ESTIMATES OF COASTAL DEEPWATER WAVE ENERGY POTENTIAL FOR THE WORLD

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ABSTRACT

This study derives potential wave energy fluxes from long-term climatological wave height/period statistics for virtually all coastal areas of the world. The basic input data are visual wave observations made from ships. Although visual wave data contain certain biases, mostly resulting in underestimation of the available energy resource, they are the only homogeneous data source available for most coastal areas of the world. In order to reduce biases, hindcast data are employed to develop correction factors for visual height and period estimates from ships. These transformations, developed for areas with both ship data and hindcast data, are applied globally to derive wave energy estimates.

1. INTRODUCTION

Increasing energy costs and probable fossil fuel shortages in the near future have led to a renewed and growing interest in harnessing the power of the waves. The global coastal wave power resource has been estimated as about 2.5×10^9 kilowatts[1]. The results of this study are in fairly close agreement, but slightly higher, at about three billion kilowatts. This potentially recoverable resource may be particularly attractive to third world nations favored by long coastlines but faced with the mounting costs of fossil fuels required by industrialization. A factor currently prohibiting an evaluation of the economic feasibility of tapping wave energy is the lack of area-specific estimates of the resource on a global basis. Wave energy potentials have been calculated for the North Atlantic[2], the coasts of the British Isles[3] and South Africa[4]. The intent of this paper is to produce estimates of the annual wave energy for all habitable coastlines of the world.

2. DATA SOURCES AND ANALYSIS

Visual wave observations made by transiting marine vessels comprise the largest and most geographically comprehensive set of wave data available. Tables of monthly and annual wave height vs. period are included in a series called Summary of Synoptic Meteorological Observations (SSMO)[5]. The SSMO's are published for about 500 coastal areas, each extending seaward about 150-200 miles. All observations of wave height and period within a particular area are summarized together. However, a bias toward lower reported values of height and period has been apparent in the set when compared with more exacting methods of observation. Reliance on this set alone for energy calculations could significantly underestimate the available resource.

Recently a set of tables similar to SSMO's, but much more comprehensive, was published for selected points along the eastern U.S. coastline[6]. These wave data were calculated via a hindcast technique utilizing 20 years of data, with results considered more representative of the actual wave climatology than visual estimates from ships. Our objective was to develop a relationship between the hindcast and SSMO data which could be applied to all SSMO areas. Five hindcast points along the coast from New England to Florida and a sixth near Puerto Rico were chosen for comparison with the nearest SSMO area data.

SSMO tables were initially modified by removing all data with indeterminate periods, setting periods <6 seconds equal to 5.5 and >13 seconds equal to 18. Seasonal and annual cumulative relative frequency (CRF) graphs were developed separately for the height and period statistics for each hindcast point and the coincident SSMO area. For each SSMO height and period class midpoint an equivalent hindcast height and period was determined. This was done by determining the CRF for each SSMO height (or period) midpoint, then determining the hindcast height (or period) value associated with that CRF for the same area and season. The SSMO and equivalent hindcast values for all six areas were plotted seasonally and annually and lines of best fit calculated. In effect, seasonal and annual transformations of SSMO data to approximated hindcast period and height data resulted. The original SSMO height and period class midpoints and the transformed annual values (in parentheses) are: height-meters .25 (.25), .50 (.59), 1.00 (1.28), 1.50 (1.97), 2.00 (2.66), 2.50 (3.35), 3.00 (4.04), 3.50 (4.73), 4.25 (5.76), 5.25 (7.14), 6.25 (8.40), 7.25 (9.89), 8.75 (11.96), 11.00 (15.05), 13.50 (18.50), 16.50 (22.63), 19.75 (27.10); period-seconds 5.50 (7.91), 6.50 (8.73), 8.50 (10.38), 10.50 (12.03), 12.50 (13.68), 18.00 (18.22). These transforms were then applied to the original SSMO data. Wave energies were calculated for each hindcast point and SSMO area by the equation[2]:

$$E\ (\mathrm{kW\ m^{-1}}) = .463\ H^2 T$$

where T is the period in seconds and H the significant wave height[7] in meters defined as the average of the highest one-third of the wave heights observed. Figure 1 demonstrates the good agreement between the hindcast and transformed SSMO energies, with a linear correlation coefficient of 0.93.

