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# OTEC Thermal Resource Report for Jakarta, Indonesia

MASTER

May 1979

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

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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.

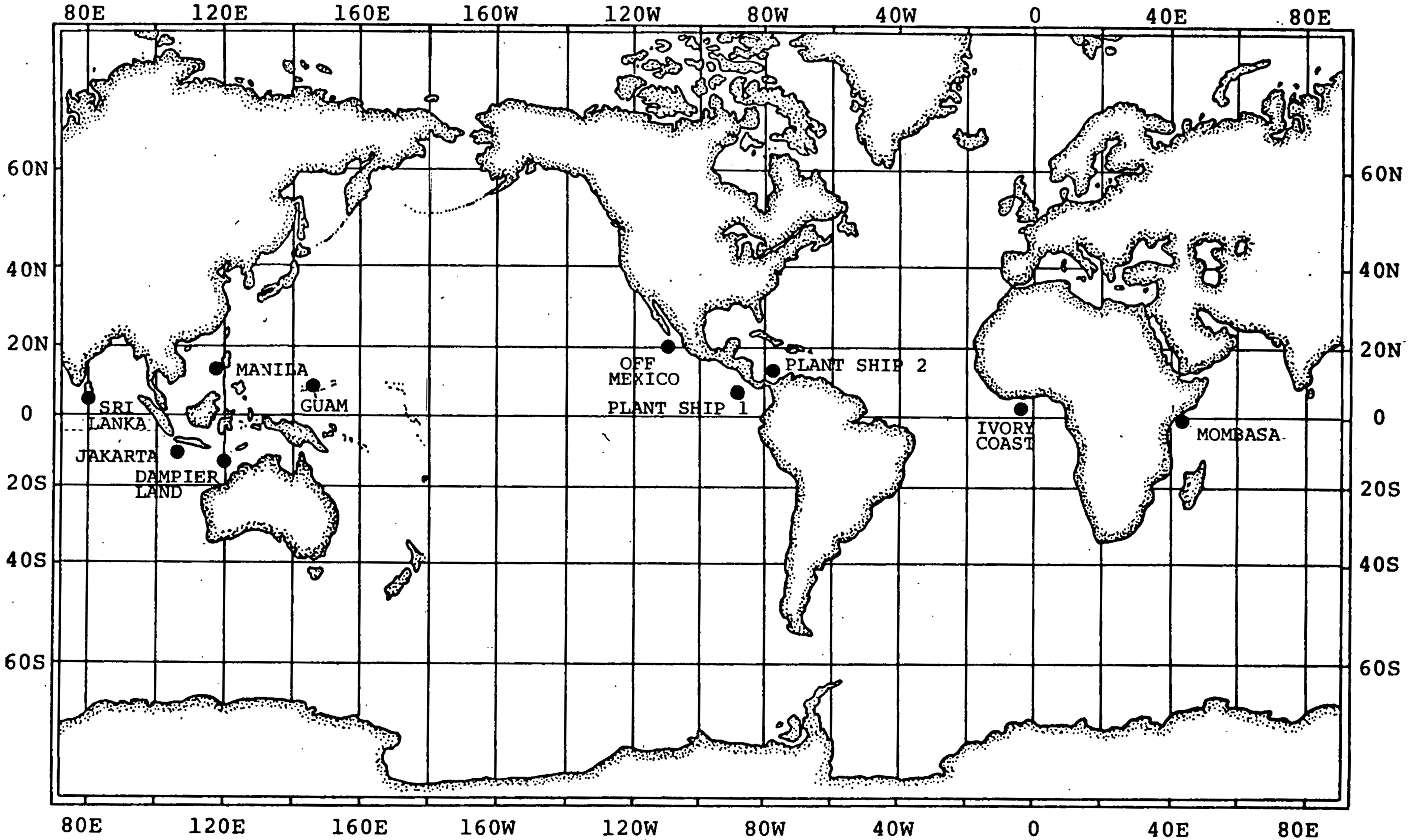
In order to define temperature structures for OTEC areas of interest, Ocean Data Systems, Inc. (ODSI) has developed computer data files of all unclassified soundings available. The primary sources for the data were NOAA's National Oceanographic Data Center, and the U.S. Navy's Fleet Numerical Weather 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 ($\Delta T$) is the primary need. A $\Delta T$ greater than 16.7°C (30°F) for the coldest month of the year would enable year round operation. The annual mean $\Delta T$ 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 | 20-30 | 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 south of Jakarta, Indonesia was studied for the area between 6-9° South latitude and 104-109° East longitude. The available thermal resource is an excellent one for OTEC exploitation. The mean surface temperature is very high, above 28°C. An average monthly $\Delta T$ of 22.8°C is available at a depth of 1000 meters. An annual average $\Delta T$ greater than 20.0°C is available at 650 meters. Mean monthly temperatures at depths greater than 400 meters do not vary by more than 1°C.

The distance from the south coast of Java to the 1000- and 1500-meter depths is not prohibitive, with depths of 1000 meters available in less than 20 kilometers. The necessary depth to provide an adequate cold water supply are not available north of the island. The distance from Jakarta, on the north west coast of the island to water 1000 meters deep is quite large. A mixed layer exists throughout the year with small seasonal variation. High winds and storms are not major problems for OTEC development or operation. Surface circulation is fairly complex with variations throughout the year. Seismic activity is a problem for this site.

## II. BATHYMETRY

Figure II-1 shows the location of the "Jakarta" site. Actually, the depths off Jakarta in the Java Sea are far too shallow to support OTEC operations so that the "Jakarta" site is off the south coast of Java in the Indian Ocean. Figure II-2, from the Defense Mapping Agency (1974), [10], shows the rough bathymetry of the area out to depths of 1500 meters.

Both the 500 and 1000 meter contours maintain a relatively uniform distance from the south coast of Java. Slopes are quite steep into the Java Trench. Table II-1 summarizes distances offshore to selected depths.

TABLE II-1: DISTANCES TO SELECTED DEPTHS OFF THE SOUTH COAST OF JAVA (JAKARTA SITE). From Defense Mapping Agency (1974), [10].

| DEPTH (Meters) | CLOSEST DISTANCE (Kilometers) | FARTHEST DISTANCE (Kilometers) |
|---|---|---|
| 100 | 7.4 | 55.5 |
| 500 | 9.3 | 57.5 |
| 1000 | 18.5 | 59.5 |
| 1500 | 29.7 | 74.0 |

The distance from Jakarta to waters 1000 meters deep is over 185 kilometers.

