OTEC Thermal Resource Report for Sri Lanka

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

Prepared by
William Alan Wolff
Ocean Data Systems, Inc.
Monterey, California 93940

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

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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
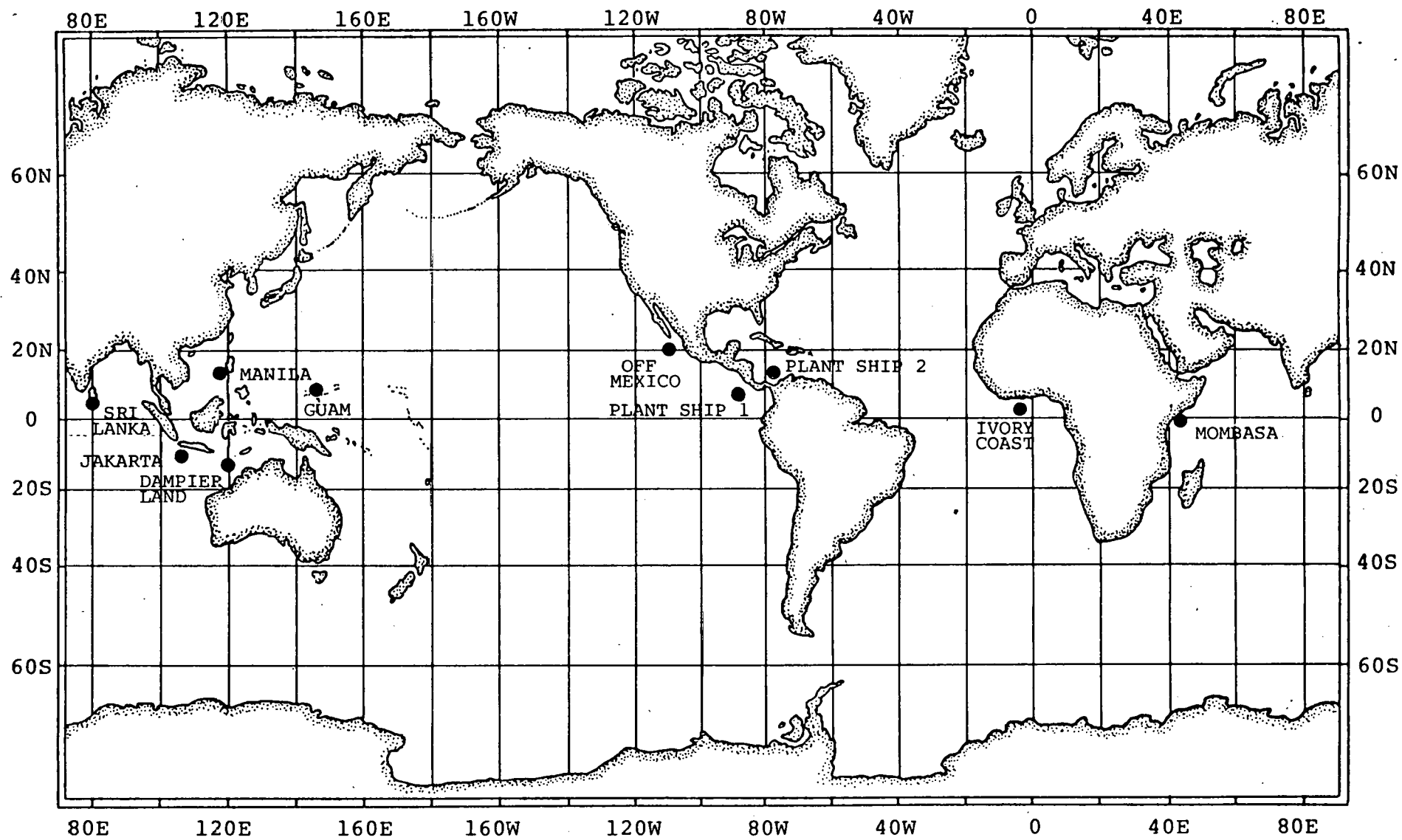
LOCATION OF THE TEN SELECTED SITES

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 water surrounding the island of Sri Lanka has a temperature difference resource which is more than adequate for potential OTEC use. The temperature resource was examined between 5°-10° North latitude and 78°-83° East longitude. This area includes the surrounding waters on all sides of Sri Lanka. There is a large area north and northwest of the island where there is insufficient depth to provide the needed cold water supply. The annual average ΔT at 1000 meters is 21.3°C. An annual average ΔT greater than 20°C is available at 800 meters. The temperature is very consistent at depths with little difference between the coldest monthly mean temperature and the warmest.

The area has an upper mixed layer the entire year, (deepest in January-February and shallowest in the fall). Winds and storms are not a major problem for this site, although there are occasional tropical storms or hurricanes. Low to moderate sea and swell conditions generally dominate throughout the year. The surface currents are generally moderate throughout the year, changing direction with the shifting monsoons.

II. BATHYMETRY

Figure II-1 shows the location of a potential site off Sri Lanka. Although only a site on the east coast of the island is indicated, sites on the western or southern coasts of the island are also possible. The area studied for the Sri Lanka site was from 5°-10° North latitude and between 78°-83° East longitude. A rough bathymetry of the area is shown in Figure II-2. The source for this bathymetry is the Defense Mapping Agency Hydrographic Center publication N.O. 721, Indian Ocean, Northern Part (1974), [11].

Northwest of the island is an extensive shallow area in which the bottom is less than 100 meters deep. This is also true for some of the area due north of the island. Depths of 1000 and 1500 meters are available west, south, east, and northeast of the island. West of Colombo, the largest city and seaport, the 1000 meter depth is within 20km of shore. The distance from shore to specified depths is shown in Table II-1.

