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OTEC Thermal Resource Report for Ivory Coast

May 1979

MASTER

Prepared for
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Central Solar Technology

Under Contract No. ET-78-C-01-2898

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OTEC Thermal Resource Report for Ivory Coast

May 1979

Prepared for
U.S. Department of Energy
Assistant Secretary for Energy Technology
Division of Central Solar Technology
Washington, D.C. 20585

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INTRODUCTION

One of the basic environmental considerations in site selection for an Ocean Thermal Energy Conversion (OTEC) power plant is the availability of an adequate temperature difference resource. OTEC plants are designed to convert the potential energy in the temperature difference between the warm ocean surface water and the cold water existing at deeper depths into electricity. The turbines which produce the electricity must run on temperature differentials which are extremely small by the standards of conventional energy plants. Therefore, a definition of the most probable temperature structure for a site is most important.

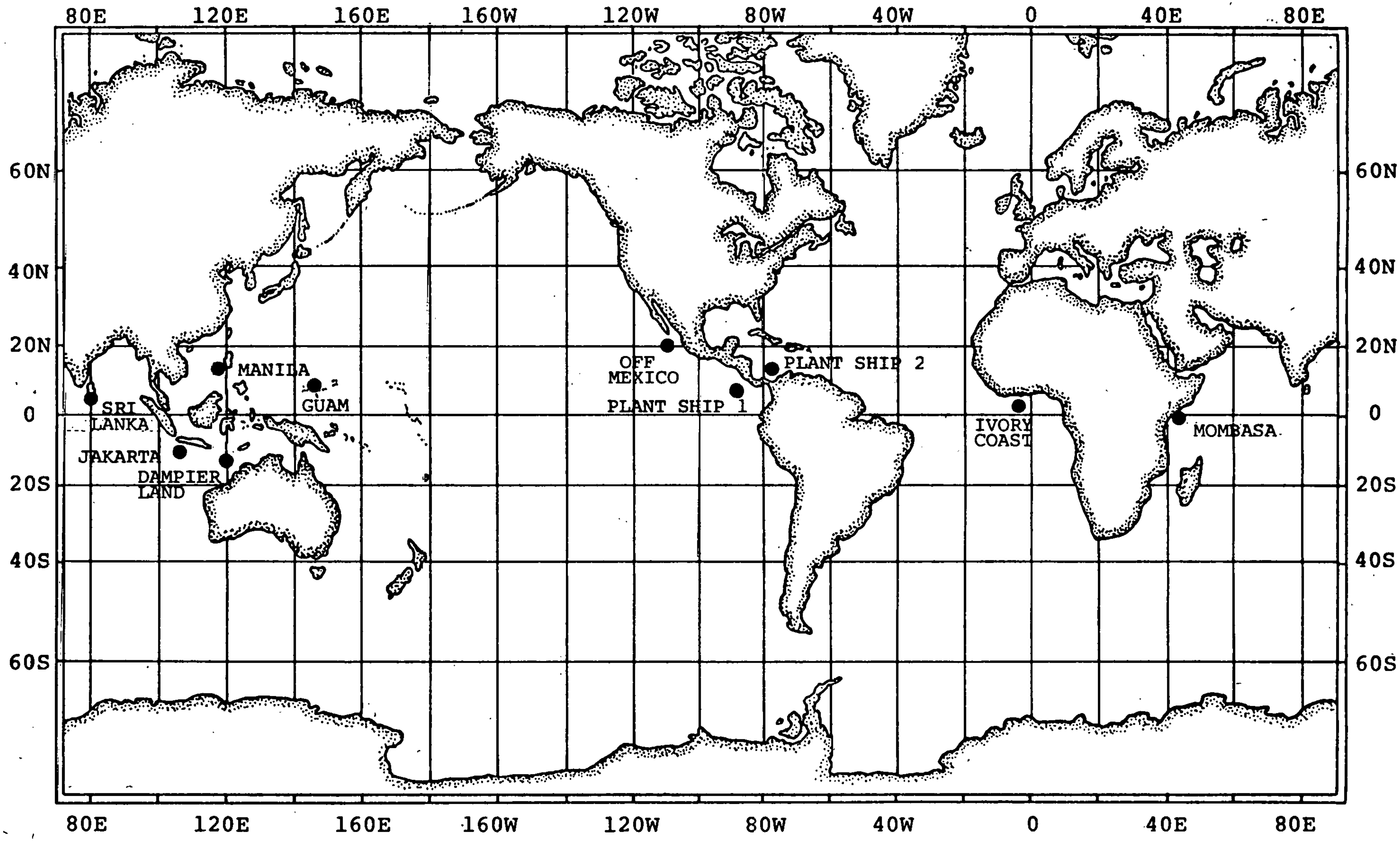
In order to define temperature structures for OTEC areas of interest, Ocean Data Systems, Inc. (ODSI) has developed computer data files of all unclassified soundings available. The primary sources for the data were NOAA's National Oceanographic Data Center, and the U.S. Navy's Fleet Numerical Weather Central. The files were updated in September 1978. Included in the data base were mechanical bathythermographs (MBT), expendable bathythermographs (XBT), salinity temperature depth systems (STD), and Nansen casts.

Under U.S. Department of Energy, Division of Solar Energy Contract No. EY-78-C-2989, ODSI has analyzed the monthly temperature structure for ten different geographical areas. The ten sites selected for study by the Department of Energy are:

		Latitude	Longitude
Bottom Mounted or Shore Plants:	Dampier Land	13-18°S	118-121°E
	Manila	14-16°N	118-120°E
	Guam	12-15°N	142-146°E
	Ivory Coast	3-6°N	3-8°W
	Jakarta	6-9°S	104-109°E
	Mexico	20-23°N	105-110°W
	Sri Lanka	5-10°N	78-83°E
	Mombasa	5°S-3°N	40-45°E
Ship Plants:	No. 1	5-10°N	90-95°W
	No. 2	13-15°N	75-80°W

The location of these sites is shown on the following map; a separate report was produced for each site.

For each area, the most probable temperature structures were determined. When the most probable temperature soundings were plotted, some month to month variability was present which was caused by the non-uniform data sample rather than by real changes in the ocean. These short-period time variations were removed by a filtering process described by Wolff, et al (1977), [44]. Availability of cold and warm water was examined at each site. In addition to warm and cold water availability, there are other requirements for the continuous operation of an OTEC plant. An adequate temperature differential (ΔT) is the primary need. A ΔT greater than 16.7°C (30°F) for the coldest month of the year would enable year round operation. The annual mean ΔT for



LOCATION OF THE TEN SELECTED SITES

a site should equal or exceed 20°C (36°F). Besides the thermal resource, there are other operational requirements. Bottom depth should be less than 1500 meters for mooring. Minimum distances offshore to 1000-meter depth is another important consideration for shore plants. Currents should be sufficient to guarantee good cold/warm water sources and to provide for dispersion of modified water. Desirable sites also have light winds, minimum sea and swell, and the lack of severe storms. These parameters have been examined for each site. The following tables summarize some of the key site parameters for each location.