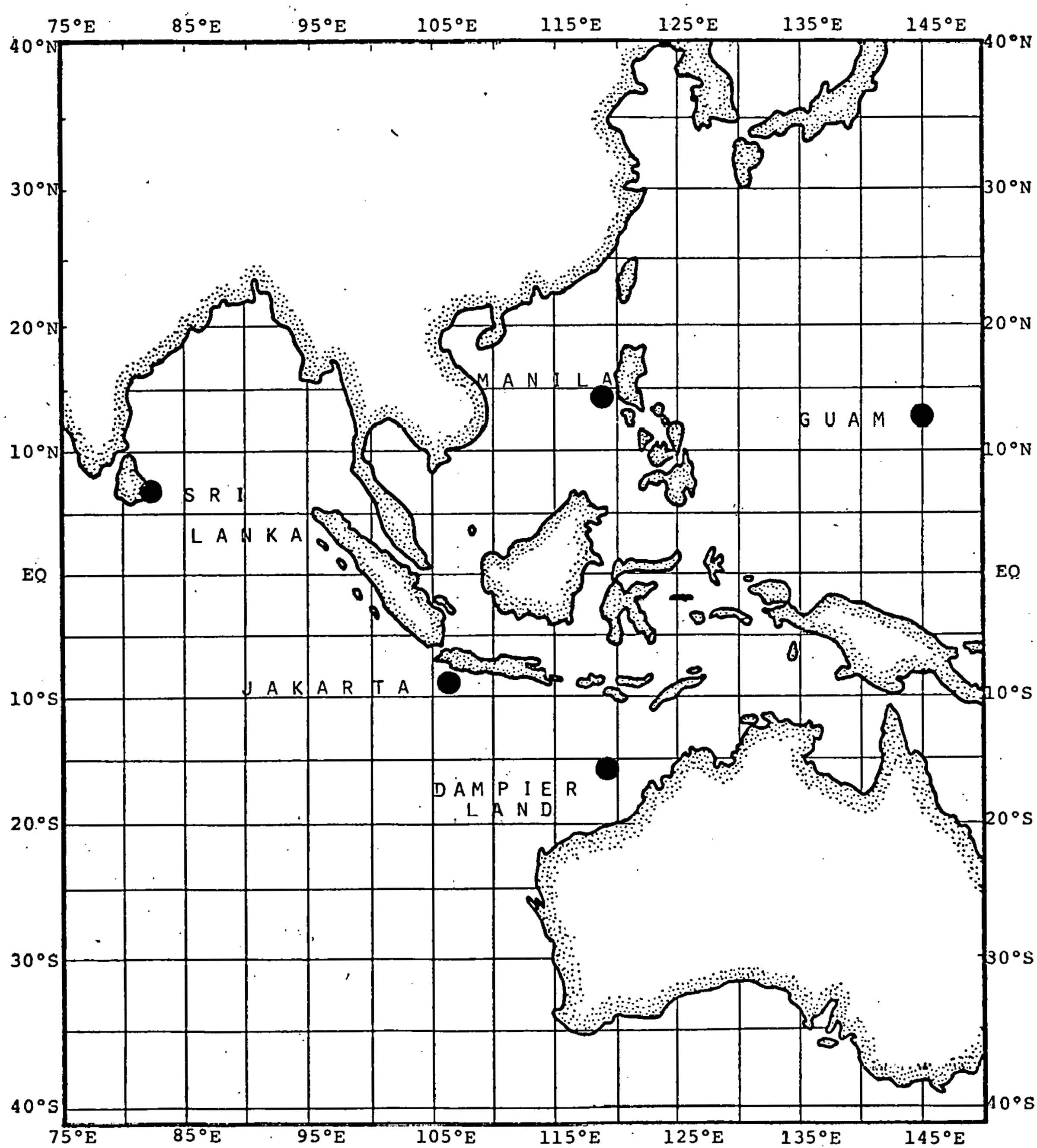



FIGURE II-1: LOCATOR CHART SHOWING AREA OF RESOURCE INVESTIGATION OFF JAVA

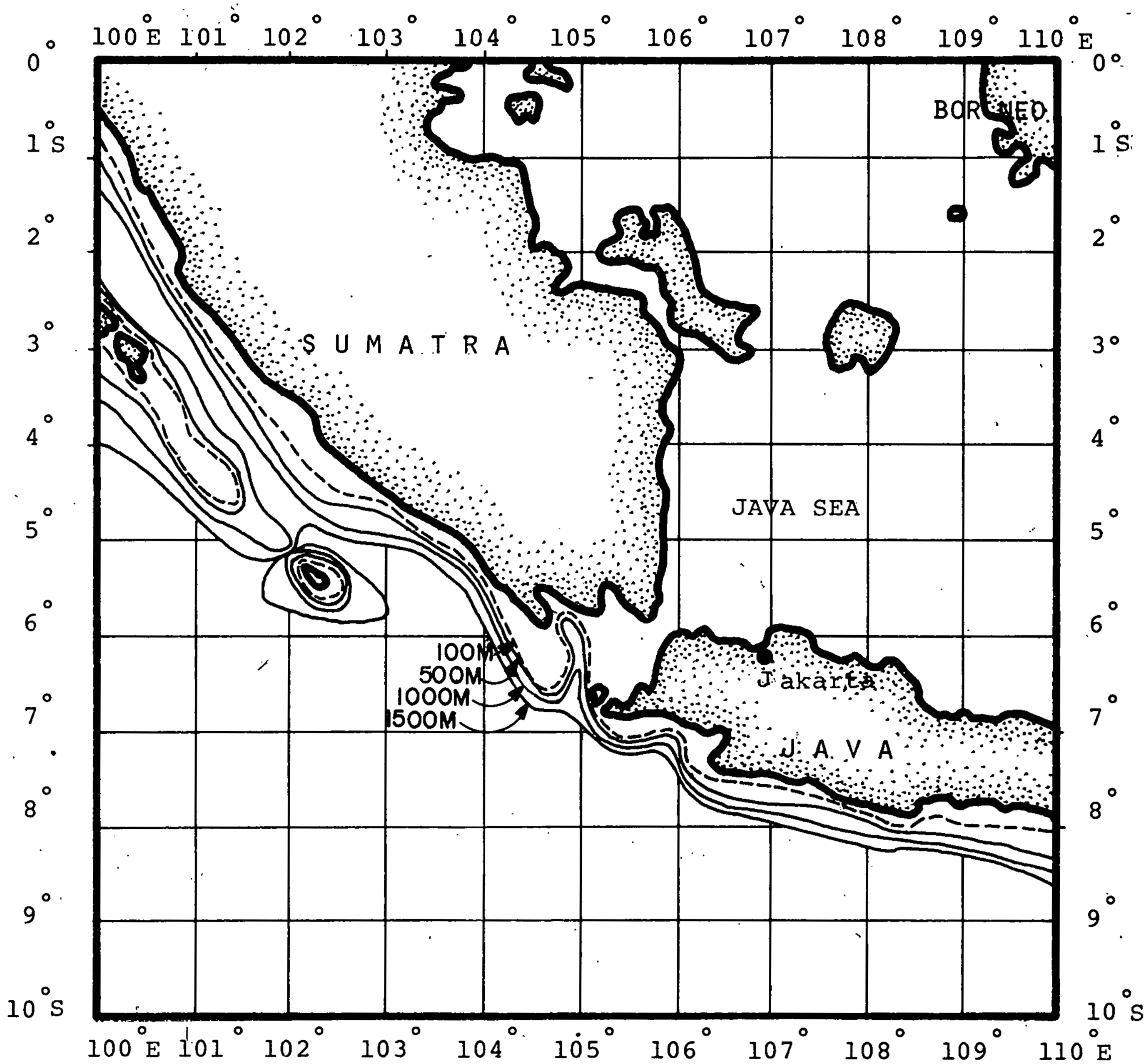



FIGURE II-2 : ROUGH BATHYMETRY FOR JAKARTA

## III. THERMAL RESOURCE

The historical oceanographic data for the area south of Java demonstrates the existence of a thermal resource with excellent potential for OTEC exploitation. The data file contains data for every month of the year, at every depth in 50-meter increments from the surface to 1500 meters. The main source for this data were NOAA's National Oceanographic Data Center, and the U.S. Navy's Fleet Numerical Weather Central, although soundings from other sources were added when available.