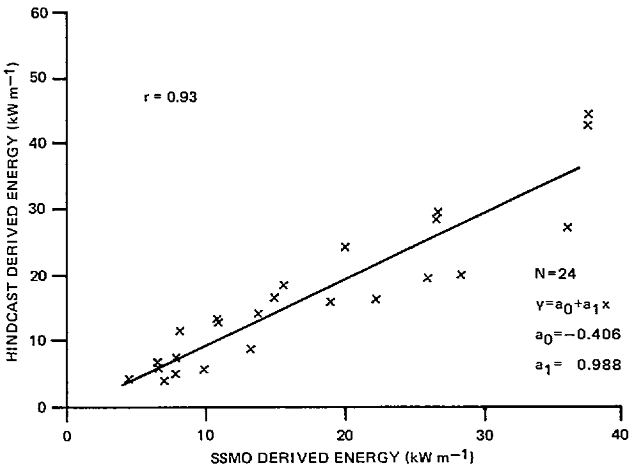

Figure 1. Correlation of seasonal wave power derived from wave statistics for six hindcast points and nearest SSMO areas.

3. ANALYSIS OF RESULTS

The height and period transforms were applied to seasonal and annual wave data for all SSMO areas and energies were computed. Only annual results are presented in this paper. Figures 2, 3 and 4 depict the estimated average annual wave power in kilowatts per meter of wave front for most coastal areas of the globe. Results compare favorably to values in the literature for the North Atlantic and British Isles. This provides some degree of confidence in applying these values for other areas of the world. Highest wave energies are observed in the North Pacific, eastern Atlantic and southern coastlines of Australia, New Zealand, South America and Africa. Annual averages exceed 10 kW m^{-1} in nearly all areas.

The results shown may be somewhat inaccurate (usually low in temperate and polar areas) for the Aleutians, south coast of Alaska, west coast of Canada, central Pacific Islands, the Mediterranean Sea and Southwest Asia due to data problems in the earliest published SSMO's. Newer data are now available and would change the estimates for these areas, drastically in some cases, but resources did not permit us to update the published data.

4. SUMMARY AND SUGGESTIONS FOR FUTURE WORK

Transformed SSMO wave height vs. period data appear to give useful estimates of regional wave power potential on a global basis. However, several improvements could be made on the estimates shown in this paper, given time and resources. Among these improvements: (a) Apply separate transforms to polar, temperate and tropical areas; (b) Refine the models using more hindcast data sets and apply results seasonally; (c) Produce revised estimates for areas where older ship summaries are suspected of having data problems; (d) Provide estimates of the directionality of wave power. This paper assumes utilization of energy from waves occurring from any direction. Many wave energy extraction devices require placement normal to the primary direction of wave movement; (e) Include shoaling; (f) Provide persistence statistics.

5. ACKNOWLEDGMENTS

Ron Baldwin did the ADP work. Bob Courtney drafted the figures and Sara Lackey typed the manuscript. The U.S. Navy funded the original publication of the SSMO's. The U.S. Army provided hindcast data.