SUMMARY OF SITE PARAMETERS

Site	Monthly Mean Temperature (°C) Surface Range	Monthly Mean Temperature (°C) 1000M	Annual Mean ΔT(°C) 500M	Annual Mean ΔT(°C) 1000M	Coldest Monthly Mean ΔT (°C) 500M	Coldest Monthly Mean ΔT (°C) 1000M
Sri Lanka	27.5-28.6	6.5-6.7	18.0	21.3	17.5	20.8
Mombasa N	25.4-28.7	7.2-7.5	17.0	19.5	15.6	18.2
Mombasa S	25.5-28.4	6.3-7.0	18.0	20.2	15.9	18.5
Jakarta	27.2-29.0	5.1-5.6	19.1	22.8	17.9	21.9
Dampier Land	25.6-28.2	4.9-5.0	19.1	22.6	17.4	20.7
Manila	27.1-29.5	4.4-4.6	20.0	24.0	18.6	22.6
Guam	27.7-29.2	4.3-4.4	21.1	24.1	20.4	23.4
Off Mexico	22.5-28.0	4.4-4.5	17.6	20.9	14.9	18.0
Plant Ship Pacific	27.1-28.5	4.6-4.8	19.4	22.8	18.1	21.7
Ivory Coast	24.3-28.1	4.5	19.2	22.1	16.8	19.7
Plant Ship Caribbean	26.4-28.4	5.0-5.3	18.1	22.4	17.2	21.3

SUMMARY OF SITE PARAMETERS

SITE	RANGE DISTANCE (IN KILOMETERS) TO SHORE FROM 1000 METERS	MONTHLY MEAN MIXED LAYER DEPTH METERS	MONTHLY MEAN SURFACE CURRENTS (CM/SEC)	SEA STATE MAX % OF TIME >3 METERS	NUMBER TROPICAL CYCLONES PER YEAR
SRI LANKA	22-55	30-80	25-62	3	0.2-1.2
MOMBASA	33-130	30-90	30-62	2	0.0-0.1
JAKARTA	18-60	55-80	25-52	2	0.0-0.1
DAMPIER LAND	265-417	30-80	25-47	4	0.4-1.2
MANILA	6-82	20-80	30-52	5	4.0-6.0
GUAM	7-18	60-120	30-47	5	2.0-3.0
OFF MEXICO	5-104	10-30	25-31	2	0.6-4.0
PLANT SHIP PACIFIC	-	0-30	30-52	2	0.0-2.0
IVORY COAST	33-52	0-30	25-31	2	0.0-0.1
PLANT SHIP CARIBBEAN	-	40-110	30-62	3	0.6-1.2

I. EXECUTIVE SUMMARY

The thermal resource off the Ivory Coast is quite good for OTEC purposes. There are consistently large ΔT (surface temperature - temperature at depth) values throughout the year. The mean ΔT at 1000 meters is approximately 22°C. A mean annual ΔT of 20°C can be reached at a depth of only 600 meters. The thermal resource for the coldest month of the year is also adequate at 600 meters.

Water 1000 meters deep is available within 35 kilometers from the shore. The waters south of the Ivory Coast do not have a particularly good mixed layer depth. Strong winds and tropical storms are a rare occurrence. Similarly, the sea and swell conditions do not present a problem for OTEC development in this area. Currents are generally moderate, although occasional periods of weak currents less than 1/4 knot can be expected. The consistently large thermal resource without major environmental problems recommends this location as a potential OTEC site.

II. BATHYMETRY

Figure II-1 shows the location of the potential site off the Ivory Coast. The study area extended from 3-6° North latitude and 3-8° West longitude. The rough bathymetry for the area is shown in Figure II-2 (from the Defense Mapping Agency, 1974, [13]). The latter figure shows that distances to water of acceptable depth do not vary greatly.

Table II-1 summarizes distances offshore to selected depths.

TABLE II-1: DISTANCES TO SELECTED DEPTHS OFF THE IVORY COAST (Defense Mapping Agency, 1974, [13]).

DEPTH (Meters)	CLOSEST DISTANCE (Kilometers)	FARTHEST DISTANCE (Kilometers)
100	7.5	26.0
500	24.0	41.0
1000	33.3	52.0
1500	35.2	56.0

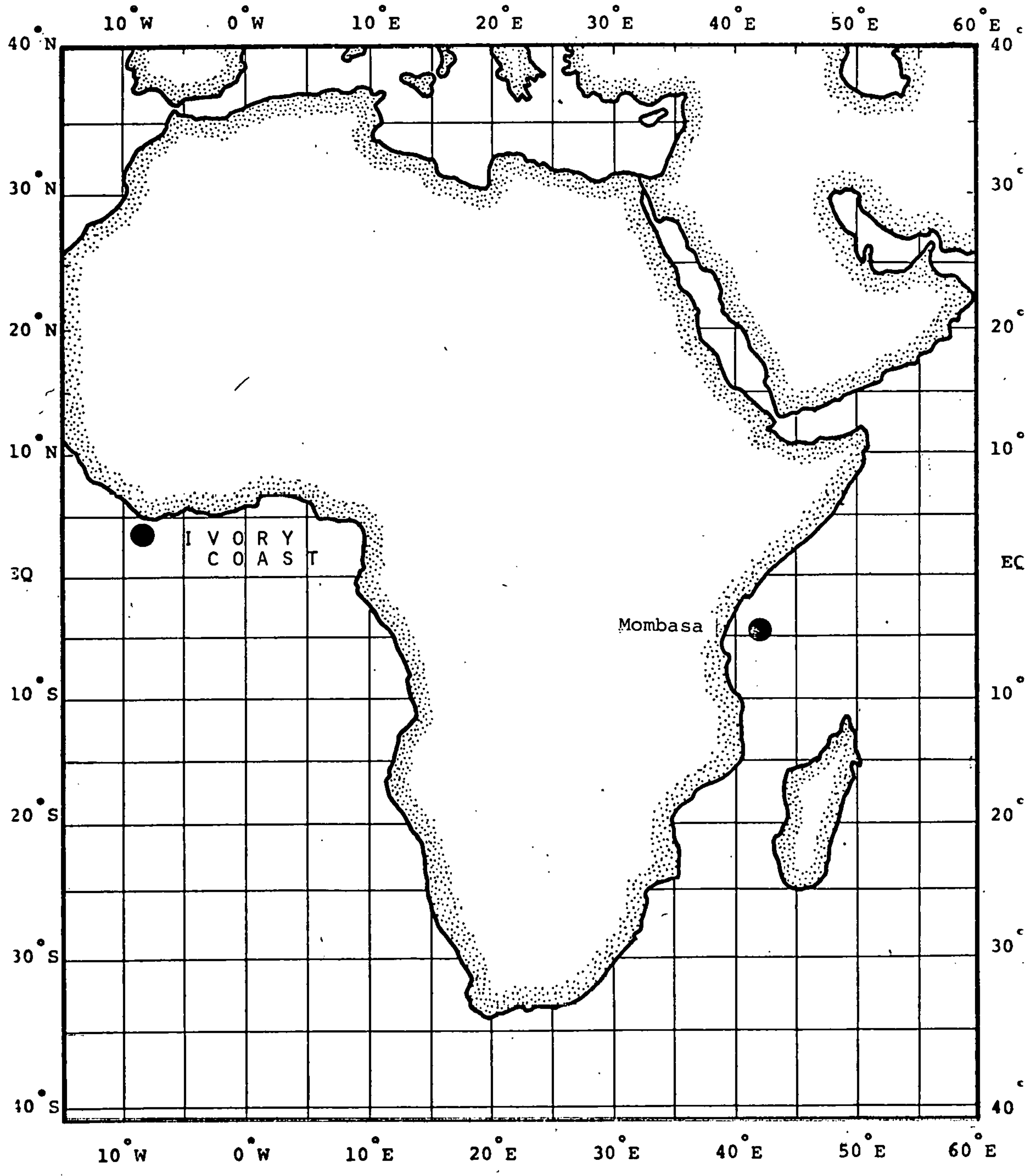


FIGURE II-1: LOCATOR CHART SHOWING THE LOCATION OF THE IVORY COAST OTEC SITE.