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].

Table 1 provides the most probable temperature profile. The annual mean surface temperature for the area is 28.2°C. During March and April, isotherms above 14°C concentrate above 150 meters. Mean monthly temperatures at 1000 meters range from 5.1°C to 5.6°C. The temperatures at depth of 1000 meters in the Indian Ocean, including the waters surrounding Jakarta, are warmer than sites in the Atlantic and Pacific. Table 2 provides ΔT, the surface temperature minus the temperature at depth differential (°C) by months.

TABLE III-1: MONTHLY MOST PROBABLE TEMPERATURE (°C) PROFILE

JAKARTA 6-9°S/104-109°E

| Depth | Month 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Annual Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 28.2 | 28.3 | 28.5 | 29.0 | 29.1 | 29.0 | 28.6 | 27.8 | 27.4 | 27.2 | 27.8 | 28.0 | 28.2 |
| 50 | 27.6 | 27.8 | 27.9 | 28.3 | 28.6 | 28.9 | 28.3 | 27.5 | 27.0 | 26.6 | 27.1 | 27.7 | 27.8 |
| 100 | 23.8 | 23.0 | 22.5 | 23.0 | 23.2 | 23.1 | 22.7 | 22.1 | 22.6 | 22.6 | 23.7 | 23.9 | 23.0 |
| 150 | 16.4 | 16.1 | 15.5 | 16.0 | 16.3 | 16.3 | 16.0 | 15.5 | 15.9 | 16.1 | 16.5 | 16.8 | 16.1 |
| 200 | 12.8 | 12.8 | 12.6 | 13.3 | 13.6 | 13.5 | 12.6 | 12.9 | 13.1 | 12.9 | 12.9 | 13.0 | 13.0 |
| 250 | 11.6 | 11.5 | 11.4 | 12.0 | 12.4 | 12.3 | 11.7 | 11.5 | 11.6 | 11.8 | 11.8 | 11.9 | 11.8 |
| 300 | 11.0 | 11.0 | 10.8 | 11.4 | 11.6 | 11.6 | 11.0 | 10.8 | 10.9 | 11.2 | 11.2 | 11.3 | 11.2 |
| 350 | 10.3 | 10.2 | 10.4 | 10.9 | 11.0 | 10.9 | 10.5 | 10.3 | 10.4 | 10.6 | 10.7 | 10.5 | 10.6 |
| 400 | 9.8 | 9.8 | 10.0 | 10.3 | 10.4 | 10.3 | 10.0 | 9.8 | 9.9 | 10.1 | 10.2 | 10.0 | 10.1 |
| 450 | 9.3 | 9.4 | 9.6 | 9.7 | 9.8 | 9.7 | 9.6 | 9.5 | 9.5 | 9.7 | 9.7 | 9.5 | 9.6 |
| 500 | 8.8 | 8.9 | 9.0 | 9.2 | 9.3 | 9.4 | 9.2 | 9.1 | 9.1 | 9.3 | 9.2 | 9.1 | 9.1 |
| 550 | 8.3 | 8.5 | 8.6 | 8.9 | 9.0 | 9.1 | 8.9 | 8.8 | 8.8 | 8.9 | 8.8 | 8.6 | 8.8 |
| 600 | 7.9 | 8.0 | 8.2 | 8.5 | 8.6 | 8.6 | 8.4 | 8.3 | 8.4 | 8.5 | 8.7 | 8.2 | 8.4 |
| 650 | 7.4 | 7.7 | 7.8 | 8.1 | 8.1 | 8.0 | 7.8 | 7.8 | 8.0 | 8.2 | 8.0 | 7.7 | 7.9 |
| 700 | 7.0 | 7.3 | 7.4 | 7.7 | 7.7 | 7.5 | 7.4 | 7.3 | 7.6 | 7.7 | 7.6 | 7.3 | 7.5 |
| 750 | 6.7 | 6.9 | 7.0 | 7.3 | 7.3 | 7.1 | 6.9 | 6.9 | 7.2 | 7.3 | 7.3 | 7.0 | 7.1 |
| 800 | 6.3 | 6.5 | 6.6 | 6.9 | 6.9 | 6.8 | 6.6 | 6.6 | 6.9 | 6.9 | 6.8 | 6.5 | 6.7 |
| 850 | 5.9 | 6.1 | 6.3 | 6.5 | 6.5 | 6.4 | 6.2 | 6.2 | 6.5 | 6.5 | 6.4 | 6.1 | 6.3 |
| 900 | 5.6 | 5.8 | 6.0 | 6.2 | 6.2 | 6.1 | 5.9 | 5.9 | 6.1 | 6.2 | 6.0 | 5.7 | 6.0 |
| 950 | 5.3 | 5.5 | 5.6 | 5.9 | 5.9 | 5.8 | 5.6 | 5.6 | 5.8 | 5.9 | 5.7 | 5.4 | 5.7 |
| 1000 | 5.1 | 5.3 | 5.4 | 5.6 | 5.6 | 5.6 | 5.4 | 5.4 | 5.5 | 5.5 | 5.3 | 5.1 | 5.4 |
| 1050 | 4.9 | 5.1 | 5.2 | 5.3 | 5.4 | 5.4 | 5.2 | 5.1 | 5.3 | 5.3 | 5.1 | 4.8 | 5.2 |
| 1100 | 4.6 | 4.8 | 4.9 | 5.1 | 5.2 | 5.2 | 5.0 | 5.0 | 5.1 | 5.0 | 4.9 | 4.6 | 5.0 |
| 1150 | 4.5 | 4.7 | 4.8 | 4.9 | 5.0 | 5.0 | 4.9 | 4.8 | 4.8 | 4.7 | 4.6 | 4.5 | 4.8 |
| 1200 | 4.3 | 4.5 | 4.6 | 4.7 | 4.7 | 4.7 | 4.6 | 4.6 | 4.6 | 4.5 | 4.4 | 4.3 | 4.5 |
| 1250 | 4.2 | 4.3 | 4.4 | 4.6 | 4.5 | 4.5 | 4.4 | 4.5 | 4.5 | 4.4 | 4.3 | 4.2 | 4.4 |
| 1300 | 4.1 | 4.2 | 4.3 | 4.5 | 4.4 | 4.4 | 4.3 | 4.4 | 4.3 | 4.2 | 4.2 | 4.1 | 4.3 |
| 1350 | 4.0 | 4.1 | 4.2 | 4.4 | 4.3 | 4.3 | 4.2 | 4.3 | 4.2 | 4.1 | 4.1 | 4.0 | 4.2 |
| 1400 | 3.8 | 3.9 | 4.1 | 4.2 | 4.1 | 4.1 | 4.0 | 4.1 | 4.1 | 4.1 | 4.0 | 3.9 | 4.0 |
| 1450 | 3.7 | 3.7 | 3.9 | 4.0 | 4.0 | 4.0 | 4.0 | 4.0 | 3.9 | 3.9 | 3.8 | 3.7 | 3.9 |
| 1500 | 3.5 | 3.6 | 3.8 | 3.9 | 3.8 | 3.8 | 3.8 | 3.9 | 3.8 | 3.8 | 3.8 | 3.6 | 3.8 |