6. REFERENCES

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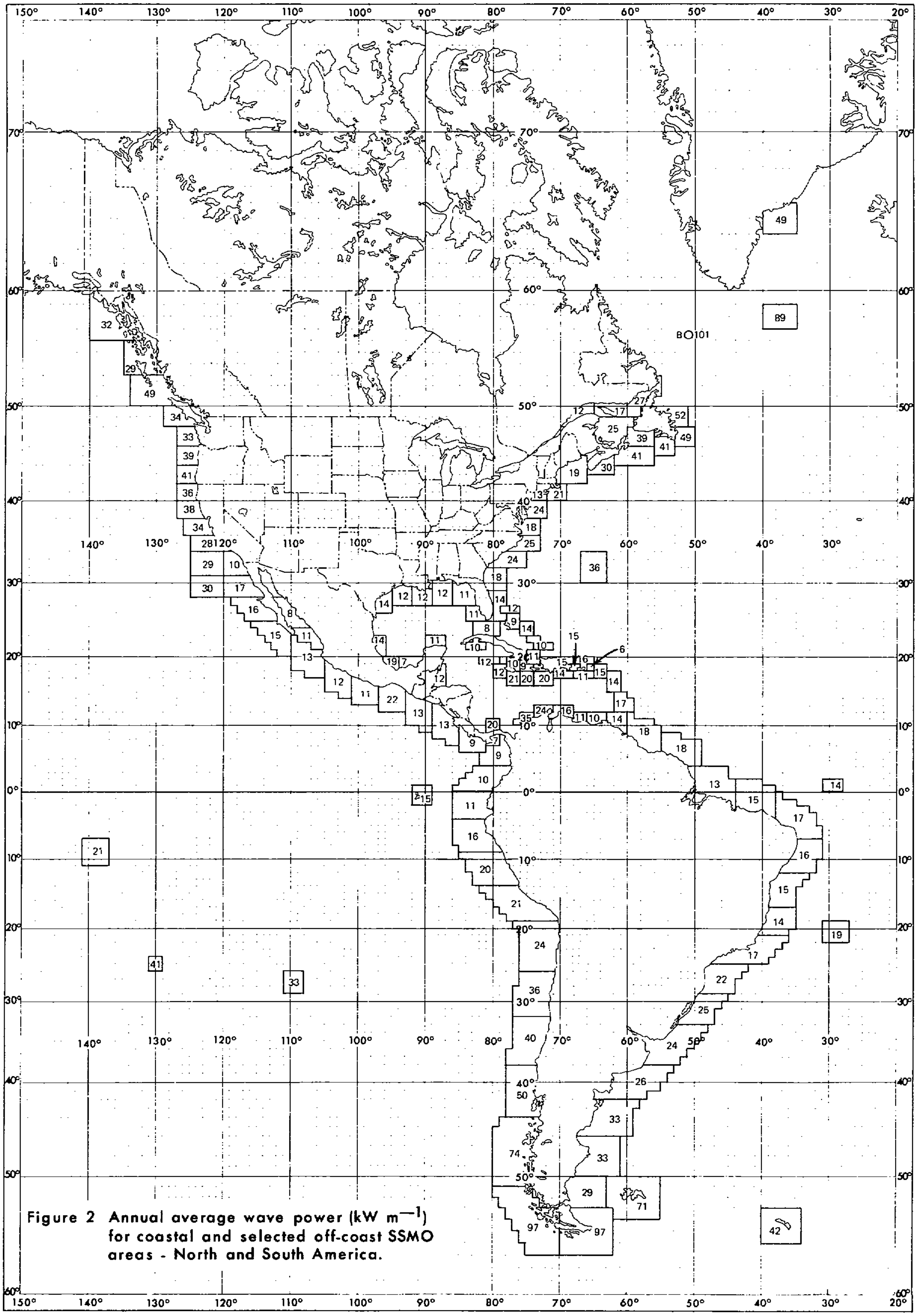

Figure 2 Annual average wave power (kW m^{-1}) for coastal and selected off-coast SSMO areas - North and South America.

