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Wave Forecasting and Hindcasting

ROBERT S. ARTHUR

(Proceedings of First Conference on Coastal Engineering, Long Beach, California, October 1950. This paper appears as Chapter 8 in the Proceedings.)

Sponsored by

Office of Naval Research
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Wave Report No. 98
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Approved for distribution:

Roger Revelle

Roger Revelle, Director

Chapter 8

WAVE FORECASTING AND HINDCASTING*

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INTRODUCTION

As a result of wartime research on ocean surface waves a method has been available since 1943 for the prediction of wave characteristics of interest to engineers (O'Brien and Johnson, 1947). The initial stimulus for the development came during the planning of the invasion of North Africa, and the methods subsequently devised were later used in a number of amphibious operations (Bates, 1949). The same techniques have found useful peacetime application in problems connected with coastal engineering. Much of the application to date has consisted in applying wave prediction techniques to historical rather than current meteorological data, hence the term "wave hindcasting."

The wind-generated waves in the ocean are conveniently divided into the three categories sea, swell, and surf. The term sea refers to waves under the direct influence of generating winds, and swell to waves which have left the generating area and are subject to decay in regions of weak winds or calms. The breakers which result when waves move from deep to shallow water comprise surf. The transformation of sea and swell into surf has been described in Chapter 3. With regard to prediction it suffices to mention that the computation of the shallow water characteristics from given deep water characteristics is readily accomplished from available graphs after refraction diagrams have been drawn (Hydrographic Office, 1944; Johnson, O'Brien, and Isaacs, 1948). The present discussion is confined to a brief consideration of, (1) forecasting sea and swell, (2) the significance and application of the forecast, and (3) hindcasting and its applications.

FORECASTING SEA AND SWELL

Sverdrup and Munk (1947) have obtained relationships for the growth and decay of waves by considering the energy transfer from wind to waves during growth and the reverse transfer from waves to atmosphere during decay. Empirical data have been utilized in evaluating certain coefficients and constants of integration. The growth of waves depends upon wind velocity, the duration of the wind, and the distance over which the wind blows, called fetch. Observations have shown that as the wind blows over a fetch, the wave height and period over the up-wind part shortly reach a steady state. As time passes the steady state region expands over the whole fetch. Generally, duration rather than fetch is critical in limiting wave growth. The forecasting graph which has been constructed from Sverdrup and Munk's relationships for the transient state is reproduced (Fig. 1a).

The wave height, H_F, and period, T_F, at the down-wind end of the fetch are altered by air resistance as the waves leave the fetch and decay. The change in H_F and T_F and the travel time required depend upon T_F and the decay distance D. The relationships of Sverdrup and Munk (1947) for decay have been utilized in preparing the decay graph (Fig. 1b).

The basic data required for a sea and swell forecast are wind velocity and duration, fetch, and decay distance. These data are obtained from synoptic weather maps or from weather forecasts made from such maps. The wave forecasting theory assumes that the wind velocity is constant over the fetch for the duration of the wind. In practice, this condition is never attained, and skill and judgment are

*Contribution from the Scripps Institution of Oceanography, New Series No. 530. This work represents results of research carried out for the Office of Naval Research, Department of the Navy; and the Beach Erosion Board, Department of the Army, under contract with the University of California. The paper was largely prepared while the writer was visiting at the University of Washington, Oceanographic Laboratories.

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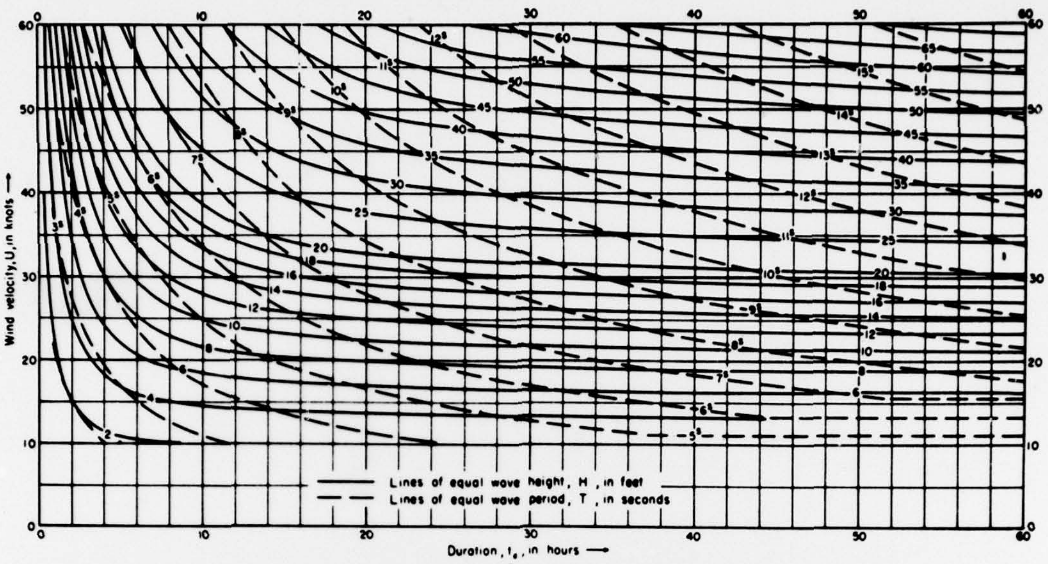