TABLE III-2: SURFACE TEMPERATURE - TEMPERATURE AT DEPTH

DIFFERENTIAL (°C) BY MONTHS JAKARTA 6-9°S/104-109°E

| Depth | Month 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Annual Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 0.6 | 0.5 | 0.6 | 0.7 | 0.5 | 0.1 | 0.3 | 0.3 | 0.4 | 0.6 | 0.7 | 0.3 | 0.5 |
| 100 | 4.4 | 5.3 | 6.0 | 6.0 | 5.9 | 5.9 | 5.9 | 5.7 | 4.8 | 4.6 | 4.1 | 4.1 | 5.2 |
| 150 | 11.8 | 12.2 | 13.0 | 13.0 | 12.8 | 12.7 | 12.6 | 12.3 | 11.5 | 11.1 | 11.3 | 11.2 | 12.1 |
| 200 | 15.4 | 15.5 | 15.9 | 15.7 | 15.5 | 15.5 | 16.0 | 14.9 | 14.3 | 14.3 | 14.9 | 15.0 | 15.2 |
| 250 | 16.6 | 16.8 | 17.1 | 17.0 | 16.7 | 16.7 | 16.9 | 16.3 | 15.8 | 15.4 | 16.0 | 16.1 | 16.5 |
| 300 | 17.2 | 17.3 | 17.7 | 17.6 | 17.5 | 17.4 | 17.6 | 17.0 | 16.5 | 16.0 | 16.6 | 16.7 | 17.1 |
| 350 | 17.9 | 18.1 | 18.1 | 18.1 | 18.1 | 18.1 | 18.1 | 17.5 | 17.0 | 16.6 | 17.1 | 17.5 | 17.7 |
| 400 | 18.4 | 18.5 | 18.5 | 18.7 | 18.7 | 18.7 | 18.6 | 18.0 | 17.5 | 17.1 | 17.6 | 18.0 | 18.2 |
| 450 | 18.9 | 18.9 | 18.9 | 19.3 | 19.3 | 19.3 | 19.0 | 18.3 | 17.9 | 17.5 | 18.1 | 18.5 | 18.7 |
| 500 | 19.4 | 19.4 | 19.5 | 19.8 | 19.8 | 19.6 | 19.4 | 18.7 | 18.3 | 17.9 | 18.6 | 18.9 | 19.1 |
| 550 | 19.9 | 19.8 | 19.9 | 20.1 | 20.1 | 19.9 | 19.7 | 19.0 | 18.6 | 18.3 | 19.0 | 19.4 | 19.5 |
| 600 | 20.3 | 20.3 | 20.3 | 20.5 | 20.5 | 20.4 | 20.2 | 19.5 | 19.0 | 18.7 | 19.1 | 19.8 | 19.9 |
| 650 | 20.8 | 20.6 | 20.7 | 20.9 | 21.0 | 21.0 | 20.8 | 20.0 | 19.4 | 19.0 | 19.8 | 20.3 | 20.4 |
| 700 | 21.2 | 21.0 | 21.1 | 21.3 | 21.4 | 21.5 | 21.2 | 20.5 | 19.8 | 19.5 | 20.2 | 20.7 | 20.8 |
| 750 | 21.5 | 21.4 | 21.5 | 21.7 | 21.8 | 21.9 | 21.7 | 20.9 | 20.2 | 19.9 | 20.5 | 21.0 | 21.2 |
| 800 | 21.9 | 21.8 | 21.9 | 22.1 | 22.2 | 22.2 | 22.0 | 21.2 | 20.5 | 20.3 | 21.0 | 21.5 | 21.6 |
| 850 | 22.3 | 22.2 | 22.2 | 22.5 | 22.6 | 22.6 | 22.4 | 21.6 | 20.9 | 20.7 | 21.4 | 21.9 | 21.9 |
| 900 | 22.6 | 22.5 | 22.5 | 22.8 | 22.9 | 22.9 | 22.7 | 21.9 | 21.3 | 21.0 | 21.8 | 22.3 | 22.3 |
| 950 | 22.9 | 22.8 | 22.9 | 23.1 | 23.2 | 23.2 | 23.0 | 22.2 | 21.6 | 21.3 | 21.9 | 22.6 | 22.6 |
| 1000 | 23.1 | 23.0 | 23.1 | 23.4 | 23.5 | 23.4 | 23.2 | 22.4 | 21.9 | 21.7 | 22.5 | 22.9 | 22.8 |
| 1050 | 23.3 | 23.2 | 23.3 | 23.7 | 23.7 | 23.6 | 23.4 | 22.7 | 22.1 | 21.9 | 22.7 | 23.2 | 23.1 |
| 1100 | 23.6 | 23.5 | 23.6 | 23.9 | 23.9 | 23.8 | 23.6 | 22.8 | 22.3 | 22.2 | 22.9 | 23.4 | 23.3 |
| 1150 | 23.7 | 23.6 | 23.7 | 24.1 | 24.1 | 24.0 | 23.7 | 23.0 | 22.6 | 22.5 | 23.2 | 23.5 | 23.5 |
| 1200 | 23.9 | 23.8 | 23.9 | 24.3 | 24.4 | 24.3 | 24.0 | 23.2 | 22.8 | 22.7 | 23.4 | 23.7 | 23.7 |
| 1250 | 24.0 | 24.0 | 24.1 | 24.4 | 24.6 | 24.5 | 24.2 | 23.3 | 22.9 | 22.8 | 23.5 | 23.8 | 23.8 |
| 1300 | 24.1 | 24.1 | 24.2 | 24.5 | 24.7 | 24.6 | 24.3 | 23.4 | 23.1 | 23.0 | 23.6 | 23.9 | 24.0 |
| 1350 | 24.2 | 24.2 | 24.3 | 24.6 | 24.8 | 24.7 | 24.4 | 23.5 | 23.2 | 23.1 | 23.7 | 24.0 | 24.1 |
| 1400 | 24.4 | 24.4 | 24.4 | 24.8 | 25.0 | 24.9 | 24.6 | 23.7 | 23.3 | 23.1 | 23.8 | 24.1 | 24.2 |
| 1450 | 24.5 | 24.6 | 24.6 | 25.0 | 25.1 | 25.0 | 24.6 | 23.8 | 23.5 | 23.3 | 24.0 | 24.3 | 24.4 |
| 1500 | 24.7 | 24.7 | 24.7 | 25.1 | 23.3 | 25.2 | 24.8 | 23.9 | 23.6 | 23.4 | 24.0 | 24.4 | 24.5 |

The annual average $\Delta T$ from the surface to 1000 meters is 22.8°C. The $\Delta T$ at 1000 meters for the coldest month of the year is well over 20°C. The annual average $\Delta T$ at 650 meters is 20.4°C. The supply of cold water is virtually inexhaustible, with open access to the Antarctic region. The flow from the Antarctic is more intense in the Indian Ocean than the Atlantic or Pacific. Figure 3 provides a plot of monthly $\Delta T$ contours for the Jakarta site.