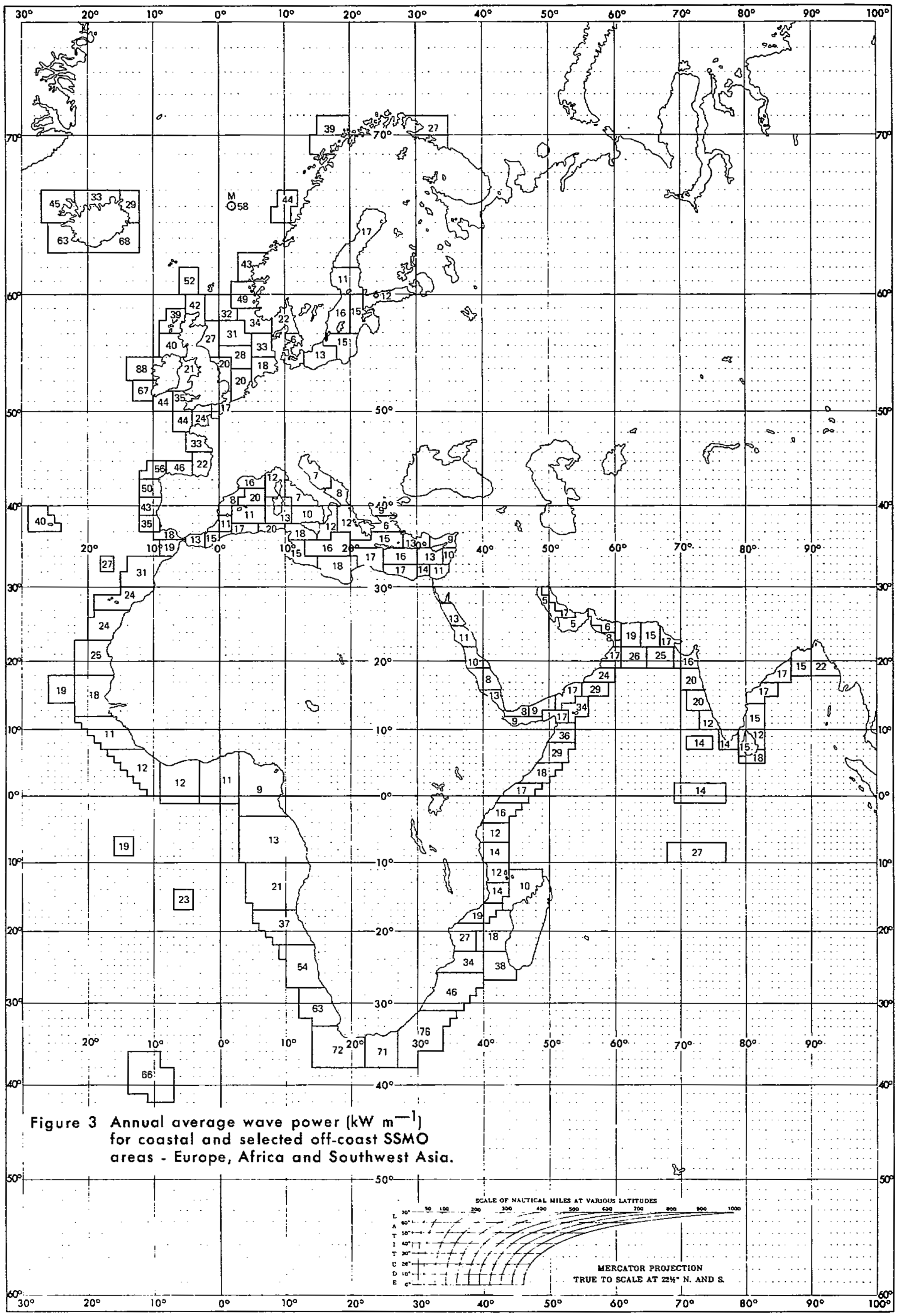

Figure 3 Annual average wave power (kW m^{-1}) for coastal and selected off-coast SSMO areas - Europe, Africa and Southwest Asia.