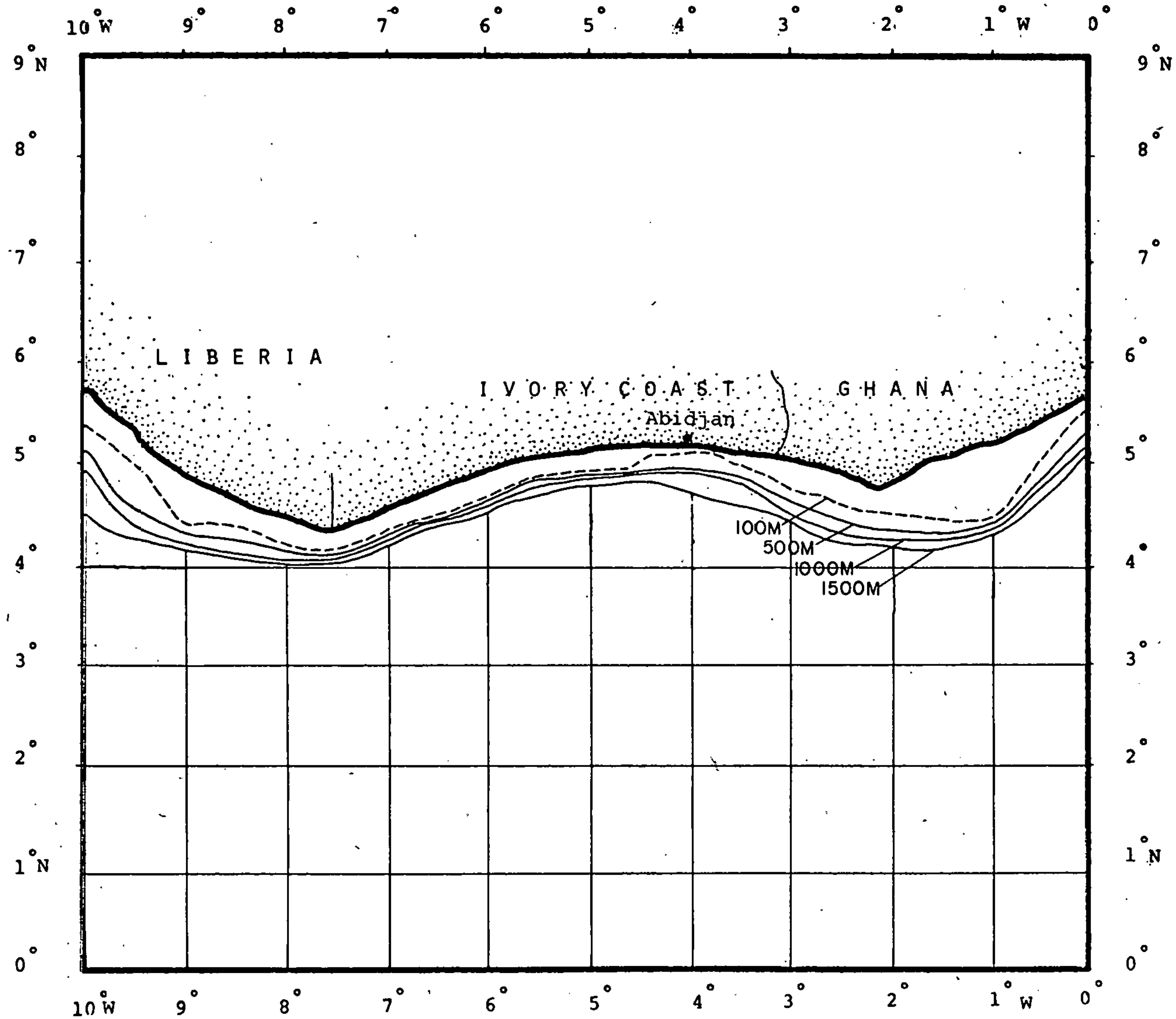


FIGURE II-2: CHART SHOWING ROUGH BATHYMETRY OFF THE IVORY COAST (From Defense Mapping Agency, 1974, [13]).

III. THERMAL RESOURCE

Table III-1 represents the most probable temperature profile (°C) for the Ivory Coast site. There were observations in Ocean Data Systems' master data file for all months of the year at every depth. Some short-period variations in the temperature with time were removed using a filtering process described by Wolff, et al (1977), [44].

There was considerable variation in monthly mean sea surface temperatures at this site (24.2°C to 28.0°C). Since temperatures at depths below 1000 meters were nearly constant, this means that values of ΔT (surface temperature minus temperature at depth) also showed considerable variation. This can be seen in Table III-2 which shows the ΔT structure as a function of depth in meters. Figure III-1 shows the same information plotted as contours of ΔT versus depth and month.

Since this site has good access to deep cold waters from the Antarctic, the supply of cold water is excellent. An annual mean ΔT of greater than 20°C is available at a depth of about 600 meters; however, due the seasonal variability, a depth of 1350 meters would have to be used to have a 20°C ΔT every month of the year.

TABLE III-1: MONTHLY MOST PROBABLE TEMPERATURE (°C)
PROFILE IVORY COAST 3-6°N/3-8°W

Depth	Month 1	2	3	4	5	6	7	8	9	10	11	12	Annual Mean
0	27.6	27.6	27.8	28.1	28.0	26.9	25.4	24.3	24.2	24.5	26.7	27.7	26.6
50	19.2	19.2	20.1	21.1	22.1	20.7	19.3	17.5	17.8	19.4	20.3	19.2	19.7
100	15.9	16.0	16.3	16.7	16.8	16.6	16.0	15.7	15.9	16.2	16.3	16.1	16.2
150	14.8	14.9	15.0	15.3	15.3	15.1	14.8	14.6	14.8	15.0	15.1	14.9	15.0
200	13.9	14.0	14.0	14.2	14.1	13.9	13.6	13.5	13.8	14.0	14.1	14.1	13.9
250	12.6	12.5	12.5	12.5	12.5	12.2	12.0	11.9	12.3	12.6	12.8	12.7	12.4
300	11.1	11.0	11.0	10.9	10.9	10.6	10.5	10.5	10.8	11.2	11.4	11.3	10.9
350	9.9	9.7	9.6	9.6	9.6	9.4	9.4	9.4	9.7	10.0	10.1	10.1	9.7
400	8.9	8.8	8.7	8.6	8.6	8.5	8.5	8.5	8.6	9.0	9.1	9.0	8.7
450	8.1	8.0	7.9	7.9	7.8	7.8	7.8	7.9	8.0	8.2	8.3	8.2	8.0
500	7.5	7.4	7.3	7.2	7.2	7.2	7.2	7.3	7.4	7.5	7.5	7.5	7.4
550	6.9	6.9	6.8	6.7	6.7	6.7	6.7	6.8	6.9	6.9	6.9	6.9	6.8
600	6.4	6.4	6.3	6.2	6.2	6.3	6.3	6.3	6.4	6.4	6.4	6.4	6.3
650	6.0	6.0	5.9	5.8	5.8	5.8	5.8	5.9	5.9	6.0	5.9	6.0	5.9
700	5.7	5.7	5.5	5.5	5.5	5.5	5.5	5.6	5.6	5.6	5.6	5.6	5.6
750	5.4	5.4	5.2	5.2	5.2	5.2	5.2	5.3	5.3	5.3	5.3	5.3	5.3
800	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.1	5.1	5.1	5.1	5.1
850	4.9	4.9	4.8	4.8	4.8	4.8	4.8	4.9	4.9	4.9	4.9	4.9	4.9
900	4.8	4.8	4.7	4.7	4.6	4.6	4.7	4.7	4.8	4.8	4.7	4.8	4.7
950	4.6	4.6	4.6	4.6	4.5	4.5	4.6	4.6	4.6	4.6	4.6	4.6	4.6
1000	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
1050	4.4	4.5	4.4	4.4	4.4	4.4	4.5	4.5	4.5	4.5	4.4	4.5	4.5
1100	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
1150	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
1200	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
1250	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
1300	4.2	4.3	4.3	4.3	4.2	4.3	4.3	4.3	4.3	4.3	4.2	4.2	4.3
1350	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.1	4.1	4.2	4.2
1400	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
1450	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
1500	4.1	4.1	4.1	4.0	4.1	4.1	4.1	4.0	4.1	4.0	4.0	4.0	4.1