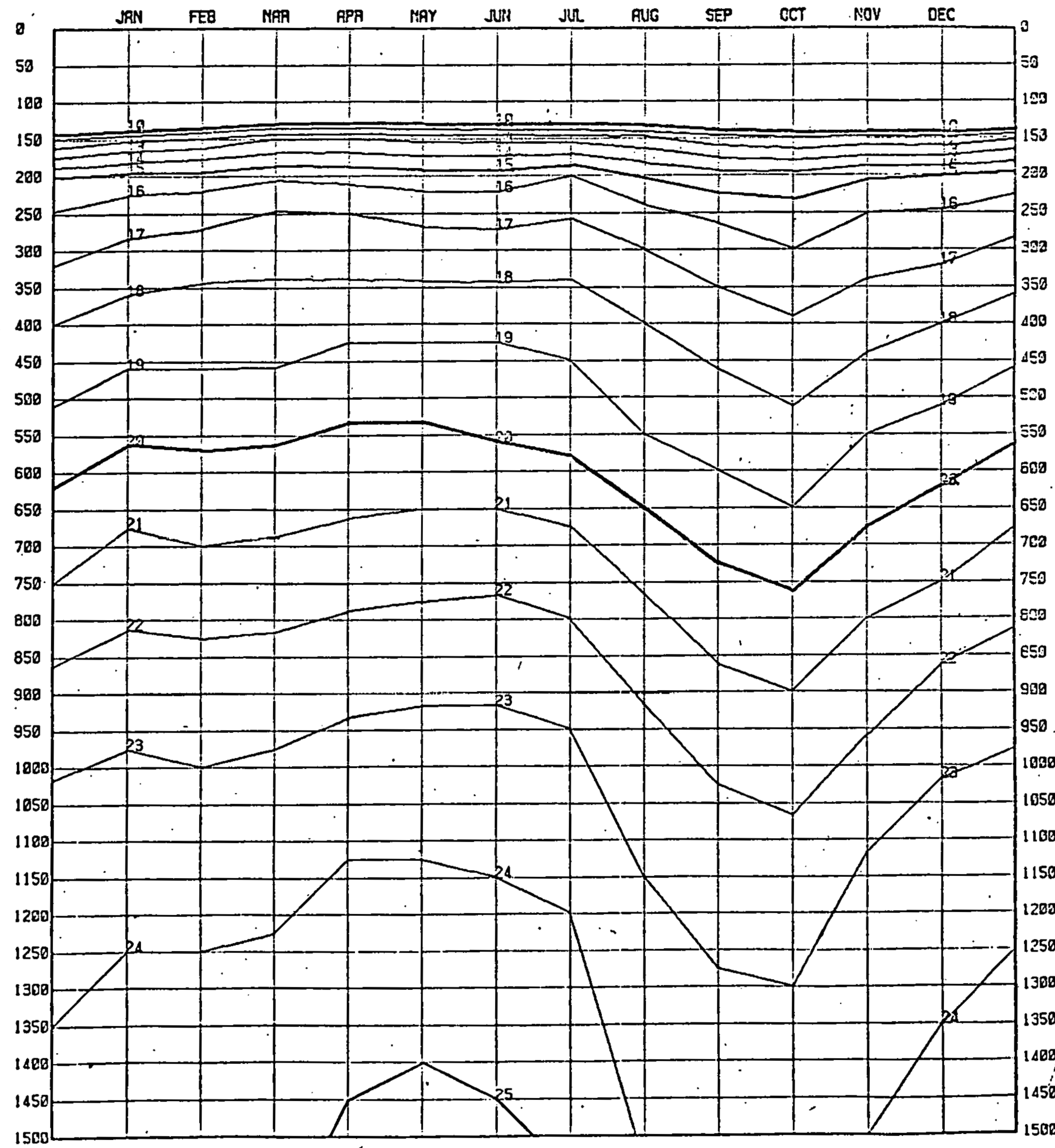



FIGURE III-1: CHART SHOWING MONTHLY ΔT CONTOURS (°C) AT 50 METER DEPTH INTERVALS FOR THE AREA OFF JAKARTA, INDONESIA (6-9°S/104-109°E).

## IV. MIXED LAYER DEPTH

For OTEC purposes the depth of the upper mixed layer is defined as the depth at which the temperature is first 1°C colder than the sea surface temperature. A well defined and moderately deep upper mixed layer is favorable for OTEC operations. There is a mixed layer depth for the Jakarta area throughout the year. It is deep enough to assure an intake of uniformly warm water. It is not too deep so that the mixed exhaust water cannot be discharged below the mixed layer depth in order to minimize the possibility of recirculation. The mixed layer depth for this region shows small seasonal variation. The MLD is generally between 50-80 meters deep. Depths of the MLD in meters off the south coast of Java are shown in Table IV-1.

TABLE IV-1: TYPICAL MIXED LAYER DEPTHS (METERS) OFF JAVA (JAKARTA SITE).

| JAN-FEB | MAR-APR | MAY-JUN | JUL-AUG | SEP-OCT | NOV-DEC |
|---|---|---|---|---|---|
| 80 | 55 | 60 | 65 | 55 | 75 |

This mixed layer is better than adequate for OTEC purposes. 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.

## V. WEATHER CONDITIONS

Table V-1, taken from the U.S. Naval Weather Service, (1974), [35], shows basic climatic information for the vicinity of Jakarta, Indonesia. The area exhibits steady flow from the west from November through February and a steady flow from the east from July to September. In the fall and spring transition period winds are more variable in both speed and direction. This is verified from wind flow statistics for the water area south of Java as shown in Table V-2 through V-5 from the U.S. Weather Bureau (1938), [31].

The thermal resource was examined south of Java between 6-9° south latitude. Tropical storms and hurricanes are not a problem for OTEC for the Jakarta site. 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° square per year. Both figures are from Crutcher and Quayle (1974), [7]. Data from this source indicates one severe storm over the period of record of 73 years in the site area.