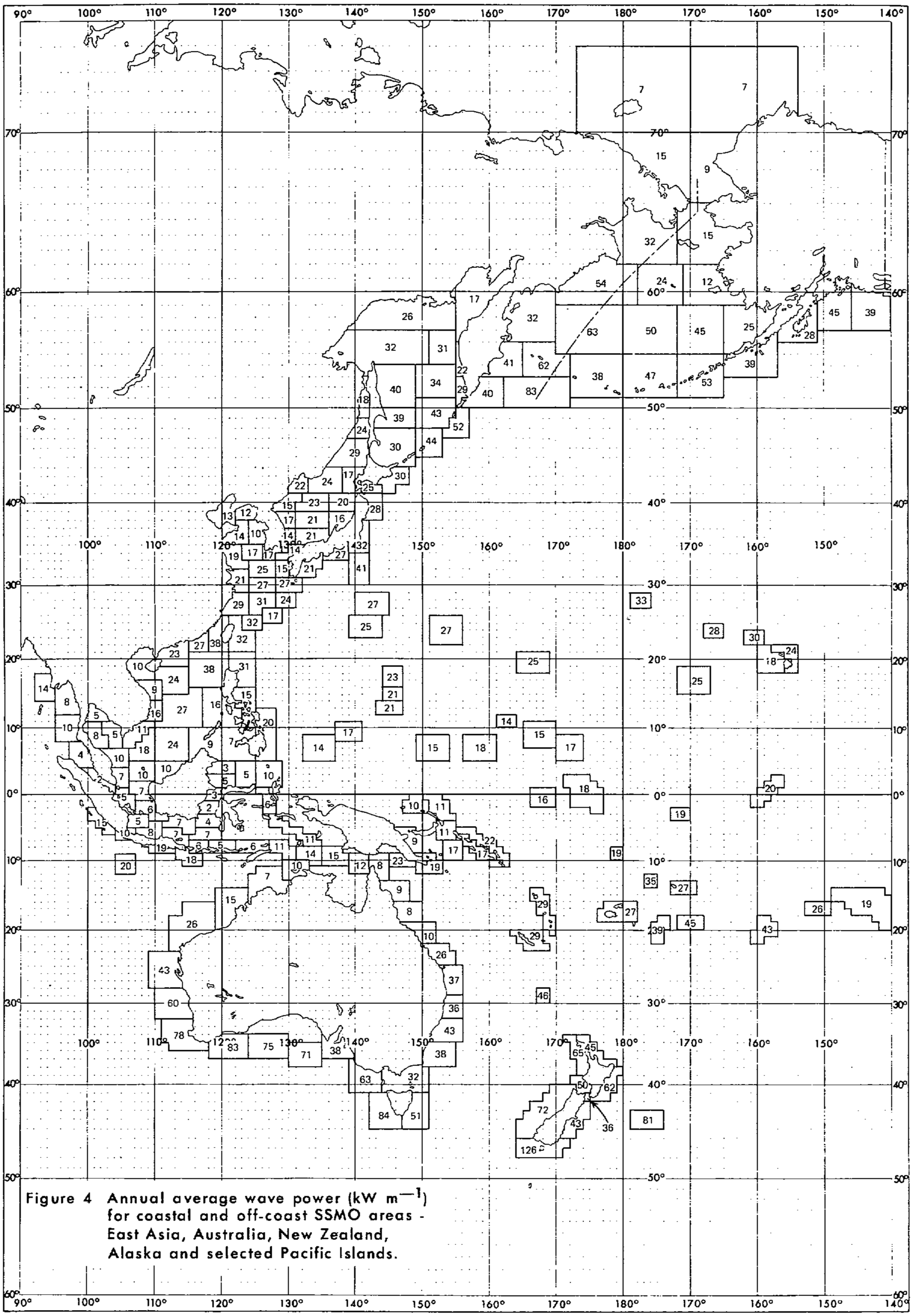

Figure 4 Annual average wave power (kW m^{-1}) for coastal and off-coast SSMO areas - East Asia, Australia, New Zealand, Alaska and selected Pacific Islands.