TABLE II-1: DISTANCE FROM SHORE TO SPECIFIED DEPTHS
IN KILOMETERS AND (NAUTICAL MILES)

Closest Distance to:	Direction			
	N	E	S	W
100 Meters	22.0(12)	14.8(8)	14.8(8)	14.8(8)
500 Meters	38.9(21)	31.5(17)	24.0(13)	18.5(10)
1000 Meters	55.0(30)	38.9(21)	38.9(21)	22.2(12)
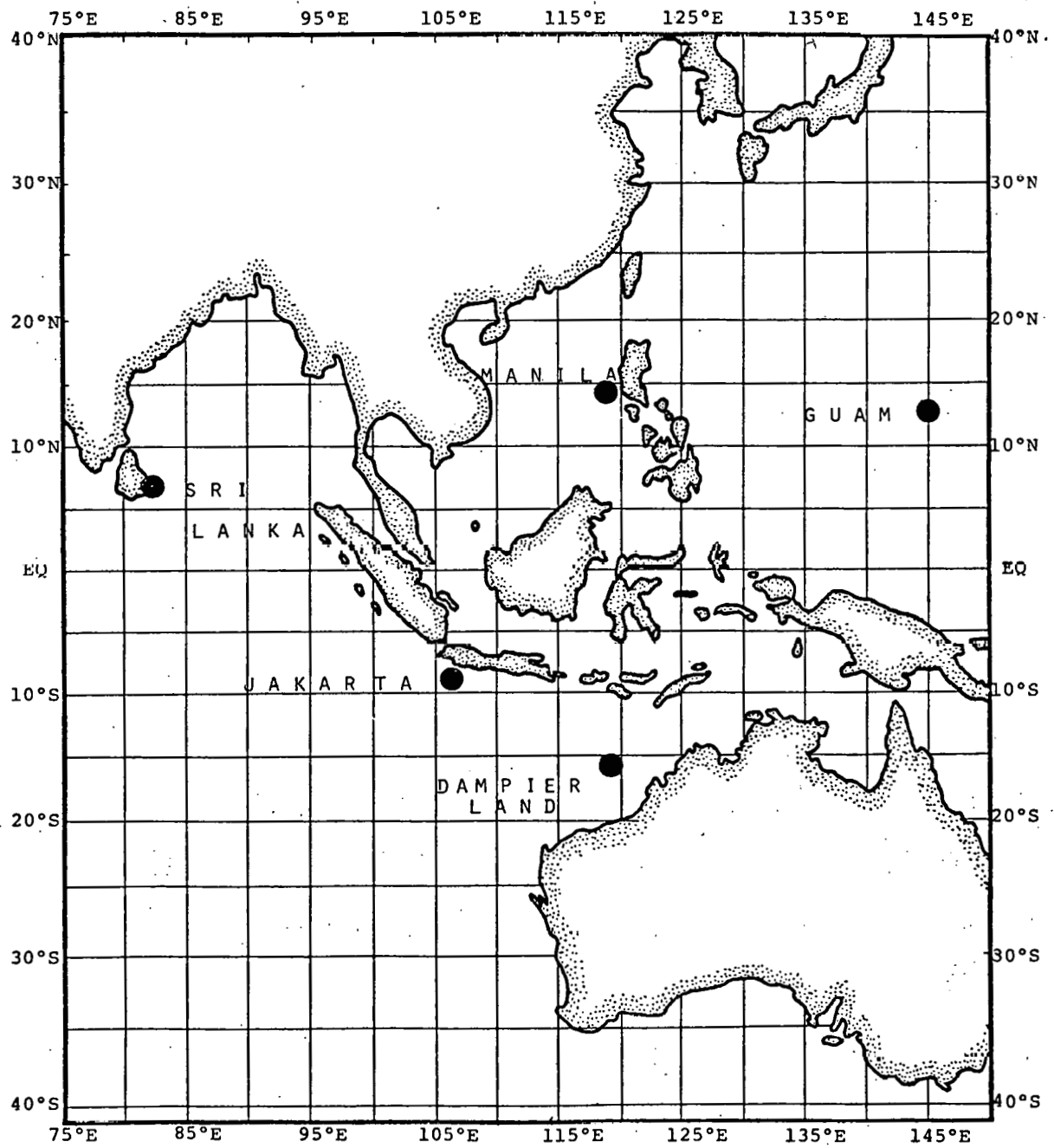
FIGURE II-1: LOCATOR CHART
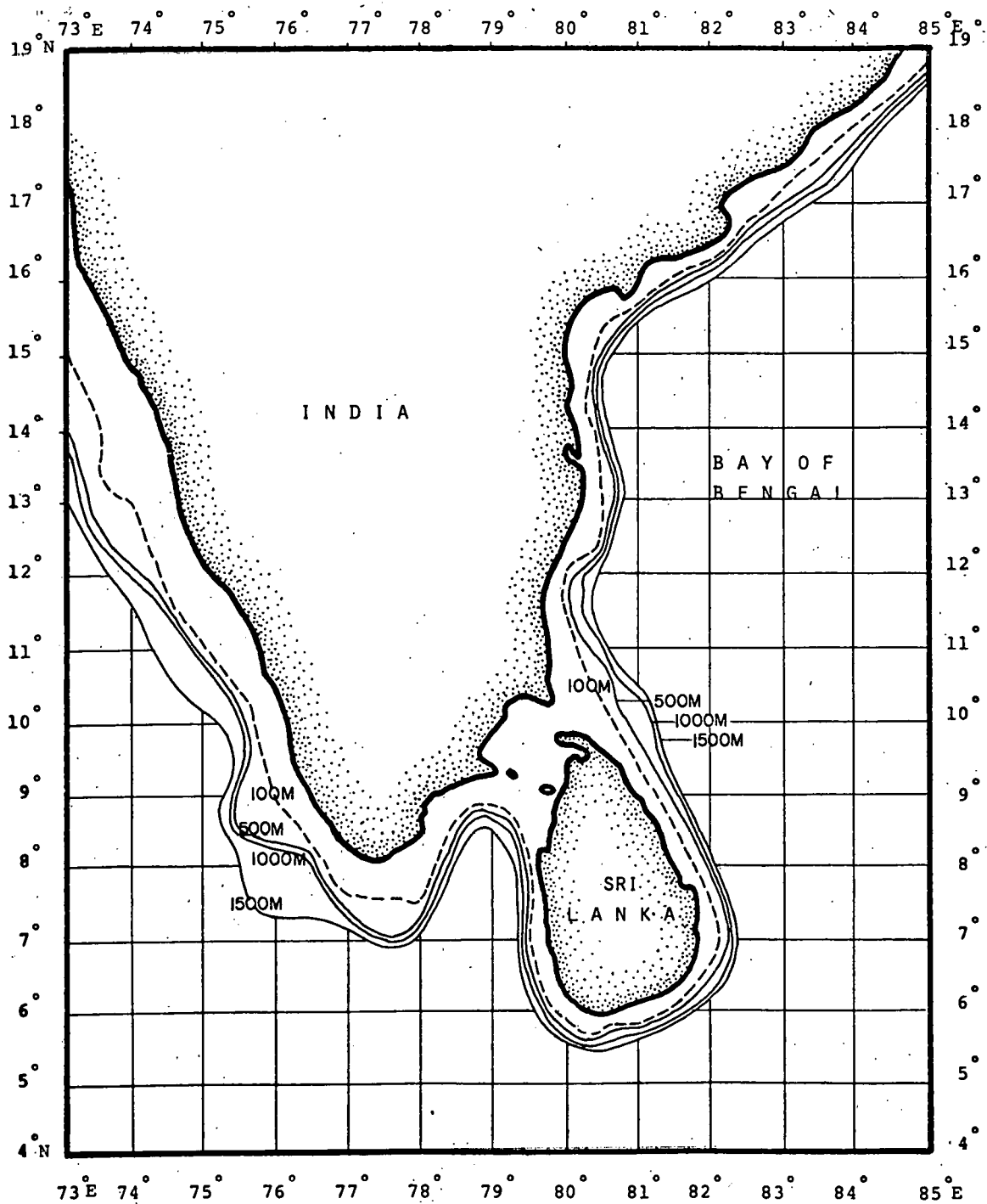
FIGURE II-2:   ROUGH BATHYMETRY TO 1500 METERS OFF SRI LANKA