TABLE V-1: CLIMATIC SUMMARY FOR JAKARTA, INDONESIA (Elevation 4.8 Meters)
Latitude 06° 09S, Longitude 106 50E.
From U.S. Naval Weather Service (1974), [35].

| PARAMETER | MONTH | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| ABSOLUTE MAX TEMP (°C) | 33 | 33 | 33 | 33 | 33 | 33 | 33 | 34 | 36 | 36 | 36 | 34 |
| AVERAGE MAX TEMP (°C) | 29 | 29 | 30 | 30 | 30 | 29 | 30 | 30 | 31 | 31 | 30 | 29 |
| MEAN TEMP (°C) | 26 | 26 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| AVERAGE MIN TEMP (°C) | 23 | 23 | 23 | 23 | 23 | 23 | 22 | 22 | 22 | 23 | 23 | 23 |
| ABSOLUTE MIN TEMP (°C) | 21 | 21 | 21 | 21 | 21 | 19 | 19 | 19 | 19 | 21 | 20 | 19 |
| AVERAGE RAINFALL (MM) | 300 | 300 | 211 | 147 | 132 | 97 | 64 | 43 | 66 | 112 | 142 | 203 |
| MEAN NO. DAYS RAIN | 19 | 18 | 16 | 12 | 9 | 8 | 6 | 4 | 6 | 9 | 13 | 16 |
| MEAN NO. DAYS THUNDERSTORM | 12 | 9 | 9 | 8 | 6 | 4 | 2 | 2 | 2 | 4 | 9 | 7 |
| MEAN NO. DAYS FOG | <1 | <1 | 1 | 1 | 1 | 1 | <1 | <1 | <1 | <1 | <1 | <1 |
| MEAN RELATIVE HUMIDITY (%) | 84 | 84 | 83 | 81 | 80 | 80 | 77 | 75 | 75 | 76 | 79 | 81 |
| PREVAILING WIND DIRECTION | W | W | N | N | NE | SW | E | E | E | S | W | W |
| MEAN WIND SPEED (M/S) | 3.1 | 4.1 | 3.1 | 3.1 | 2.6 | 2.1 | 3.1 | 3.6 | 3.6 | 1.5 | 3.1 | 4.1 |

TABLE V-2

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<br>5.1-6.2E | 4.1-5.1 | 6.2-7.2W<br>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-3

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<br>10-20S | 1-5 | 1-5 | 1-5 | 5 | 0 | 0 | 0 | 1-5 |
| AUG | 0 | 1-5S<br>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<br>1-5E | 1-5 | 0 | 1-5 | 1-2 | 1 | 1 | 1-5 |
| NOV | 0 | 0 | 1-5 | 1-5 | 0 | 10-15N<br>1-10S | 5-15 | 1-5 | 0-5 | 1-5 |
| DEC | 0 | 1-2 | 0W<br>1-5E | 1-5 | 0 | 10-15N<br>5-10S | 1-5 | 1-5 | 0 | 1-5 |

* 0 = few or none.

TABLE V-4

PERCENTAGE OF WINDS WITH BEAUFORT FORCE 8 AND HIGHER

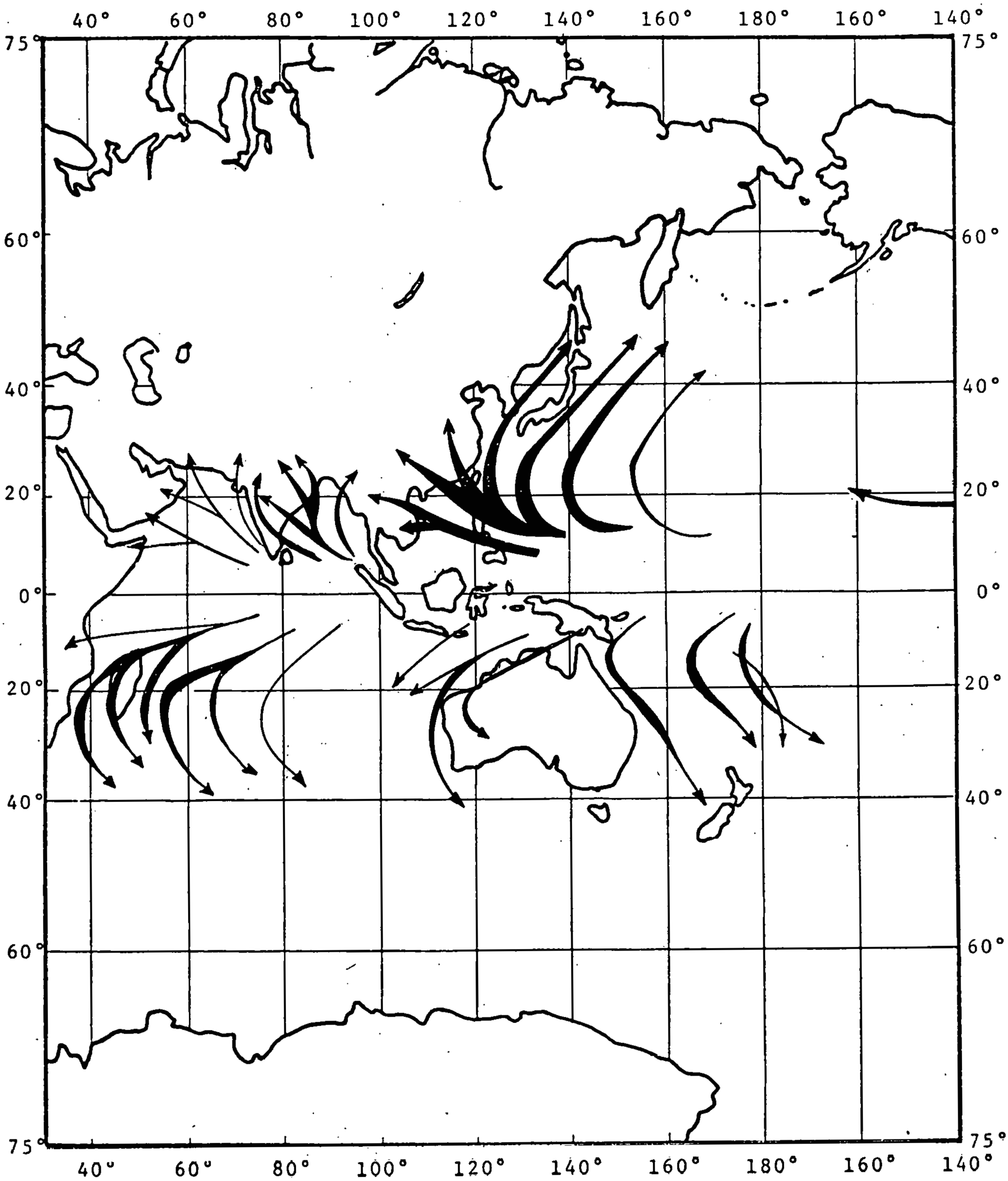
(≥ 17.5 meters per second)

| LOCATION | Dec-Jan-Feb | Mar-Apr-May | Jun-Jul-Aug | Sep-Oct-Nov |
|---|---|---|---|---|
| Ivory Coast | 0 | 1 | 0 | 0 |
| Mombasa | N 1<br>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-5