FIGURE 1a. WAVE HEIGHT AND WAVE PERIOD AS FUNCTIONS OF DURATION OF WIND AND WIND VELOCITY

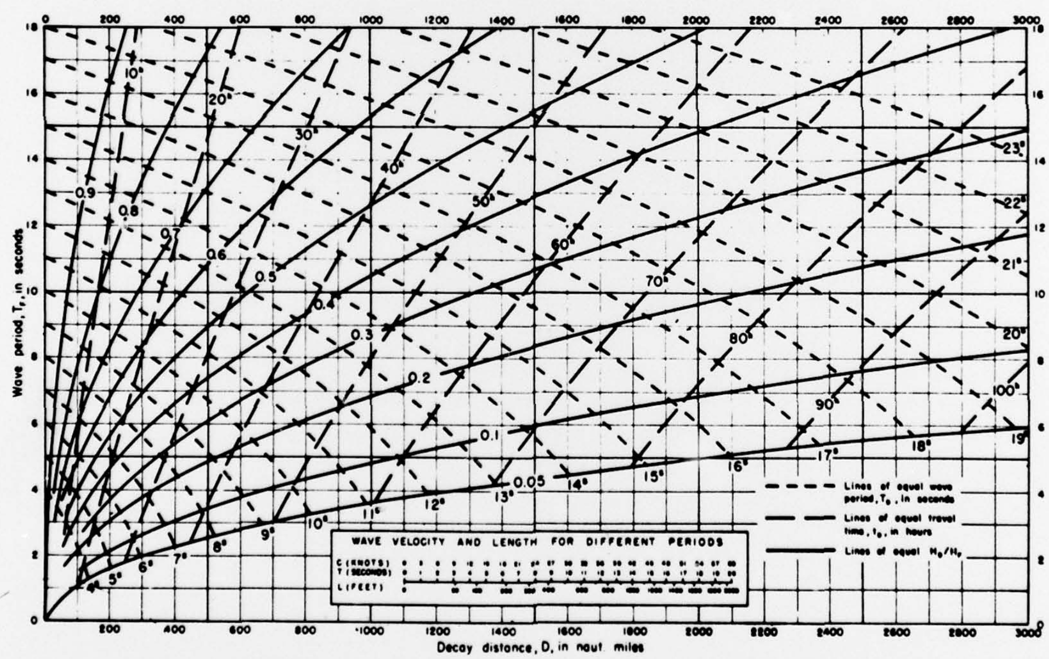

FIGURE 1b. WAVE PERIOD AT END OF DECAY DISTANCE, TRAVEL TIME, AND RATIO BETWEEN WAVE HEIGHT AT END OF DECAY DISTANCE AND AT END OF FETCH AS FUNCTIONS OF DECAY DISTANCE AND WAVE PERIOD AT END OF FETCH

required in selecting fetch, duration of the wind, and average values of wind velocity such that accurate forecasts are obtained. For this reason, persons with experience in meteorology have usually been selected for training in wave forecasting. During World War II a number of meteorologists in the armed services were trained to use the Sverdrup-Munk methods. The successful application in the field is indicated by Bates (1949), who concludes that "the techniques were basically correct and could be modified by meteorologists trained in the methods to provide reliable forecasts for amphibious operations wherever they might be held."

THE SIGNIFICANCE AND APPLICATION OF THE FORECAST

The waves in the sea are extremely complex in the sense that wave height, period, and length vary widely with respect to space and time in an apparently irregular fashion. This complexity and irregularity have made it essential to introduce statistical measures in order that wave records and observations may be characterized in a meaningful manner and the significance of the forecast be established. In many applications, only the heights and periods of the higher waves in a wave train are of practical significance. For this reason, the average height and period of the highest one-third of the waves, after ripples and waves of height less than one foot are eliminated from consideration, are useful statistical measures. These averages have been called "significant wave height" and "significant wave period," respectively (Sverdrup and Munk, 1946).