III. THERMAL RESOURCE

There was temperature data for every month of the year and at each 50-meter level from the surface to the 1500-meter depth. The main sources for this data were NOAA's National Oceanographic Data Center, and the U.S. Navy Fleet Numerical Weather Central, although soundings from university or other sources were added when available. The data at depth and for some months of the year is sparse.

When the available data was plotted, some month-to-month variability was present which was caused by the sparse and 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].

The thermal resource is a good one, although not quite as good as several of the other ten sites being studied under this contract. While there are observations of 30°C or greater in the upper layer, the monthly mean surface temperature for nine months was between 27°C and 28°C. The winter surface waters are influenced by the slightly cooler Bay of Bengal waters. The temperatures at depths of 1000 meters in the Indian Ocean, including the waters surrounding Sri Lanka, are several degrees Centigrade warmer than sites in the Atlantic and Pacific. The average mean temperature at 1000 meters is 6.6°C for the Sri Lanka site region.

Table III-1 provides the monthly most probable temperature (°C) profile for Sri Lanka. The annual mean temperatures for each depth were computed by averaging the monthly most probable temperature figures. Table III-2 provides ΔT, the surface temperature minus the temperature at depth differential (°C) by months. The annual mean ΔT, was computed by taking the differential of the annual mean surface temperature and the annual mean temperature at depth from Table III-1. Figure III-3 provides a plot of monthly ΔT contours for the Sri Lanka site.

TABLE III-1

MONTHLY MOST PROBABLE TEMPERATURE (°C) PROFILE
SRI LANKA 5-10°N/78-83°E

Depth	Month												Annual Mean
	1	2	3	4	5	6	7	8	9	10	11	12	
0	27.5	27.5	28.3	28.6	28.6	28.0	27.5	27.6	27.7	27.8	27.9	27.8	27.9
50	27.2	27.3	27.5	27.5	27.0	26.5	25.3	25.5	25.5	27.0	27.3	27.5	26.8
100	22.8	23.9	22.9	22.3	21.6	20.8	20.2	19.7	20.3	21.6	21.6	22.8	21.7
150	17.5	17.7	17.1	16.8	16.9	16.0	15.3	15.6	16.1	16.7	16.7	17.2	16.6
200	14.4	14.4	14.1	14.0	13.8	13.6	13.3	13.6	13.8	13.7	13.7	13.9	13.9
250	13.0	12.9	12.7	12.6	12.5	12.5	12.2	12.5	12.7	12.5	12.6	12.6	12.6
300	12.0	12.0	11.8	11.9	11.8	11.8	11.7	11.7	11.9	11.7	11.8	11.7	11.8
350	11.3	11.3	11.2	11.3	11.3	11.3	11.2	11.2	11.3	11.2	11.3	11.3	11.3
400	10.9	10.8	10.7	10.8	10.8	10.8	10.7	10.8	10.9	10.8	10.8	10.7	10.8
450	10.4	10.4	10.3	10.4	10.4	10.4	10.4	10.4	10.5	10.3	10.4	10.3	10.4
500	10.0	10.0	9.9	10.0	10.1	10.0	9.9	9.8	9.9	9.8	9.8	9.9	9.9
550	9.6	9.6	9.6	9.6	9.6	9.5	9.5	9.4	9.6	9.5	9.5	9.5	9.6
600	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2	9.3	9.2	9.1	9.2	9.2
650	8.9	8.9	8.9	9.0	8.9	8.8	8.8	8.8	8.9	8.8	8.8	8.8	8.9
700	8.5	8.5	8.5	8.6	8.6	8.7	8.6	8.6	8.5	8.5	8.5	8.5	8.5
750	8.1	8.2	8.2	8.3	8.3	8.3	8.2	8.2	8.2	8.2	8.1	8.1	8.2
800	7.8	7.9	7.8	7.9	7.9	7.9	7.8	7.8	7.8	7.8	7.8	7.9	7.8
850	7.5	7.5	7.4	7.5	7.6	7.7	7.6	7.5	7.5	7.5	7.5	7.5	7.5
900	7.2	7.2	7.1	7.1	7.2	7.3	7.3	7.2	7.2	7.2	7.2	7.2	7.2
950	6.9	6.8	6.8	6.8	6.9	7.0	7.0	6.9	6.9	6.9	6.9	6.9	6.9
1000	6.6	6.5	6.5	6.5	6.6	6.7	6.7	6.7	6.6	6.6	6.6	6.6	6.6
1050	6.3	6.2	6.2	6.2	6.3	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.3
1100	6.0	6.0	6.0	6.0	6.0	6.1	6.1	6.2	6.1	6.1	6.1	6.1	6.1
1150	5.8	5.7	5.7	5.7	5.7	5.8	5.9	5.9	5.9	5.9	5.9	5.8	5.8
1200	5.5	5.5	5.5	5.5	5.5	5.6	5.6	5.6	5.6	5.7	5.6	5.6	5.6
1250	5.3	5.3	5.4	5.3	5.3	5.3	5.4	5.4	5.4	5.4	5.4	5.3	5.4
1300	5.1	5.1	5.2	5.1	5.1	5.1	5.2	5.2	5.2	5.2	5.2	5.1	5.2
1350	4.9	4.9	5.0	4.9	4.9	4.9	5.0	5.0	5.0	5.0	4.9	4.8	4.9
1400	4.7	4.8	4.9	4.8	4.7	4.7	4.7	4.8	4.8	4.7	4.7	4.6	4.8
1450	4.5	4.6	4.6	4.7	4.6	4.5	4.5	4.5	4.5	4.5	4.5	4.4	4.5
1500	4.2	4.3	4.4	4.5	4.4	4.3	4.3	4.3	4.3	4.3	4.2	4.2	4.3