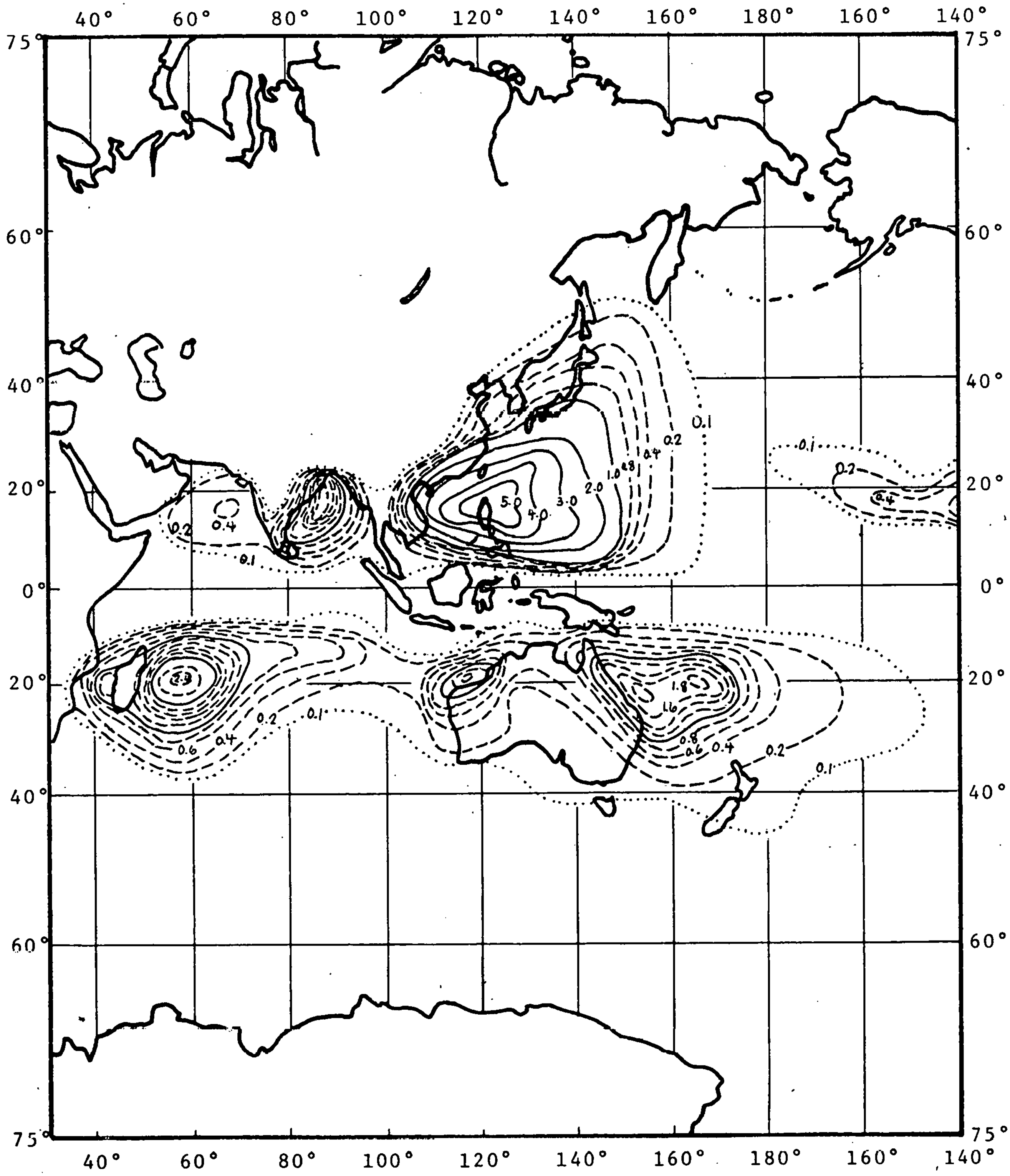
PREDOMINANT SURFACE WIND DIRECTION

| 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




AVERAGE NUMBER OF
TROPICAL CYCLONES PER 5°
SQUARE PER YEAR

FIGURE V-2

# VI. SEA AND SWELL CHARACTERISTICS

Low sea and swell conditions are predominant throughout the year for the Jakarta region. For the January-February period, low seas of 0.3-0.9 meters exist approximately 73% of the time. High seas greater than 2.4 meters occur only 1% of the time. Similarly, for January-February, low swell conditions of 0.3-1.8 meters occur 78% of the time, and high swell of greater than 3.6 meters occurs <4% of the time. During July and August, the conditions are only slightly rougher. During these months, low seas occur about 57% of the time, and high seas only 1% of the time. The distribution of low swell conditions is 55% during July-August, with high swell <4% of the time. Conditions during spring and fall vary only slightly from these figures. This data is from Wind Waves at Sea by H. B. Bigelow and W. T. Emundson, (1947), [5].

Table VI-1 provides wave statistics for the Jakarta area taken from Ocean Wave Statistics (1967), [19]. This statistical breakdown shows the number of observations in various height versus period categories. The observations are from an area somewhat larger than the area chosen for site analysis, but the conditions over the area are represented as being homogeneous. Figure VI-1 provides a graph of the relative frequency of various wave heights for the Jakarta site.

TABLE VI-1: STATISTICAL BREAKDOWN SHOWING NUMBER OF SHIPS OBSERVATIONS SOUTH OF JAVA 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 21 | Total | Percent of Grand Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.25 | 171 | 281 | 17 | 3 | 1 | 2 | 1 | | | 2 | 1 | 479 | 2 |
| 0.5 | 28 | 1030 | 106 | 30 | 13 | 7 | 2 | 1 | 1 | 1 | 26 | 1245 | 5 |
| 1.0 | 50 | 2508 | 1435 | 375 | 135 | 49 | 12 | 6 | | 14 | 22 | 4606 | 17 |
| 1.5 | 101 | 1747 | 3502 | 1408 | 403 | 160 | 53 | 11 | 2 | 2 | 2 | 7391 | 27 |
| 2.0 | 64 | 500 | 2140 | 1951 | 764 | 259 | 76 | 22 | 7 | 1 | 1 | 5785 | 21 |
| 2.5 | 38 | 174 | 998 | 1324 | 752 | 265 | 88 | 26 | 6 | | | 3671 | 13 |
| 3.0 | 28 | 59 | 388 | 710 | 544 | 213 | 88 | 15 | 2 | | | 2047 | 7 |
| 3.5 | 7 | 23 | 135 | 352 | 312 | 164 | 52 | 16 | 2 | | | 1063 | 4 |
| 4.0 | 6 | 11 | 91 | 182 | 191 | 113 | 56 | 20 | 5 | | | 675 | 2 |
| 4.5 | 1 | 8 | 49 | 84 | 84 | 86 | 36 | 17 | 2 | 1 | | 368 | 1 |
| 5.0 | 4 | | 2 | 10 | 14 | 18 | 6 | 3 | 1 | | | 58 | <1 |
| 5.5 | 4 | | 10 | 13 | 11 | 13 | 11 | | | | | 62 | <1 |
| 6.0 | 4 | 4 | 8 | 6 | 9 | 5 | 8 | 2 | 1 | | | 47 | <1 |
| 6.5 | | 3 | 6 | 5 | 7 | 9 | 3 | 3 | 1 | | | 37 | <1 |
| 7.0 | | | | 5 | 4 | 2 | 2 | | | | | 13 | <1 |
| 7.5 | | | | 8 | 1 | 1 | 2 | 3 | 1 | | | 16 | <1 |
| 8.0 | 1 | | | | 2 | 1 | | 1 | 1 | 3 | | 9 | <1 |
| 8.5 | | 1 | | 2 | 1 | 3 | 2 | | | | | 9 | <1 |
| Total | 507 | 6349 | 8887 | 6468 | 3248 | 1370 | 497 | 146 | 32 | 25 | 52 | 27581 | |
| Percent of Grand Total | 2 | 23 | 32 | 23 | 12 | 5 | 2 | <1 | <1 | <1 | <1 | | |