TABLE III-2: SURFACE TEMPERATURE - TEMPERATURE AT DEPTH DIFFERENTIAL (°C) BY MONTHS IVORY COAST 3-6°N/3-8°W

Depth	Month 1	2	3	4	5	6	7	8	9	10	11	12	Annual Mean
50	8.4	8.4	7.7	7.0	5.9	6.2	6.1	6.8	6.4	5.1	6.4	8.5	6.9
100	11.7	11.6	11.5	11.4	11.2	10.3	9.4	8.6	8.3	8.3	10.4	11.6	10.4
150	12.8	12.7	12.8	12.8	12.7	11.8	10.6	9.7	9.4	9.5	11.6	12.8	11.6
200	13.7	13.6	13.8	13.9	13.9	13.0	11.8	10.8	10.4	10.5	12.6	13.6	12.6
250	15.0	15.1	15.3	15.6	15.5	14.7	13.4	12.4	11.9	11.9	13.9	15.0	14.1
300	16.5	16.6	16.8	17.2	17.1	16.3	14.9	13.8	13.4	13.3	15.3	16.4	15.6
350	17.7	17.9	18.2	18.5	18.4	17.5	16.0	14.9	14.5	14.5	16.6	17.6	16.9
400	18.7	18.8	19.1	19.5	19.4	18.4	16.9	15.8	15.6	15.5	17.6	18.7	17.8
450	19.5	19.6	19.9	20.2	20.2	19.1	17.6	16.4	16.2	16.3	18.4	19.5	18.6
500	20.1	20.2	20.5	20.9	20.8	19.7	18.2	17.0	16.8	17.0	19.2	20.2	19.2
550	20.7	20.7	21.0	21.4	21.3	20.2	18.7	17.5	17.3	17.6	19.8	20.8	19.8
600	21.2	21.2	21.5	21.9	21.8	20.6	19.1	18.0	17.8	18.1	20.3	21.3	20.2
650	21.6	21.6	21.9	22.3	22.2	21.1	19.6	18.4	18.3	18.5	20.8	21.7	20.7
700	21.9	21.9	22.3	22.6	22.5	21.4	19.9	18.7	18.6	18.9	21.1	22.1	21.0
750	22.2	22.2	22.6	22.9	22.8	21.7	20.2	19.0	18.9	19.2	21.4	22.4	21.3
800	22.5	22.6	22.8	23.1	23.0	21.9	20.4	19.3	19.1	19.4	21.6	22.6	21.5
850	22.7	22.7	23.0	23.3	23.2	22.1	20.6	19.4	19.3	19.6	21.8	22.8	21.7
900	22.8	22.8	23.1	23.4	23.4	22.3	20.7	19.1	19.4	19.7	22.0	22.9	21.8
950	23.0	23.0	23.2	23.5	23.5	22.4	20.8	19.7	19.6	19.9	22.1	23.1	22.0
1000	23.1	23.1	23.3	23.6	23.5	22.4	20.9	19.8	19.7	20.0	22.2	23.2	22.1
1050	23.2	23.1	23.4	23.7	23.6	22.5	20.9	19.8	19.7	20.0	22.3	23.2	22.1
1100	23.2	23.2	23.4	23.7	23.6	22.5	21.0	19.9	19.8	20.1	22.3	23.3	22.2
1150	23.2	23.2	23.4	23.7	23.6	22.5	21.0	19.9	19.8	20.1	22.3	23.3	22.2
1200	23.3	23.3	23.5	23.8	23.7	22.6	21.1	20.0	19.9	20.2	22.4	23.4	22.3
1250	23.3	23.3	23.5	23.8	23.7	22.6	21.1	20.0	19.9	20.2	22.4	23.4	22.3
1300	23.4	23.3	23.5	23.8	23.8	22.6	21.1	20.0	19.9	20.2	22.5	23.5	22.3
1350	23.4	23.4	23.6	23.9	23.8	22.7	21.2	20.1	20.0	20.4	22.6	23.5	22.4
1400	23.5	23.5	23.7	24.0	23.9	22.8	21.3	20.2	20.1	20.4	22.6	23.6	22.5
1450	23.5	23.5	23.7	24.0	23.9	22.8	21.3	20.2	20.1	20.4	22.6	23.6	22.5
1500	23.5	23.5	23.7	24.1	23.9	22.8	21.3	20.3	20.1	20.5	22.7	23.7	22.5