TABLE III-2

SURFACE TEMPERATURE – TEMPERATURE AT DEPTH
DIFFERENTIAL (°C) BY MONTHS   SRI LANKA 5–10°N/78–83°E

| Depth	1	2	3	4	5	6	7	8	9	10	11	12	Annual Mean
50	0.3	0.2	0.8	1.1	1.6	1.5	2.2	2.1	2.2	0.8	0.6	0.3	1.1
100	4.7	3.6	5.4	6.3	7.0	7.2	7.3	7.9	7.4	6.2	6.3	5.0	6.2
150	10.0	9.8	11.2	11.8	11.7	12.0	12.2	12.0	11.6	11.1	11.2	10.6	11.3
200	13.1	13.1	14.2	14.6	14.8	14.4	14.2	14.0	13.9	14.1	14.2	13.9	14.0
250	14.5	14.6	15.6	16.0	16.1	15.5	15.3	15.1	15.0	15.3	15.3	15.2	15.3
300	15.5	15.5	16.5	16.7	16.8	16.2	15.8	15.9	15.8	16.1	16.1	16.1	16.1
350	16.2	16.2	17.1	17.3	17.3	16.7	16.3	16.4	16.4	16.6	16.6	16.5	16.6
400	16.6	16.7	17.6	17.8	17.8	17.2	16.8	16.8	16.8	17.0	17.1	17.1	17.1
450	17.1	17.1	18.0	18.2	18.2	17.6	17.1	17.2	17.2	17.5	17.5	17.5	17.5
500	17.5	17.5	18.4	18.6	18.5	18.0	17.6	17.8	17.8	18.0	18.1	17.9	18.0
550	17.9	17.9	18.7	19.0	19.0	18.5	18.0	18.2	18.1	18.3	18.4	18.3	18.4
600	18.2	18.3	19.1	19.4	19.4	18.8	18.3	18.4	18.4	18.6	18.8	18.6	18.7
650	18.6	18.6	19.4	19.6	19.7	19.2	18.7	18.8	18.8	19.0	19.1	19.0	19.0
700	19.0	19.0	19.8	20.0	20.0	19.3	18.9	19.0	19.2	19.3	19.4	19.3	19.4
750	19.4	19.3	20.1	20.3	20.3	19.7	19.3	19.4	19.5	19.6	19.8	19.7	19.7
800	19.7	19.6	20.5	20.7	20.7	20.1	19.7	19.8	19.9	20.0	20.1	19.9	20.1
850	20.0	20.0	20.9	21.1	21.0	20.3	19.9	20.1	20.2	20.3	20.4	20.3	20.4
900	20.3	20.3	21.2	21.5	21.4	20.7	20.2	20.4	20.5	20.6	20.7	20.6	20.7
950	20.6	20.7	21.5	21.8	21.7	21.0	20.5	20.7	20.8	20.9	21.0	20.9	21.0
1000	20.9	21.0	21.8	22.1	22.0	21.3	20.8	20.9	21.1	21.2	21.3	21.2	21.3
1050	21.2	21.3	22.1	22.4	22.3	21.6	21.1	21.2	21.3	21.4	21.5	21.4	21.6
1100	21.5	21.5	22.3	22.6	22.6	21.9	21.4	21.4	21.6	21.7	21.8	21.7	21.8
1150	21.7	21.8	22.6	22.9	22.9	22.2	21.6	21.7	21.8	21.9	22.0	22.0	22.1
1200	22.0	22.0	22.8	23.1	23.1	22.4	21.9	22.0	22.1	22.1	22.3	22.2	22.3
1250	22.2	22.2	22.9	23.3	23.3	22.7	22.1	22.2	22.3	22.4	22.5	22.5	22.6
1300	22.4	22.4	23.1	23.5	23.5	22.9	22.3	22.4	22.5	22.6	22.7	22.7	22.8
1350	22.6	22.6	23.3	23.7	23.7	23.1	22.5	22.6	22.7	22.8	23.0	23.0	23.0
1400	22.8	22.7	23.4	23.8	23.9	23.3	22.8	22.8	22.9	23.1	23.2	23.2	23.2
1450	23.0	22.9	23.7	23.9	24.0	23.5	23.0	23.1	23.2	23.3	23.4	23.4	23.4