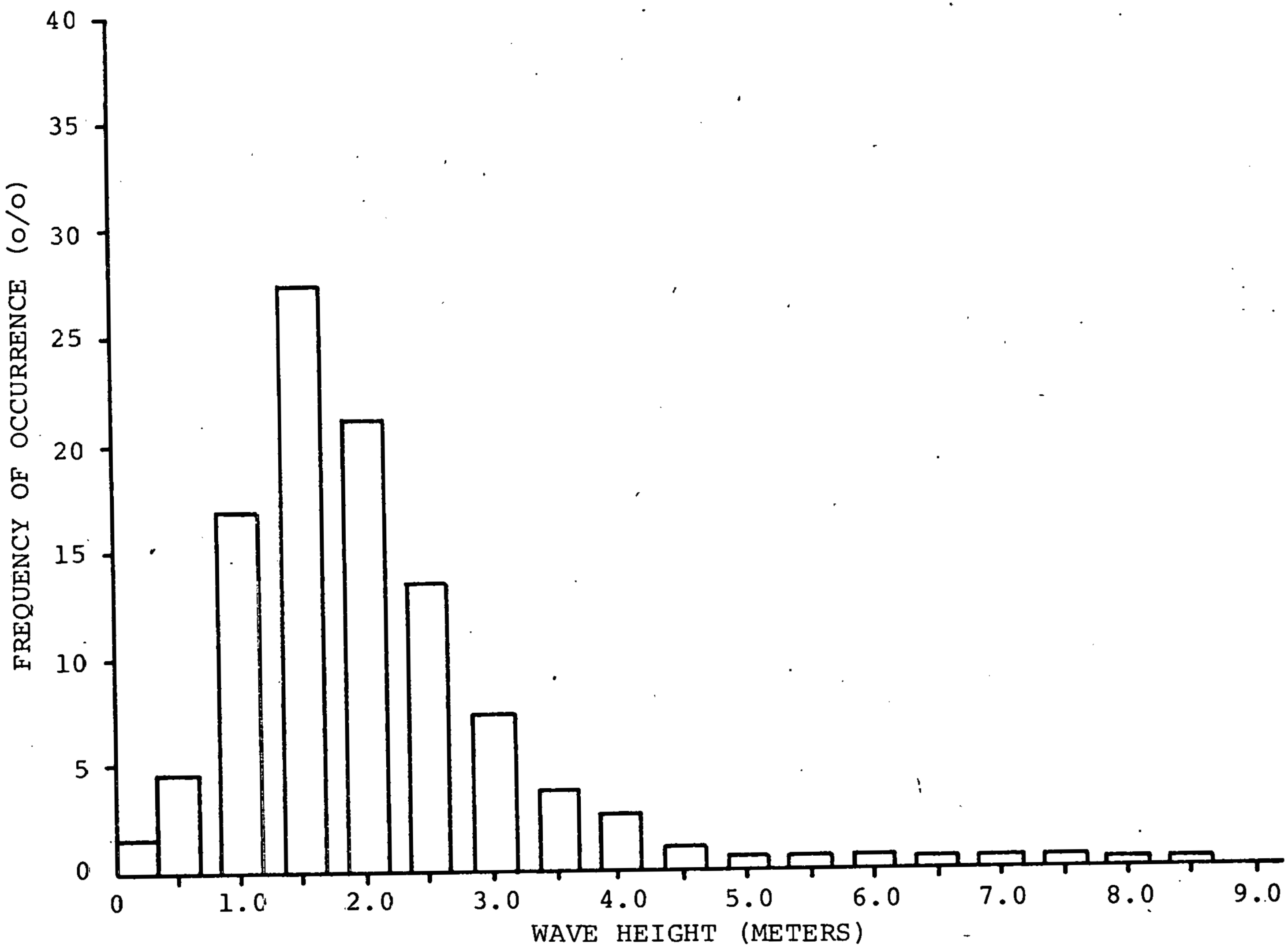



FIGURE VI- 1

WAVE HEIGHT FREQUENCIES (JAKARTA)

Table VI-2, from Climatic Summaries for Major Indian Ocean Ports and Waters (1974), [35], provides monthly mean wave heights for the Jakarta site. The monthly mean wave height for every month for most of this site region is less than 1 meter.

TABLE VI-2: MONTHLY MEAN WAVE HEIGHT (METERS) FOR SITE SOUTH OF JAVA

| JAN | FEB | MAR | APR | MAY | JUN |
|---|---|---|---|---|---|
| 0.6-0.9 | 0.6-0.9 | 0.6-0.9 | 0.6-0.9 | 0.6-0.9 | 0.6-1.5 |
| **JUL** | **AUG** | **SEP** | **OCT** | **NOV** | **DEC** |
| 0.6-1.5 | 0.6-1.5 | 0.6-1.5 | 0.6-1.5 | 0.6-1.5 | 0.6-1.5 |

## VII. CURRENTS

The surface circulation of the area is complex and shows variation seasonally. The westward flowing South Equatorial Current, which originates in the region south of Java, dominates during the Monsoon period. The Monsoon effects influence a maximum depth of between 150-200 meters off Java according to Düing (1970, [14]). An outflow from the Sunda Strait occurs during most of the year. In the fall, this current shifts to the south. The Equatorial Countercurrent turns southeast into the area in November. In August-September, the South Equatorial Current flows strongly off the western portion of Java. During most of the rest of the year, the Java coastal current flows along the coast to the southeast. The concentration of isotherms above 14°C in the upper 150 meters may perhaps be due to a reduced inflow through the Sunda Strait or by upwelling. South of Java the South Equatorial Current flow meanders. Wyrtki (1970, [46]) states that the velocity of the South Equatorial Current in its axis is more than 50 cm/sec. The pattern at 100 meters is the same with smaller velocities.

Currents are generally moderate in strength, being between 25 and 50 cm/sec closer to shore. Occasional periods of weak currents of less than 15 cm/sec can be expected. Variation in direction also occurs seasonally. This current information from studies by Colburn (1974, [6]) and Düing (1970, [14]) is largely based on ships logs which are derived from calculations of ship's drift. Düing felt there was insufficient data for monthly charts of the currents. Few subsurface current measurements exist, and they are not consistent.

The rare hurricane that effects the area can have an effect on the 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 data showed a current of approximately 50 cm/sec. A theoretical study of 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 of up to a week. This upwelling will cause anomalous vertical current shears. A study by Wyrtki (1972, [45]) also shows that strong upwelling occurs south of Java, and that upwelling along Java's south coast is the strongest in the area. Previously the strongest upwelling was thought to occur off Northwest Australia. The region south of Java has very low temperature at 200 meters, very high concentrations of inorganic phosphate to depths of 100 meters, and a high plankton biomass. All are indications of strong upwelling. This upwelling not only poses problems to OTEC in terms of the temperature difference resource, or biofouling, but also may cause vertical current shears. Wyrtki (1971, [46]) estimates the upwelling to contribute 24 million $m^3$/sec for the South Equatorial Current. Vertical and horizontal current shears are also observed in association with major current systems. This site is located in the region where the South Equatorial Current is formed.

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