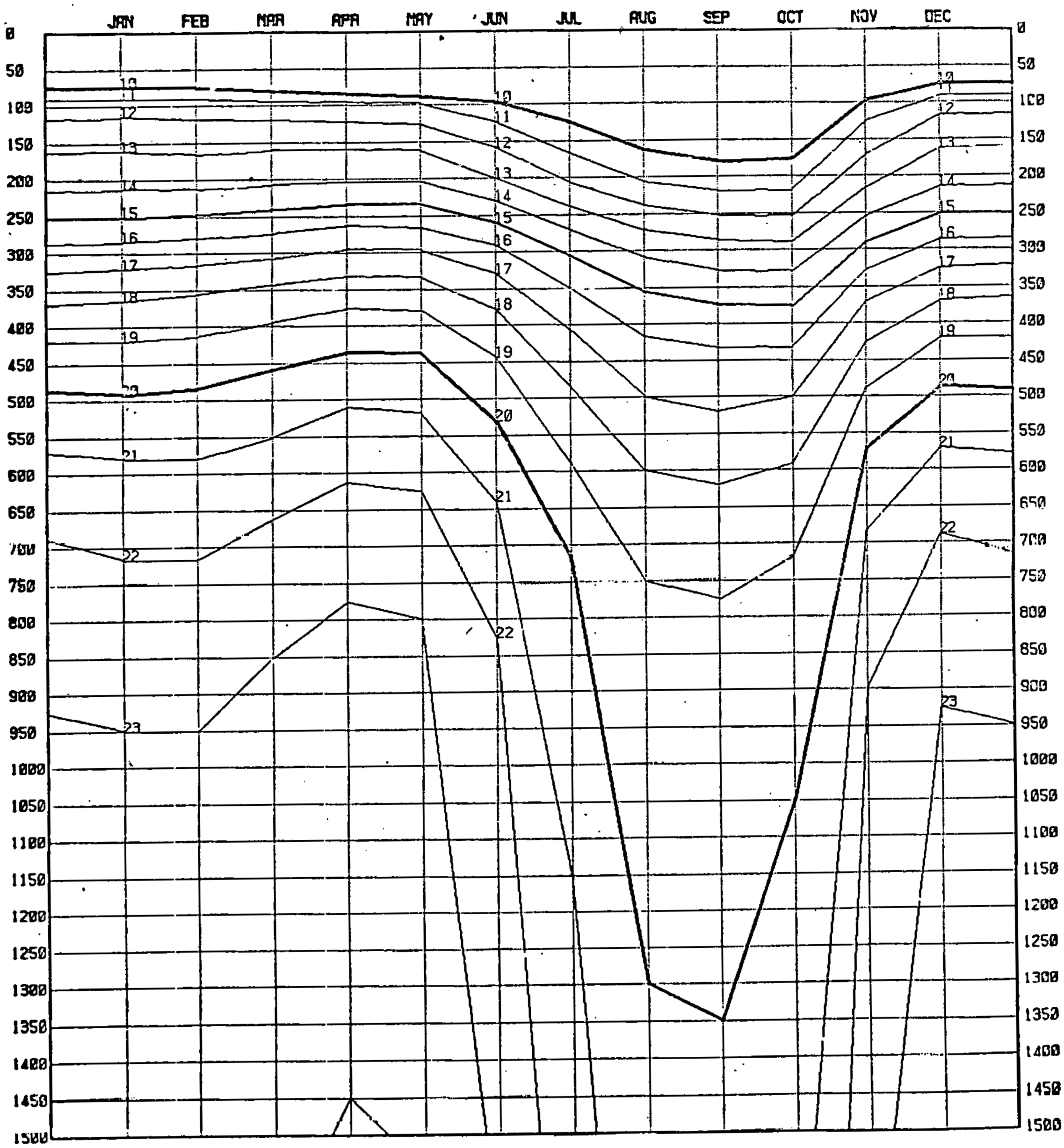


FIGURE III-1: CHART SHOWING MONTHLY ΔT CONTOURS AT A DEPTH RESOLUTION OF 50 METERS OFF THE IVORY COAST (3-6°N, 3-8°W).

IV. MIXED LAYER DEPTH

For OTEC purposes, the Mixed Layer Depth (MLD) is defined as the depth at which the temperature first becomes colder than the surface temperature by 1°C. A well-defined upper mixed layer is favorable for OTEC operations. Ideally, the layer should be deep enough to insure a good supply of warm water but not so deep as to lead to the possibility of recirculation of discharged, modified water.

The vertical temperature gradient is very strong off the Ivory Coast in the first 50 meters below the surface. Because of the light winds and lack of wave mixing from January through March, there is often no MLD during this period. When there is an upper mixed layer, it is generally very shallow.

V. WINDS AND STORMS

The site off the Ivory Coast is located between 3-6° North latitude. This area is part of the doldrums, characterized by calms or very light winds. Tropical storms are rare in the area. In January, 24% of the time the winds are calm. Similarly, the winds for spring, summer, and fall periods are generally light. The following figures demonstrate the weak winds in the area:

June	September
5% calm	8% calm
55% 4-10 knots	62% 4-10 knots
25% 11-16 knots	20% 10-16 knots
10-15% 17-27 knots	8% 17-27 knots
1% ≥ 28 knots	

The prevailing wind direction throughout the year is from the south. This data is from the Oceanographic Atlas of the North Atlantic Ocean (1963), [37].

Tables V-1 through V-4 with data from the Weather Bureau's Atlas of Climatic Charts of the Oceans provides information on the winds for each of the ten sites under this contract. These tables show that winds of near gale force or greater are unusual for the Ivory Coast site.

Figure V-1 adapted from H.L. Crutcher and R.G. Quayle (1974), [7], shows the preferred annual storm tracks this area.

TABLE V-1

RESULTANT WINDS

Average Wind Velocity in Meters per Second

Location	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug	Sep-Oct-Nov
Ivory Coast	3.1-4.1	3.1-4.1	4.1-5.1	4.1-5.1
Mombasa	5.1-6.2	4.1-5.1	6.2-7.2	4.1-5.1
Sri Lanka	4.1-5.1W 5.1-6.2E	4.1-5.1	6.2-7.2W 7.2-8.2E	5.1-6.2
Jakarta	4.1	3.1-4.1	5.1-6.2	5.1-6.2
Dampier Land	4.1-5.1	4.1-6.2	5.1-6.2	4.1-5.1
Philippines	5.1-6.2	3.1-4.1	4.1	6.2-7.2
Guam	5.1-6.2	4.1-5.1	4.1-5.1	4.1-5.1
Off Mexico	3.1-4.1	2.1-4.1	2.1-4.1	4.1-5.1
Plant Ship Pacific	3.1-4.1	3.1-4.1	4.1-5.1	4.1-6.2
Plant Ship Caribbean	6.2-7.2	5.1-6.2	6.2-8.2	4.1-5.1

TABLE V-2

FREQUENCY AND PERCENTAGE OF MODERATE GALES AND STRONGER WINDS,

BEAUFORT FORCE 7 AND HIGHER

(≥ 14.4 meters per second)

MONTH	IVORY COAST	MOMBASA	SRI LANKA	JAKARTA	DAMPIER LAND	PHILLIPINES	GUAM	OFF MEXICO	PLANT SHIP (PACIFIC)	PLANT SHIP (CARIBN)
JAN	0*	0-1	0	0	0	1-5	1-5	1-5	0	5
FEB	0	0	1	1-5	1-5	5	1-2	1-2	0	5
MAR	1-2	0	0	1-2	1-2	1	0	1-2	0	1-5
APR	0	0	0	1-2	0	1	1-5	1	0	1-5
MAY	0	1	1-5	1	0	1-5	0	0	0	1
JUN	0	5-10	5-10	1-5	0	1-5	0	1	0	1-5
JUL	0	5-10N 10-20S	1-5	1-5	1-5	5	0	0	0	1-5
AUG	0	1-5S 5-15N	1-5	0	0	1-5	1-5	1-5	0	1-5
SEP	0	0	1-5	1-5	0	5	1-5	0	0	1
OCT	0	0	0W 1-5E	1-5	0	1-5	1-2	1	1	1-5
NOV	0	0	1-5	1-5	0	10-15N 1-10S	5-15	1-5	0-5	1-5
DEC	0	1-2	0W 1-5E	1-5	0	10-15N 5-10S	1-5	1-5	0	1-5

* 0 = few or none.

