnel from CRAWFORD

CRAWFORD depart Mayaguez for Hagueyez

CRANFORD arrives Magueyez

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cove

HYDROCAST

BIOCAST

WEATHER

XBT

CURRENT

PLANKTON

TRANS

HYDRO/BIOCAST

Hydrostation, bottle samples at depths of 0, 50, 100, 150, 200, 250, 300*,400*, 600, 800, 1000 m (*=both protected and? unprotected for thermonetric depth), read temp (protected, unprotected, auxiliary), wire angles, meter depth, collect samples for salinity, nutrients, dissolved oxygen.

Hydrocast for biological parameters, bottle samples, (depths of 0, 25, 50, 75, 100, 125, 150, 175, 200, 250, 300, 400 m), read temp, wire angie, meter depth, collect samples for salinity, chlorophyll.

Standard weather observations: time, wind, dir., wind speed, air, tenp (wet and dry bulb), actual "weather State", barometer, cloud type and cover, visibility, wave ht., wave dir., wave period. The times. indicated correspond with the U.S. Weather Station at the Punta Tuna Light? (isce)

Expendable bathythermograph-automatic record time, set probe and fire.

Stationary current profile - profile of current speed and direction vs. depth. All is internally recorded--must use hydro winch and lower the meter and read--wire angle and meter depth. Each depth shall be set for about 10 minutes. Depths used shall be 25, 50, 75, 100, 128, 150, 175, 200, 280, 300, 408, Sé0, m

Plankton tow--either horizontal tow or vertical tow.

Transmissivity--measured by lowering instrument and reading out remotely. Reading shall be sensor reference, depth at about 10-20 meter intervals, both lowering and raising.

Hydrocast for both physical and biological Parameters, bottle samples will be taken at depths of i, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, 00,600, 800, and 1060 m. Data taken will include protected and unprotected thermometer, wire angle, meter depth, collect samples for salinity, nutrients, chlorophyll, dissolved oxygen.

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EQUIPHENT LIST--cR-805

STATION DATA SHEETS-20 TmeR-1

TRANSMISSOMETER DATA SHEETS-5 CURRENT METER-1 195 1D

ATER SIMPLING EOTTLES/MISRIR-19 SPARE PARTS KIT-1

TUBING FOR SAMPLING BOTTLES-25 ft mount

ESSENGERS-ALL GEAR SET-1

SPARTS FOR NISKIN BOTTLES cu pAPER-2

WETER MiEEL-A Panton

No SPEED ETEReL ere

SEA STATE GUIDE-1 antoo.e

cxovo eutoe-1 DOUBLE TRIP NECHANISH

SYHROMETER-1 FORQALIN 8 UFFER

SYCHROMETER THEROOMETER SPARE=1 PuasTiC aAns

PSYCARONETER WICKS TWEEZERS

sr oucrer

proses-15 00 Eno avs

TEST CANISTERS cHocKeR eave & Lane

coaar-2 ike stor

RECORDER NET RING

LAUNCHER, HAND "TRANSHISSOMETER-1

a0, Resoout=1

bare

AEVERSING THERVONETERS-ALL EBLE"T000 fe

REVERSING THERVONETERREADER-2 DEPT Sexson

FLASHLIGHTS-1 Yarge, 1 snalT uaa

REVERSING THERMOMETER CORRECTING SHEETS=? _cALCULATORS-2

MISC WRITING WATERIALS stove L1oHT-1

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Log 800Ks-3

DISTILLED H,0

SILICONE GREASE

BATTERY CHARGING CABLE (50")

SOLDERING 10K

NUCLEOPORE FILTERS-1 box

GAF FILTERS-1 box

NUTRIENT/SALINITY BOTTLES-6 boxes

CHLOROPHYLL, BOTTLES-18

(CHLOROPHY FILTER CONTAINERS-ALL

PARAFILM

MARKING PEN-6

CLIP poaros-3/4

?CHLOROPHYLL CHEMICALS & EYE OROPER

Tool. B0x-2

MULTIMETER

WEATHER LoG-6

BOTTLE RACKS-3

BOTTLE RACK. SCREWS

SAFETY CLIPS-16

MESSENGER BUCKET

COTTON LINE=1 e011

?TAPE MISC.

PAPER TONELS-~6

PIPETTES

BURRETTES

FLASKS

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TIME SHEETS-10

AN. VACUUM

carsoy

CHLOROPHYLL BUCKETS

DRILL & BITS.