1500	23.3	23.2	23.9	24.1	24.2	23.7	23.2	23.3	23.4	23.5	23.7	23.6	23.6
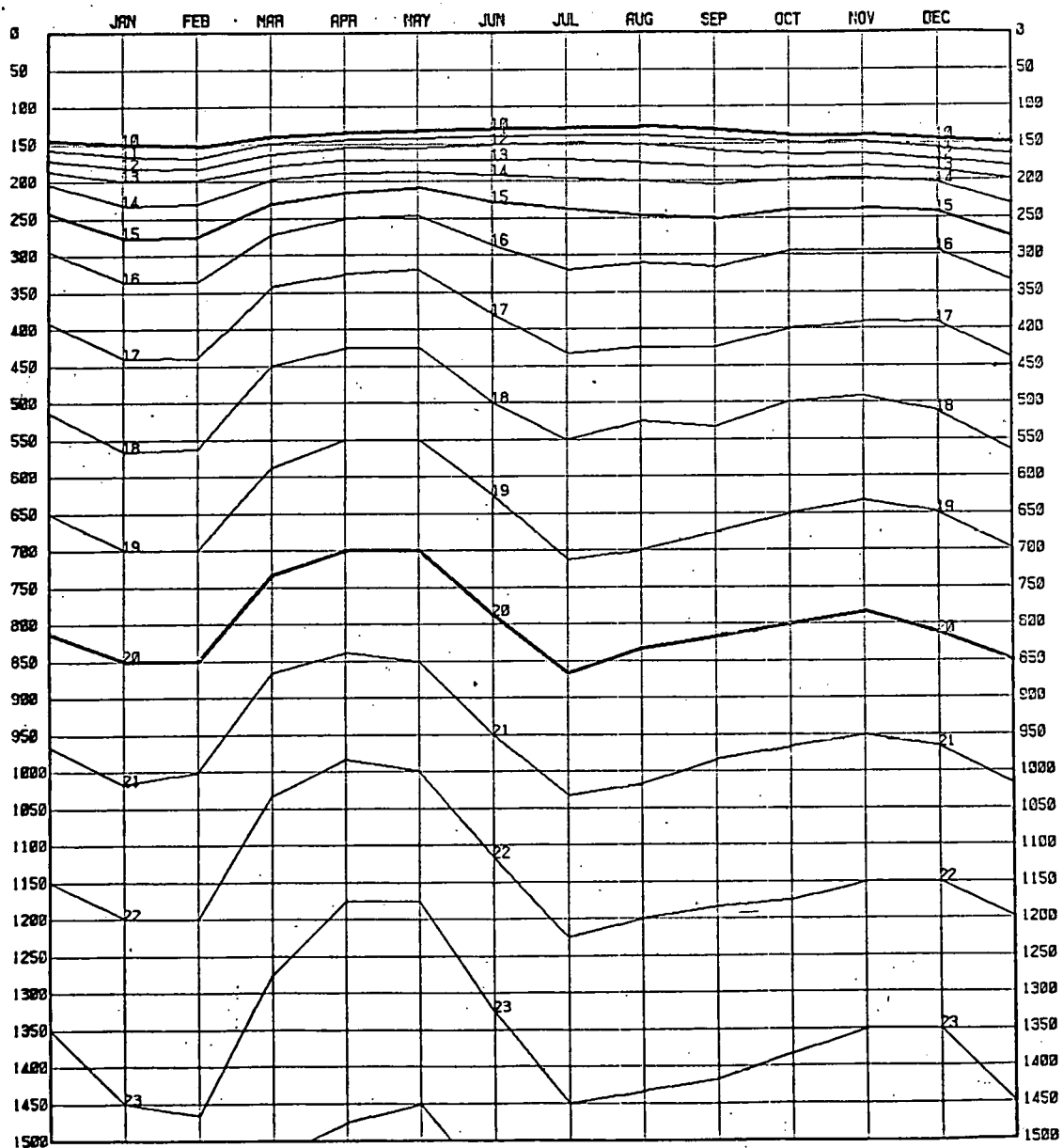
FIGURE III-1:   CHART SHOWING MONTHLY ΔT CONTOURS (°C)
                AT A   DEPTH RESOLUTION OF 50 METERS
                OFF SRI LANKA (5-10N/78-83E)

IV. MIXED LAYER DEPTH

An upper mixed layer is found in the coastal waters of Sri Lanka throughout the year. Between November and February the Mixed Layer Depth (MLD) is the deepest (generally at least 50 meters in depth). From May to June, the MLD is shallower (generally ranging between 30-50 meters in depth). The depth of the mixed layer varies slightly depending on which coast is chosen for the site. Depths of the MLD (in meters) off the respective coasts are as follows:

	JAN-FEB	MAR-APR	MAY-JUN	JUL-AUG	SEP-OCT	NOV-DEC
North Coast	50	35	30	50	35	50
East Coast	50	50	30	30	50	50
West Coast	70	50	30	30	50	50
South Coast	80	50	40	40	55	50

This mixed layer should be adequate for OTEC purposes, since it is deep enough to assure an intake of uniformly warm water at or very close to the surface temperature. Also, the mixed layer depth off Sri Lanka is not so deep that discharged exhaust water will cause recirculation problems. The Thermal Structure of the Indian Ocean by Colburn (1974), [6] was consulted for mixed layer depth values together with our own temperature data file. The mixed layer depth was defined for OTEC purposes to be the depth at which the temperature is first colder than the surface value by 1° Centigrade.

V.   WEATHER CONDITIONS

Table V-1, taken from the U.S. Naval Weather Service,
(1973), [36] shows basic climatic information for the city
of Colombo, Sri Lanka. It is clear that there are two rainy
seasons and a distinct monsoonal wind regime. The area
exhibits steady flow from the west or southwest from May
through September and a steady wind flow from the northeast
from November through February. In the fall and spring
transition periods winds are more variable in both speed and
direction. This is verified by wind flow statistics for
water areas around Sri Lanka as shown in Table V-2 (from and
U.S. Dept. of Agriculture, (1938), [31]).