In some engineering applications, averages for the highest ten percent of the waves, or in some cases only the maximum wave height, are the important statistics. Munk (1944), Seiwell (1949), and Wiegel (1949) have determined the ratios between various statistical measures (see Table I). These ratios show variation with respect to locality and time; however, the time fluctuations at a given locality appear to be small enough so that the ratios are of great practical use.

TABLE I

Ratios of mean wave height, average of highest ten percent, and maximum height to significant wave height

	Scripps[1] (swell)	Point[2] Sur	Heceta[2] Head	Point[2] Arguello	Cuttyhunk[3]	Bermuda[3]
Interval over which averages formed	46 waves	three 20 min. intervals per day			2 minute intervals	
Ratio of mean to significant	0.67				0.64	0.64
Ratio of highest 10 percent to significant		1.27	1.30	1.30		
Ratio of maximum height to significant		1.85	1.91	1.87		

[1]Munk (1944); [2]Wiegel (1949); [3]Seiwell (1949).

The question arises as to how the wave height and period as predicted on the basis of the Sverdrup-Munk method compare with the various statistical measures. Munk (1944) has shown that the usual visual observations are best identified with significant height and period. Since visual observations were used in developing the forecasting method, it would appear that predicted wave heights and periods might be considered to be significant heights and periods. Isaacs and Saville (1949) have demonstrated that this is the case by a comparison of predicted heights and periods with significant heights and periods extracted from records made at several west coast stations. Preliminary indications show the same results for a study on the east coast sponsored by the Beach Erosion Board (James, 1951).

The investigations described in this section serve to indicate the significance of the wave forecast with respect to the actual waves occurring in the sea.

Ratios such as those given in Table I are extremely important in this regard. For application in problems of sand erosion during construction of coastal works, predictions of significant wave height and period may be desirable. On the other hand, in problems of structural strength under wave action, predictions of the maximum wave height are needed. Wave forecasting has advanced to a stage where it is possible in many localities to furnish useful predictions of the various wave characteristics to engineers engaged in the construction of coastal works.

HINDCASTING AND ITS APPLICATIONS

Because of the lack of wave records or adequate visual observations of waves in many regions, there has been a demand for wave data obtained by hindcasting (Burt and Sauer, 1948). Accumulated wind data are generally sufficient for most localities in the Northern Hemisphere to permit computation by means of the forecasting method of past wave characteristics. In particular, the Daily Synoptic Series, Historical Weather Maps, Northern Hemisphere, have been found most useful in this regard (see Chapter 10).

The hindcasting technique can provide statistical wave data over a large area in a short period of time. In one application for the Corps of Engineers, Los Angeles District, two forecasters and three clerks computed in about four months, the deep-water wave characteristics over a three-year period for the California Coast (Scripps Institution of Oceanography, 1947). The cost of such data is not large relative to the cost of installing and maintaining wave meters and analyzing the resulting records over a three-year period.

Such data have proven useful in providing a basis for the design of coastal structures such as off-shore drilling installations. Use has also been made in examining the question of the stability of beaches prior to construction of coastal works. Inman (1950) has used wave data provided by the hindcasting technique in a coastal beach study in the vicinity of Mugu Lagoon, California, and two illustrations are reproduced from his report. Fig. 2 shows the sources and period ranges for waves approaching the coast near Mugu Lagoon from various directions. Fig. 3