TABLE V-3

PERCENTAGE OF WINDS WITH BEAUFORT FORCE 8 AND HIGHER

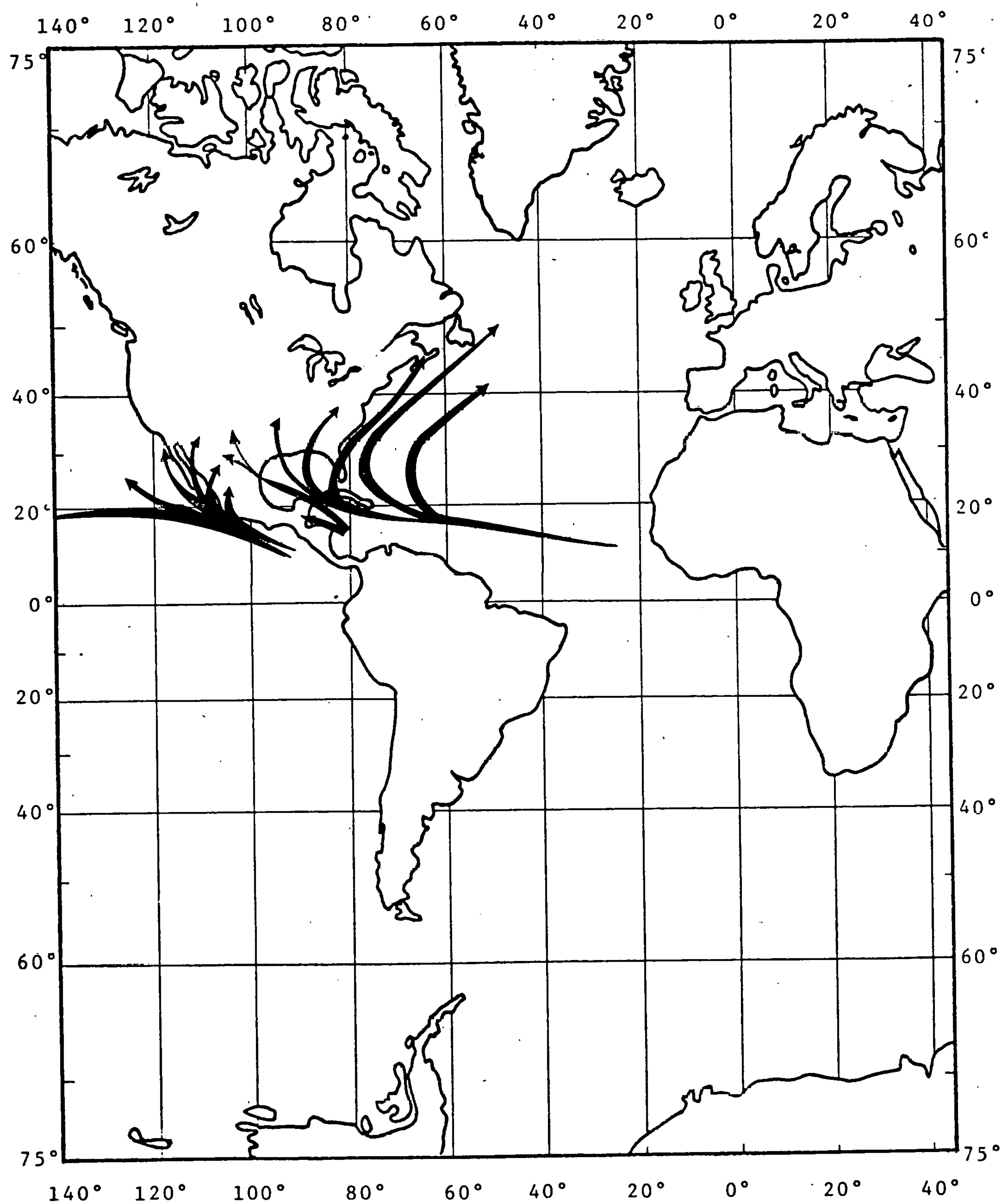
(≥ 17.5 meters per second)

LOCATION	Dec-Jan-Feb	Mar-Apr-May	Jun-Jul-Aug	Sep-Oct-Nov
Ivory Coast	0	1	0	0
Mombasa	N 1 S 0	0	0	0
Sri Lanka	0	0	1	0
Jakarta	1	1	0	1
Dampier Land	1	1	0	0
Philippines	5	0	1	1-5
Guam	0	1	1	1-5
Off Mexico	1	1	0	1
Plant Ship Pacific	0	1	0	0
Plant Ship Caribbean	1	0	1	0

TABLE V-4

PREDOMINANT SURFACE WIND DIRECTION

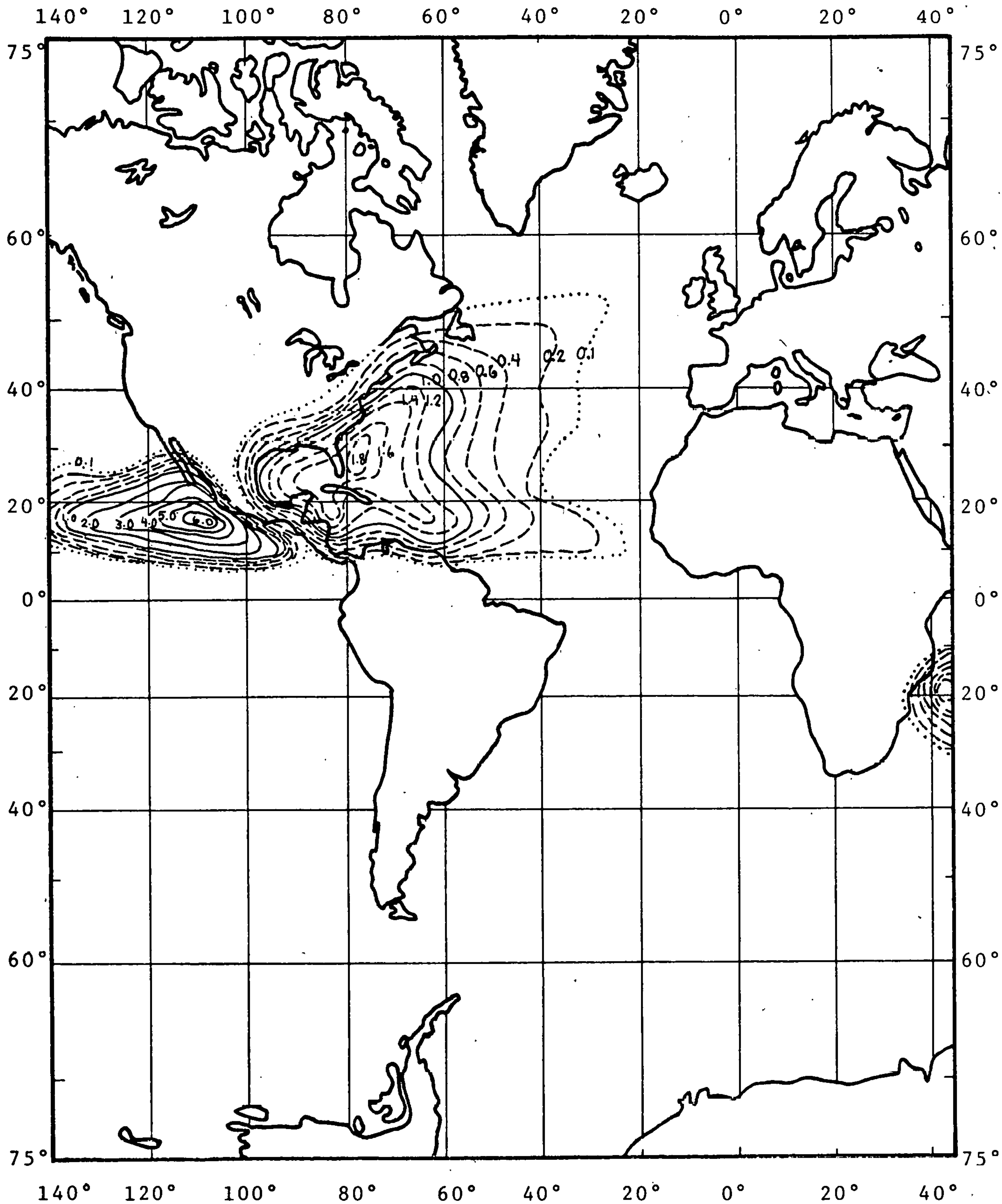
MONTH	MOMBASA	SRI LANKA	DAMPIER LAND	JAKARTA	MANILA	GUAM	OFF MEXICO	PLANT SHIP (PACIFIC)	PLANT SHIP (CARIBN)	IVORY COAST
JAN	↓ ↓	↙	↗↗	↘	↙	↙	↘	↙	↙	↑↗
FEB	↓	↙	↗	→	↙	↙	↓	↙	↙	↑
MAR	↙	↘ O ↙↓	↘ ↗	→	↙	↙	↘	↙	←	↑
APR	O° ↙ / ↖	O↗	↖↖	↖	↙	↙	↘	↙	←	↑
MAY	↑↑	↗	↖	↖	↙ ↖	↙	↘	↖	←	↑
JUN	↑	↗	↖	↖	↗	←	↘	↘ ↙ ↑	←	↑
JUL	↑	↗	↖	↖	↗	↑ ↑ ←	↘	↑	←	↑
AUG	↑	↗	↖	↖	↗	← ↖	↓	→ → ↑	←	↗
SEP	↑	→O↗	↖	↖	↙↗	←	↘	↗	←	↑
OCT	↖	→	↖	↖	↙	↙	↓	↑	←	↑
NOV	↙ / ↖	→O↙	↖↗	↘ ↖	↙	↙	↓	↙↓ ↖↖	←	↑
DEC	↙	↙	↗	↗	↓	↙	↓	↙	↙	↗