THERMOMETER (SHIELDED)=1

DISSOLVED OXYGEN BOTTLES-15

CONPLETE DIVE SETS-2

TEST TUBE RACK-1

FREEZER CONTAINER-2

ICE cHEST-2

INSULATION

TIDE TABLE-1 set

SCREMS

(R LUBRICANT

DESCICANT OR SILICA GEL

MAGNESIUM CARBONATE SUSPENSION

SAFETY HARNESS

NYLON LINE-1. e041

RAIN GEAR (FROM SULTANA)

SSHACKLES-4

SAFETY WIRE-10 ft

FILTERING SET UP

Punes-2

TUBING

WATER TRAP

VACUUM FLASK

---Page Break---

GLASSNARE & CLAMPS. FUNNEL

?ROPERS:

MAGNESIUM SULFATE SOLUTION FOR OXYGEN

ALKILINE IODINE SOLUTION FOR OXYGEN

?SULFURIC ACID (CON) FOR OXYGEN

?THIOSULFATE SOLUTION FOR OXYGEN

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APPENDIX H

PROCEDURE FOR DETERMINATION OF DISSOLVED OXYGEN

u.

Itt.

Reagents

1

MnS0,. Use 367 g/L. Filter, This solution is

stable but should not be used directly from the

stock bottle.

KI_- NaOH, Use 360 g of NaOH + 150g of KI/L.

2

This solution will develop some turbidity in time. If this occurs it sould be discarded.

3. Hy80,- Use 50% viv.

4, NaySp05- Use 5 grams per 2 liters (approx .01 N).

Add 0.50 g sodium borate as a preservative.

5. Starch indicator. Add 10 9 of starch to 25 ml

cold, distilled water, Make paste. Pour rapidly

jnto?one liter of botiing distilled water. Pre-

serve with 50 mg HgT.

6. Standards: KH (103)2. Use 0.325 g/L (0.01 N).

Sampling

Oxygen samples should be drawn from reversing bottles

before any other samples are collected and as soon as

possible after the bottle is retrieved. Place a length

of rubber tubing on the top. Exel ali air from the

fube, rinse Oe sample bottle. F111, samp bottle

always keepin

the end of thc cute below the water

level as it fills. The stopper must be replaced in

such a way that no bubbles are trapped.

Addition to Reagents

1.

Immediately after collection introduce the follow-

reagents from an automatic pipette, the tip of

which fs kept under the surface of the water.

A, Lal of Mnso,.

B. 1 mi of KI-NaoH.

Shake thoroughly and allow precipitate to settle

(25 min). Shake a second tine and again allow the

Precipitate to settie 2/3 of way to bottom.

---Page Break---

W.

C. Add 1 m1 of 50% HpSO,.

3. Shake thoroughly until all precipitate has dis-

solved. Maximum 12-18 hours before titration.

Titration

1. Pipette 50 ml of the treated sample into a 125 ml

Erlenmeyer flask.

2. Titrate with standardized Na,S,0, until the yellow

color has almost disappeared?

3. Add 4 drops of starch indicator, (Not used).

4. Titrate until solution is colorless.

5. Repeat at least twice, or until difference is less

?than 0.03 ml.

Reagent Blank

1. To 50 ml of distitled water in an Erlenmeyer

flask add:

AL Lal of 508 Hy504.

8. swirl

?. 1m of KI-NaOH.

D. swirl

E. Lat of HnS04.

F. Swirl and then titrate as above. This value

should be zero.

Standardization of Na,S203 at room temperature.

1. Pipette 50 ml of distilled water into a 125 ml

Erlenmeyer flask.

Add in order:

A. 1 al of 50% #504.

8.1 ml KI-NaoH.

C. Lat mnso,.

D. 5 ml .01 N KH(10,)2 (exactly: use volumetric

Pipette).

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3. Titrate as above.

4, Repeat at least three times or until reproduction

fs within .02 m1 NaySp03.

VIII, Calculations: YM

1x

1. Normality of NayS)0, =

y,

2

2. Concentration of 0, in the water sample = 0, (ml/L)

B 1000

= Nx (Vorb) x ? x 5.6 x ??

b-2 s

Where N= normality of NayS,033 Ny = normality of

KH(10,)95 Vy = m1 of standard KH(103), solution;

Vp) = Mm) of NapSp0,; 8 = volume of sample bottles;

S'= volune of sample titrated; and b = blank titer

obtained under ¥.

*Excerpt from Instruction Manual for Routine Measurements for

the U.S. Program in Bfology, International Indian Ocean

Expedition. August 1962, David Menzel, WHOI.

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APPENDIX I

LISTINGS OF THE COMPUTER PROGRAMS USED

FOR ANALYSIS OF THE MOORED CURRENT METER DATA

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queding 943 wos Bulainsay

nduog wes6odd S}uL

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38g 4939K UEWINg 242 wods

540399) @AJSS46oud 201d 03 4aynduop ay3 sasn WesBOud SUL

pdb 1d0ud

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2320 4939" qUaJaNg 943 wo4y

Sue46035 14 UO}32e44q PUL paads ay; sz014 weABoug SyuL

varaqastH

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