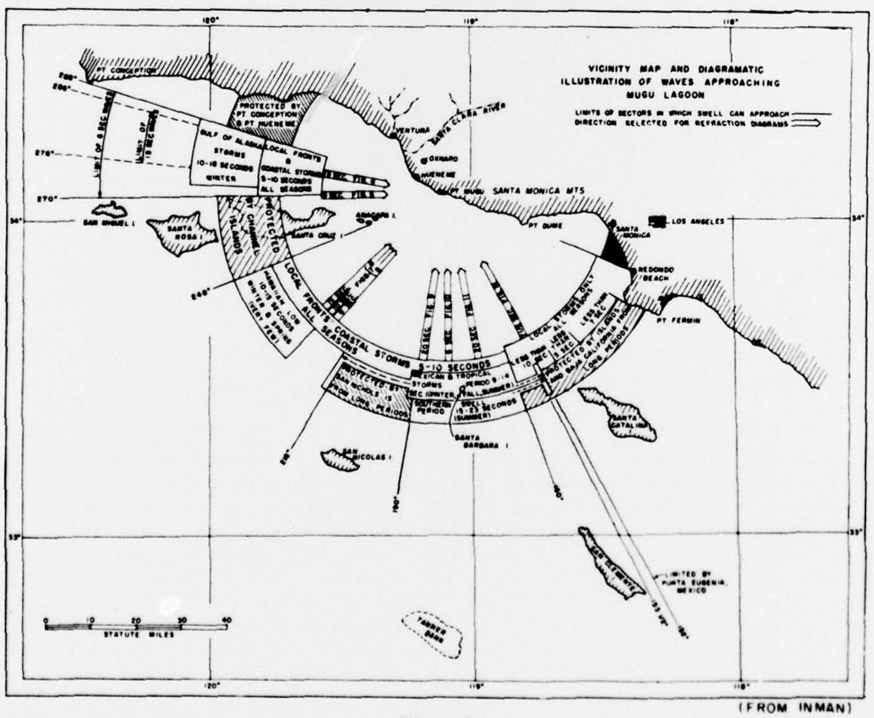

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Fig. 2

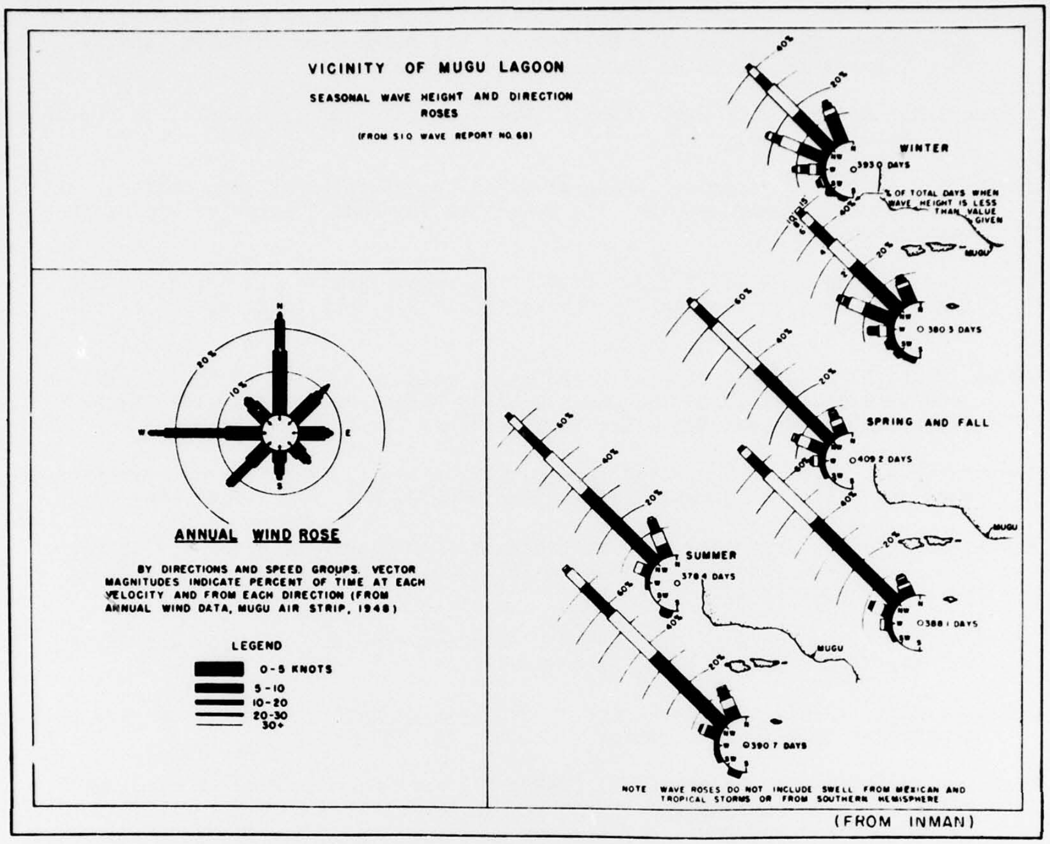

Fig. 3

shows seasonal wave height and direction roses for a three-year period for the portion of the coast near Mugu Lagoon. The source material for both figures was obtained by an examination of past meteorological situations and hindcasting from historical weather maps.

Hindcasting has also been useful in providing information on the characteristics of waves which have caused failures in coastal installations (Horrer, 1950). In the past, adequate records have often not been kept of the wave conditions associated with such failures even though the damage has been carefully noted. Hindcasting can help fill in the gap in order that future designs may be improved.

Finally, it is to be emphasized that although hindcasting is a useful technique for providing wave data it should supplement rather than supplant wave records and observations. Every individual hindcast is subject to the uncertainties contained in the forecasting method, and may, therefore, be in error compared to the actual wave conditions. In the statistical accumulation of many hindcasts these errors tend to compensate, but the security of the results must always depend ultimately on comparison with actual observations.

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