ANNUAL PERFERRED STORM TRACKS FOR TROPICAL STORMS

FIGURE V-1

Figure V-2 from the same source provides the average number of tropical cyclones per 5° square per year. As these figures show tropical storms and hurricanes are not a problem for the Ivory Coast site.



AVERAGE NUMBER OF
TROPICAL CYCLONES PER 5°
SQUARE PER YEAR

FIGURE V-2

VI. SEA AND SWELL CHARACTERISTICS

Table VI-1, taken from Ocean Wave Statistics, (1967), [19], presents a statistical breakdown showing the number of observations in various wave heights versus period categories. This summary is based upon actual ships' observations from a somewhat larger region south of the Ivory Coast, however, conditions over the area are represented as being homogeneous.

The predominant direction of the waves is from the south. This direction is constant sixty to eighty percent of the time. The roughest average sea conditions exist during June and July. Throughout the year, however, the state of the sea can be characterized as slight with waves less than one meter. Similarly, the low swell conditions predominate throughout the year with swells less than two meters.

TABLE VI-1: STATISTICAL BREAKDOWN SHOWING NUMBER OF SHIPS OBSERVATIONS SOUTH OF THE IVORY COAST REPORTING VARIOUS HEIGHT/PERIOD COMBINATIONS (ALL SEASONS). From Ocean Wave Statistics (1967), [19].

Wave Height (meters)	Wave Period (Seconds) Calm	<5	6-7	8-9	10-11	12-13	14-15	16-17	18-19	20-21	over 22	Total	Percent of Grand Total
0.25	1589	1484	41	15	5	4	7	1		31	28	3208	16
0.5	101	3338	319	99	49	18	8	4		7	237	4180	20
1.0	90	4665	1899	379	100	63	20	9	1	7	67	7300	35
1.5	35	1330	1963	625	150	71	29	9	1		6	4219	20
2.0	9	171	535	381	130	28	17	4	3		1	1279	6
2.5	3	21	100	142	49	24	4		1			344	2
3.0		5	17	25	19	11	3	1			1	82	<1
3.5		4	2	10	4	1						21	<1
4.0			2	2	1	2				2		9	<1
4.5		1		6	1	1	2	2		1		14	<1
5.0	5	1										6	<1
5.5	1	1										2	<1
6.0		2		1				2				5	<1
6.5		1		2			2					5	<1
7.0	1			1								2	<1
TOTAL	1834	11024	4878	1688	508	223	92	32	6	48	340	20673	
Percent of Grand Total	9	53	24	8	2	1	<1	<1	<1	<1	1		

VII. CURRENTS

The predominant current of the South Atlantic Ocean is the Benguela Current, which flows along the west coast of Africa. As the Benguela Current proceeds towards the equator, it leaves the coast and continues as the northern portion of the South Equatorial Current which flows towards the west across the Atlantic, usually between 0° and 20° south. Three degrees north latitude is the northernmost boundary of the South Equatorial Current. Thus, the region of this study is in the area of the Equatorial Countercurrent. The Guinea Current, which flows eastward off the coast of the Ivory Coast is a part of the undercurrent. The flow of the equatorial undercurrent can be quite strong. The Encyclopedia of Oceanography (1966, [30]) states that the flow can be up to 116 cm/sec at the equator at the longitude of the Ivory Coast site. Between 3-6°N the current speeds are generally less than 50 cm/sec.

Hurricanes, while rare at this site, can cause changes in surface currents. Leipper's 1967 [21] study of Hurricane Hilda showed that a current had developed in the area transversed by the storm. Analysis of temperature - depth showed a current of approximately 50 cm/sec. A theoretical study by O'Brien and Reid (1967, [27]) states that hurricanes will cause currents with a speed of approximately one meter per second.

The passage of hurricanes will induce upwelling of subsurface waters for a temporary period. This upwelling will cause anomalous vertical current shears. Adamec and O'Brien (1978, [1]) state that strong upwelling occurs throughout the Gulf of Guinea. Vertical and horizontal current shears are also observed in association with major current systems. Some of the strongest current shears are in equatorial undercurrents. Equatorial undercurrents exist for this site. Avery, et al (1976, [3]), concluded that the strong current shear within five degrees latitude of the equator excludes the use of plant ships within most of that region. Strong current shears are also a problem for bottom-mounted OTEC plants.

REFERENCES

1. Adamec, D., and O'Brien, J.J., November 1978, "The Seasonal Upwelling in the Gulf of Guinea Due to Remote Forcing", J. Phys. Oceanogr., 8, No. 6, 1050-1060.

2. Atwood, D.K., et al., 1976, Ocean Thermal Energy Conversion, Resource Assessment and Environment Impact for Proposed Puerto Rico Site, University of Puerto Rico.

3. Avery, W.H., et al., 1976, Maritime and Construction Aspects of Ocean Thermal Energy Conversion (OTEC) Plant Ships, The John Hopkins University Applied Physics Laboratory, Laurel, Maryland.

4. Bathen, K.H., et al., 1977, "Consolidated Oceanographic and Meteorological Data for Four North Pacific OTEC Sites", University of Hawaii.

5. Bigelow, H.B., and W.T. Emundson, 1947, Wind Waves at Sea, U.S. Hydrographic Office, Washington, D.C.

6. Colburn, J.G., 1974, "The Thermal Structure of the Indian Ocean", International Indian Ocean Expedition Oceanographic Monograph No., 2; The University Press of Hawaii; Honolulu, Hawaii.