Sri Lanka lies on the southern edge of the tropical
storm/cyclone belt in the Indian Ocean. Figure V-1 shows
the preferred tropical storm tracks for the region while
Figure V-2 shows the average number of tropical cyclones per
5 degree square per year. Both figures are from Crutcher
and Quayle (1974), [7]. A recent climatic study by the U.S.
Naval Weather Service (1972), [36] confirms these statistics;
their results are summarized in Table V-3.

Hurricanes will cause winds which may sustain speeds of
30 to 50 meters per second. Mountainous waves can be pro-
duced. Gentry (1970), [18] states that occasional waves of
over 20 meters have been reported in association with hurricanes
and that there are numerous reports of waves 1015 meters. A
NDBO study, (1978), [20], indicates that hurricanes can
cause a temperature anomaly of -3°C for a period of four

days. While this result was measured in the Gulf of Mexico, it should be indicative of the effects of hurricanes on the thermal resource anywhere in the tropics, including the waters off Sri Lanka.

TABLE V-1: CLIMATIC SUMMARY FOR COLOMBO, SRI LANKA (Elevation 7 meters, Latitude 06 54N, Longitude 79 52E). From U.S. Naval Weather Service (1973), [36].

PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ABSOLUTE MAX TEMP (°C)	35	36	36	37	33	36	32	31	32	32	32	33
AVERAGE MAX TEMP (°C)	31	31	29	32	31	31	29	29	29	29	29	29
MEAN TEMP (°C)	26	27	26	28	28	27	27	27	27	27	26	26
AVERAGE MIN TEMP (°C)	22	23	24	25	26	25	25	25	25	24	23	22
ABSOLUTE MIN TEMP (°C)	15	16	18	21	21	22	22	21	22	21	19	17
AVERAGE RAINFALL (MM)	89	69	147	231	371	224	135	109	160	348	315	147
MEAN NO. DAYS RAIN	10	6	12	17	23	22	16	14	18	22	20	12
MEAN NO. DAYS THUNDERSTORM	7	7	13	16	12	4	1	2	3	8	12	8
MEAN NO. DAYS FOG	3	6	5	1	<1	1	1	1	1	1	4	4
MEAN RELATIVE HUMIDITY (%)	69	69	70	72	75	74	73	73	72	72	71	69
PREVAILING WIND DIRECTION	NE	NE	W	W	W	W	W	W	SW	W	NE	NE
MEAN WIND SPEED (M/S)	4	3	4	4	5	5	4.5	4.5	4	4.5	3	4

TABLE V-2:   WIND FLOW STATISTICS FOR WATER AREAS
             AROUND SRI LANKA (from
        and U.S. Dept. of Agriculture, 1938, [31]).

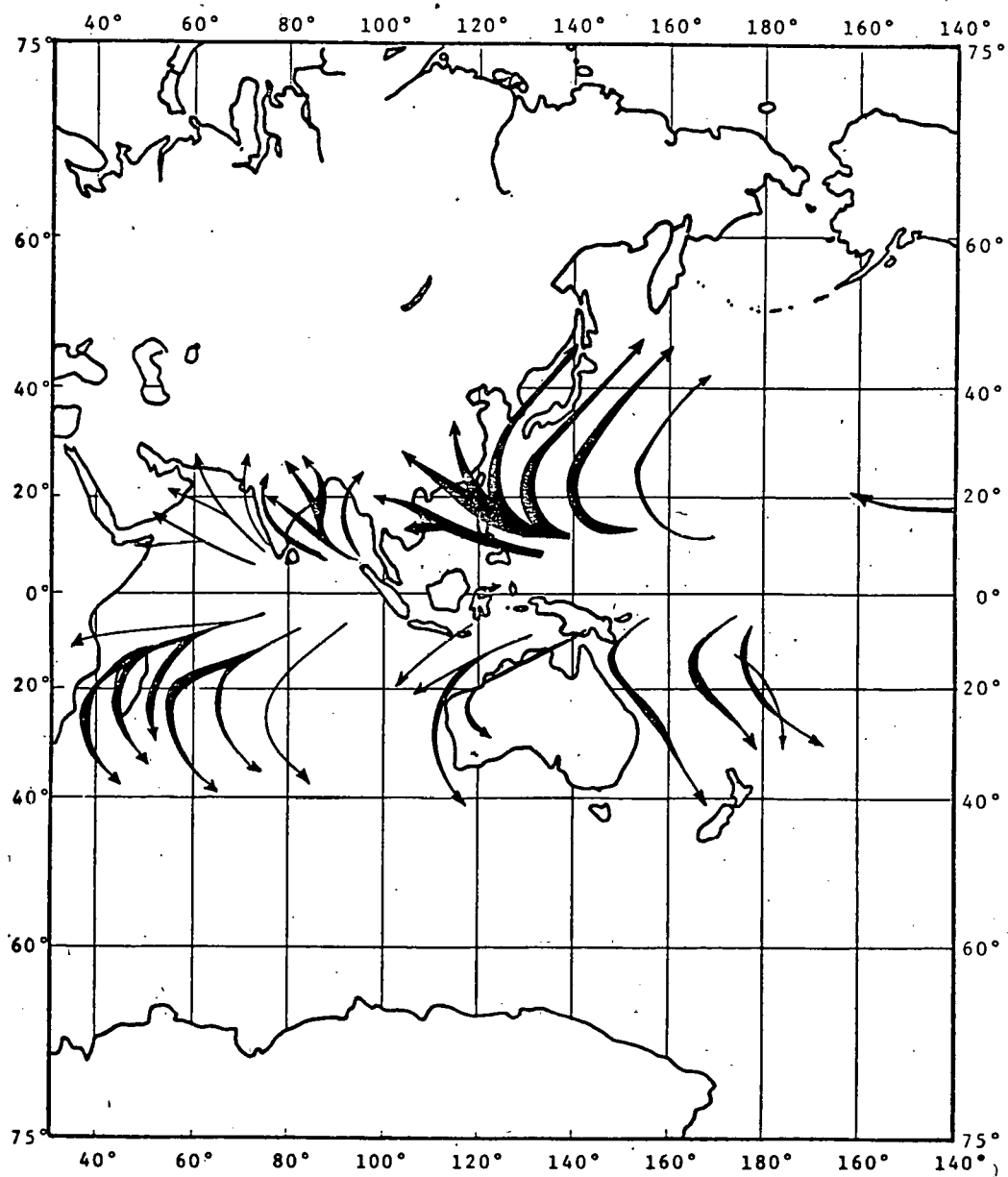|	JAN	MAR	MAY	JUL	SEP	NOV
Resultant wind direction in tens of degrees from North	04	05	23	23	23	06
Resultant wind speed in meters/sec	4	2	4	6	6	2
Wind steadiness in percent	75	48	71	86	81	49
Winds over Beufort force 7 (>15m/s) in percent	0	0	1-5	1-5	1-5	1-5

FIGURE V-1: ANNUAL PREFERRED STORM TRACKS FOR TROPICAL STORMS
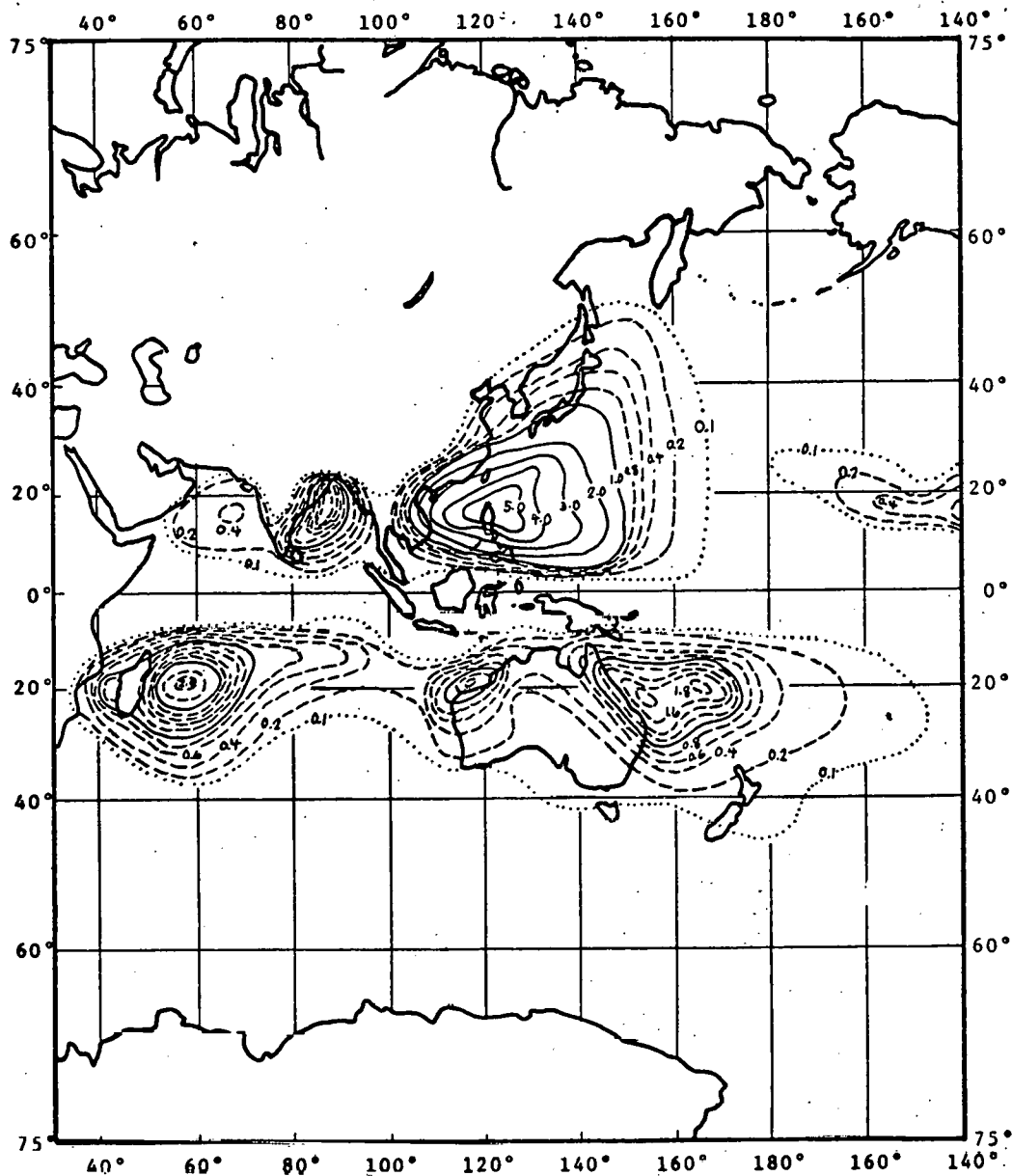(Crutcher and Quayle, 1974, (7]).

FIGURE V-2: AVERAGE NUMBER OF TROPICAL CYCLONES PER 5° SQUARE PER YEAR (Crutcher and Quayle, 1974, (7)).

TABLE V-3: TROPICAL STORM TRACK STATISTICS FOR THE SRI LANKA
AREA. From U.S. Naval Weather Service (1973), [36].

	MONTH											
PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1. MOST PROBABLE DIRECTION OF MOVE-MENT (Toward)	WNW	---	WNW	NW	NNW	---	---	---	---	NW	NW	NW
2. LIKELIHOOD STORM WILL MOVE THIS DIRECTION (Percent)	96	---	68	98	74	---	---	---	---	95	85	97
3. PROBABLE LATERAL SPEED OF MOVEMENT (M/S)	<5	---	<5	<5	<5	---	---	---	---	<5	<5	<5
4. NUMBER OF STORMS OR CYCLONES PER YEAR PER 5° SQUARE	0.04	*	0.02	0.01	0.05	*	*	*	*	0.12	0.13	0.21

* None Observed In Two 5° Squares Around Sri Lanka (5-10N, 75-85E).