7. Crutcher, H.L. and R.G. Quayle, 1974, "Mariners Worldwide Climatic Guide to Tropical Storms at Sea", NAVAIR 50-1C-61, Naval Weather Service; Asheville, N.C.

8. Defense Mapping Agency Hydrographic/Topographic Center, 1978, Pilot Chart of the North Pacific, DMA Stock Numbers PILOT 557801, 557804, 557810, Washington, D.C.

9. Defense Mapping Agency Hydrographic/Topographic Center, 1978, Pilot Chart of the North Atlantic Ocean, DMA Stock Numbers PILOT 167801, 167804, 167807, 167810, Washington, D.C.

10. Defense Mapping Agency Hydrographic Center, South Pacific Ocean, Sheet IV, Pub. N.O. 623, revised 1974, Washington, D.C.

11. Defense Mapping Agency Hydrographic Center, Indian Ocean, Northern Part, Pub No. 721, 1974, Washington, D.C.

12. Defense Mapping Agency Hydrographic Center, Gulf of Mexico and Carribean Sea, Pub. No. 410, revised 1973, Washington, D.C.

13. Defense Mapping Agency Hydrographic Center, North Atlantic Ocean, Southeastern Sheet, Publication N.O. 125, 4th ed., 1974, Washington, D.C.

14. Düing, W., 1970; "The Monsoon Regime of the Currents in the Indian Ocean", International Indian Ocean Expedition Oceanographic Monograph No. 1, Hawaii Institute of Geophysics Contribution No. 331, the University of Hawaii Press; Honolulu, Hawaii.

15. Düing, W. and F. Schott; March 1978, "Measurements in the Source Region of the Somali Current during the Monsoon Reversal", J. Phys. Oceanogr., 8, 278-289.

16. Emilsson, J., 1970, "On the Upper Layer Circulation in the Cayman Sea", from the Symposium on the Investigations and Resources of the Caribbean Sea and Adjacent Regions, UNESCO, Paris France.

17. Fleet Numerical Weather Central (FNWC), FNWC and National Oceanographic Data Center digitized reports.

18. Gentry, R.C., 1970, "Hurricanes, One of the Major Features of Air-Sea Interaction in the Caribbean Sea", from the Symposium on the Investigation and Resources of the Caribbean Sea and Adjacent Regions, UNESCO, Paris, France.

19. Hogben, N., and F. Lumb, 1967, Ocean Wave Statistics, National Physical Laboratory, Ministry of Technology, London. Her Majesty's Stationery Office.

20. Johnson, A. and S. Denwick, 1978; "Data Report Buoy Observations During Hurricanes Anita and Babe, August-September, 1977", NOAA Data Buoy Office, National Space Technology Laboratories, NSTL Station; Mississippi.

21. Leipper, D.F., 1967, "Observed Ocean Conditions and Hurricane Hilda, 1964. J. Atmos Sci., 24, p 182-196.

22. McFadden J.D., "Airborne Investigations of the Effects of Hurricanes on the Thermal Structure of the Surface Layer of the Ocean", from the Symposium on Investigation and Resources of the Caribbean Sea and Adjacent Regions, UNESCO, Paris France.

23. National Oceanographic Data Center, The Variability of Water Masses in the Indian Ocean, Publication G-11, Washington, D.C.

24. National Oceanographic Data Center, Data File BTG75A, Washington, D.C., 1977.

25. National Oceanographic Data Center, Data Files SD40A5/0A6 from SD76A (1/30/76) 3509 STA: Washington, D.C., 1977.

26. National Science Foundation, 1972, Meteorological Atlas of the International Indian Ocean Expedition, Volume 7, Washington, D.C.

27. O'Brien, J.J., and R.O. Reid, 1967, "The Non-Linear Response of a Two Layer Baroclinic Ocean to a Stationery Axially Symetric Hurricane", J. Atmos. Sci., 24, p 197-215.

28. Ramage, C.D., 1972, "Indian Ocean Surface Meteorology", International Indian Ocean Expedition, Collective Reprints VIII, Contribution No. 624, pgs 407-540; Paris, France.

29. Sirvastava, P.S., P.K. Vyayarayou and M.X. Joseph, 1972 "Monthly Wave Characteristics of the Bay of Bengal", International Indian Ocean Expedition, Collective Reprints VIII, Contribution No. 625, Paris, France.

30. The Enclyopedia of Oceanography, 1966, Reinhold Publishing Corp., New York, New York.

31. U.S. Department of Agriculture, Weather Bureau, 1938, "Atlas of Climatic Charts of the Oceans", Washington, D.C.

32. U.S. Department of Commerce, NOAA, 1971, Eastropac Atlas, Volume 3, Washington, D.C.

33. U.S. Navy, 1975, Marine Climatic Atlas of the World, Volume III, Indian Ocean, Washington, D.C.

34. U.S. Navy Hydrographic Office, 1964, Atlas of Sea and Swell Charts, Northeastern Pacific Ocean, Publication No. 799D, revised 1976, Washington, D.C.

35. U.S. Naval Weather Service, September 1974, Climatic Summaries For Major Indian Ocean Ports and Waters, NAVAIR 50-1C-63, Asheville, N.C.

36. U.S. Naval Weather Service, November 1973, Climatic Summaries For Major Seventh Fleet Ports and Waters, NAVAIR 50-1C-62, Asheville, N.C.

37. U.S. Naval Oceanographic Office, 1963, Oceanographic Atlas of the North Atlantic Ocean, Washington, D.C.

38. U.S. Naval Oceanographic Office, Bathymetric Atlas of the Northeastern Pacific Ocean, Pub No. 1303-S, No. 0902N, 0903N, 1002N, 1003N, Washington, D.C.

39. U.S. Naval Oceanographic Office, Indian Ocean, Africa-East Coast Publication No. 724, 1st ed., 1974, Washington, D.C.

40. U.S. Naval Oceanographic Office, 1971, Bathymetric Atlas of the Northeastern Pacific Ocean, H.O. Pub No. 1303-S, N.O. 1104N, 1105N, 1204N, 1204N, Washington, D.C.

41. U.S. Naval Oceanographic Office, 1971, Bathymetric Atlas of the Northeastern Pacific Ocean, H.O. Pub N.O. 1301-S, 2403N, 2040N, Washington, D.C.

42. U.S. Naval Oceanographic Office, 1970, Bathymetric Atlas of the Northwestern Pacific Ocean, H.O. Pub. 1201-S, N.O. 2203N, Washington, D.C.

43. Wolff, P.M. and W.E. Hubert, 1976, "Ocean Thermal Energy Conversion: Resource, Ecological and Environmental Studies", Contract No. NSF-C1020, Ocean Data Systems, Inc., Monterey, California.

44. Wolff, P.M., et al, 1977, "OTEC Resource Report for Hawaii", Contract EG-77-C-01-4028, Ocean Data Systems, Inc., Monterey, California.

45. Wyrtki, K., 1972, "The Upwelling in the Region Between Java and Australia during the South-East Monsoon, Collected reprints of the International Indian Ocean Expedition, Volume I, Contribution No. 15, pp 151-161.

46. Wyrtki, K., 1972, "Geopotential Topographics and Associated Circulation in the South Eastern Indian Ocean", Collected reprints of the International Indian Ocean Expedition, Volume I, contribution No. 14.

47. Wyrtki, K., 1971, Oceanographic Atlas of the International Ocean Expedition, National Science Foundation, NSF-IOE-1, Washington, D.C.

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