VI.   SEA AND SWELL CHARACTERISTICS

High sea and swell conditions are a consideration, though not a major concern for OTEC plants off Sri Lanka. The distribution of high sea and swell conditions, however, shows that extreme conditions occur here more often than the other studied sites (Jakarta, Mombassa) in the Indian Ocean geographic region.

The direction of the waves usually follows the direction of the monsoonal wind pattern. The wave amplitudes during the northeast monsoon are lower then during the southwest monsoon season. The average height of the waves are just under 1 meter. During June and July, southwesterly winds blowing steadily over a longer fetch gives rise to a steady state for most of the month and the roughest average sea conditions of the year (in spite of the larger number of cyclones late in the year). Table VI-1 shows monthly wave characteristics for Sri Lanka reported by Srivastava, Vyayaraza and Joseph (1972), [29].

Table VI-2, taken from Ocean Wave Statistics (1967), [19], presents a statistical breakdown showing the number of observations in various height versus period categories. This summary is based upon actual ships observations from a somewhat larger region around Sri Lanka; however, they are generally representative of that monsoonal flow which characterizes the area.

TABLE VI-1: SUMMARY OF WAVE CHARACTERISTICS AROUND SRI LANKA.
From Srivastava, Vyayaraza and Joseph (1972), [29].

MONTH	PARAMETER	AREA					
		9-11N 79-81E	7-9N 79-81E	5-7N 79-81E	9-11N 81-33E	7-9N 81-83E	5-7N 81-83E
JANUARY	$H_{1/3}$ S D	1.0 1.26 NE	1.0 0.86 NNE	1.0 0.62 N	1.5 0.59 NE	1.3 0.64 NE	1.5 0.56 NE
MARCH	$H_{1/3}$ S D	0.8 0.53 NE	1.0 0.54 N	0.7 0.71 N	0.3 0.84 NE	0.8 0.78 NNE	0.8 0.81 NNE
JUNE	$H_{1/3}$ S D	1.6 1.02 SW	1.2 0.68 SW	1.2 0.69 SW	1.8 1.24 SW	1.3 0.64 SW	2.1 0.84 SW
JULY	$H_{1/3}$ S D	1.2 0.72 SSW	1.5 0.50 SSW	1.3 0.68 SW	1.3 0.72 SW	1.0 0.71 SSW	1.7 0.93 SW
AUGUST	$H_{1/3}$ S D	1.2 0.61 S	1.5 0.39 WSW	1.3 0.68 SW	1.2 0.79 SW	1.1 1.07 S	1.5 0.48 SW
OCTOBER	$H_{1/3}$ S D	1.0 1.13 SSE	1.9 0.85 SSW	1.2 0.83 SW	0.8 0.75 SW	1.0 1.00 S	1.1 0.96 SW
NOVEMBER	$H_{1/3}$ S D	1.0 0.94 N	0.7 0.26 N	1.0 0.85 NNW	0.8 0.55 N	0.8 0.69 N	0.5 0.91 NNE

$H_{1/3}$ = Average "Significant" wave height in meters.
 S = Standard deviation of average height in meters.
 D = Predominant wave direction (direction from which waves are coming).
[NOTE: Predominant wave periods are less than 5 seconds in all cases.]

TABLE VI-2: STATISTICAL BREAKDOWN SHOWING NUMBER OF SHIPS
OBSERVATIONS AROUND SRI LANKA REPORTING VARIOUS
HEIGHT/PERIOD COMBINATIONS. (All Seasons) From Ocean
Wave Statistics (1967), [19].

Wave Height (meters)	Wave Period (Seconds)											Total	Percent of Grand Total
	Calm	<5	6-7	8-9	10-11	12-13	14-15	16-17	18-19	20-21	over 21		
0.25	1392	1718	28	11	13		2	1	2	33	16	3216	11
0.5	96	3607	326	84	17	7	4	1	1	5	134	4282	15
1.0	70	5099	2102	488	131	56	10	3	2	12	53	8026	28
1.5	70	2060	3143	974	245	95	19	11	2	1	1	6621	23
2.0	43	444	1660	1014	200	73	15	4			1	3454	12
2.5	11	146	608	558	192	66	19	2		1	2	1605	6
3.0	9	44	156	246	101	39	9	2				606	2
3.5	7	13	64	94	45	17	7					247	1
4.0	1	11	16	27	30	14	2					102	<1
4.5	1	3	5	7	13	12						41	<1
5.0		1	1		1	4						7	<1
5.5		1		4		1						6	<1
6.0				2								3	<1
6.5				1								1	<1
Total	1700	13147	8109	3510	988	384	87	25	7	53	207	28217	
Percent of Grand Total	6	47	29	12	4	1	<1	<1	<1	<1	1		

The surface current structure in this area responds to changes in the monsoons, and is largely determined by prevailing winds. The beginning of the northeast monsoons in November causes a shift in circulation to a westward and northwestward pattern, flowing from Sri Lanka up around India and along the western Indian coast. During the summer months, the southwest monsoon controls the pattern and the circulation is generally eastward and southeastward through September. During the monsoons, the currents are generally moderate in strength with little variation in direction.

Düing (1970, [14]) found that the effects on current structure due to monsoonal winds usually penetrate to a depth of about 400 meters in the Indian Ocean but may penetrate to only 250 meters around Sri Lanka. He further concluded, the insufficient current data is available from this area to define current structure with depth on a monthly basis. The Encyclopedia of Oceanography (1966), [30] states that surface currents to the south of Sri Lanka average about 50-100 cm/sec and may sometimes be as great as 150 cm/sec. Some values of surface current speeds reported by the National Oceanographic Data Center [23] for the Sri Lanka area are shown in Table VII-1.

TABLE VII-1: TYPICAL SURFACE CURRENT SPEEDS
AROUND SRI LANKA IN CM/SEC.
From National Oceanographic Data Center [31].

AREA	MONTH			
	OCT	NOV	DEC	JAN
WEST COAST	5-15	15-41	26-51	36-77
SOUTH COAST	15-31	26-77	51-102	36-77

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