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PREFACE

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MEASURING THE NEARSHORE WAVE CLIMATE: CALIFORNIA EXPERIENCE

Richard J. Seymour

California Department of Navigation and Ocean Development

ABSTRACT

A nearshore wave climate measurement network for the California coastline has been expanded to 16 stations since its inauguration in 1975. The system utilizes a compact slope array to measure wave directionality in shallow water as well as offshore buoys and nearshore non-directional gages. Data are collected and analyzed automatically by a central computer. Plans are being developed to expand the system to provide high density coverage of the whole state coastline.

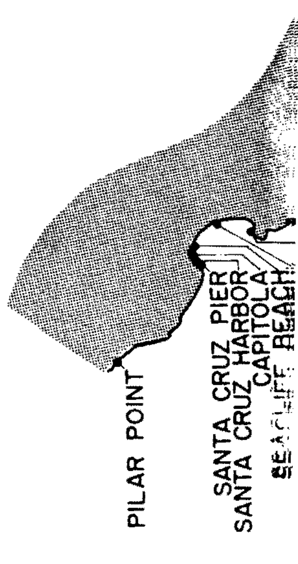
INTRODUCTION

The need for characterizing the nearshore or coastal wave climate follows the experience of more conventional meteorological climate measurement programs: the higher the population density, the more intense the usage of the resource, the greater the penalty for ignorance -- then the greater the need for local detail and accuracy in the climate statistics. California has a coastline roughly as long as the stretch from Massachusetts to Florida. Much of it is heavily developed. The continental shelf has an extremely convoluted bathymetry and much of the state is partially sheltered by a long string of offshore islands. The coastline is predominantly rocky, punctuated by long reaches of sandy beaches in delicate dynamic equilibrium with the waves and currents, and fed by occasionally swiftly flowing rivers which dump sediment directly into the ocean. These factors combine to produce a situation in which there is a pronounced spatial inhomogeneity in the nearshore wave climate and strong political and economic pressures to define it accurately. This has led the State, through its Department of Navigation and Ocean Development (DNOD), to test the feasibility of constructing a coastal wave data network to automatically acquire coastal wave climate statistics by direct measurement. The principal purpose for this system is to provide information on which to base decisions on coastal erosion protection programs. A secondary purpose is to gather data on wave climates that impact boating and other navigational activities.

THE CALIFORNIA WAVE NETWORK

The system was inaugurated in 1975 by the Scripps Institution of Oceanography (SIO) with overall direction and financial support by DNOD, and with additional funding support by the Sea Grant program during the second year. The expansion of the system beyond the initial seven stations funded by DNOD has been supported by the South Pacific Division of the Army Corps of Engineers. A total of 16 stations were installed by the summer of 1978. These include four directional measurement stations. Three of the stations have "Waverider" wave measuring buoys offshore at a depth of approximately 80 meters in addition to the nearshore wave energy measurement capability. A system map is shown in Figure 1.

The first station, at Imperial Beach near the Mexican Border, has been reporting data since December 1975. With substantial support from the Army Corps of Engineers, the network is expected to be expanded to include well over 100 new stations along the California coast in the period 1979-1982. The basic station consists of one or more bottom-resting pressure transducers which are placed at a depth of about 10 meters. This results in their remaining outside the surf zone under all conditions in the present locations. The transducers are hard wired to a terminal on the beach or on a pier head which contains a telephone connection. When offshore buoys are deployed, a radio telemetry link connects the wave measuring buoy and the terminal on shore. Each channel of information is sampled, digitized and stored in memory in the terminal. The standard sampling rate for ocean waves is 1 Hz and the sampling interval is 1024 secs (approximately 17 minutes). The most recent data is maintained in memory. Each station is automatically polled every ten hours by a central minicomputer at SIO using ordinary dialup telephone lines. A schematic of the system is shown in Figure 2. Details of the data transmission system are described in *Seymour and Sessions* (1976). On certain stations, either the wave buoy or a nearshore pressure gage is monitored continuously. The number of zero upcrossings and the mean squared value of surface elevation or bottom pressure are calculated over 30 seconds and stored in memory. This provides a nearly continuous record of the variance from which data on wave



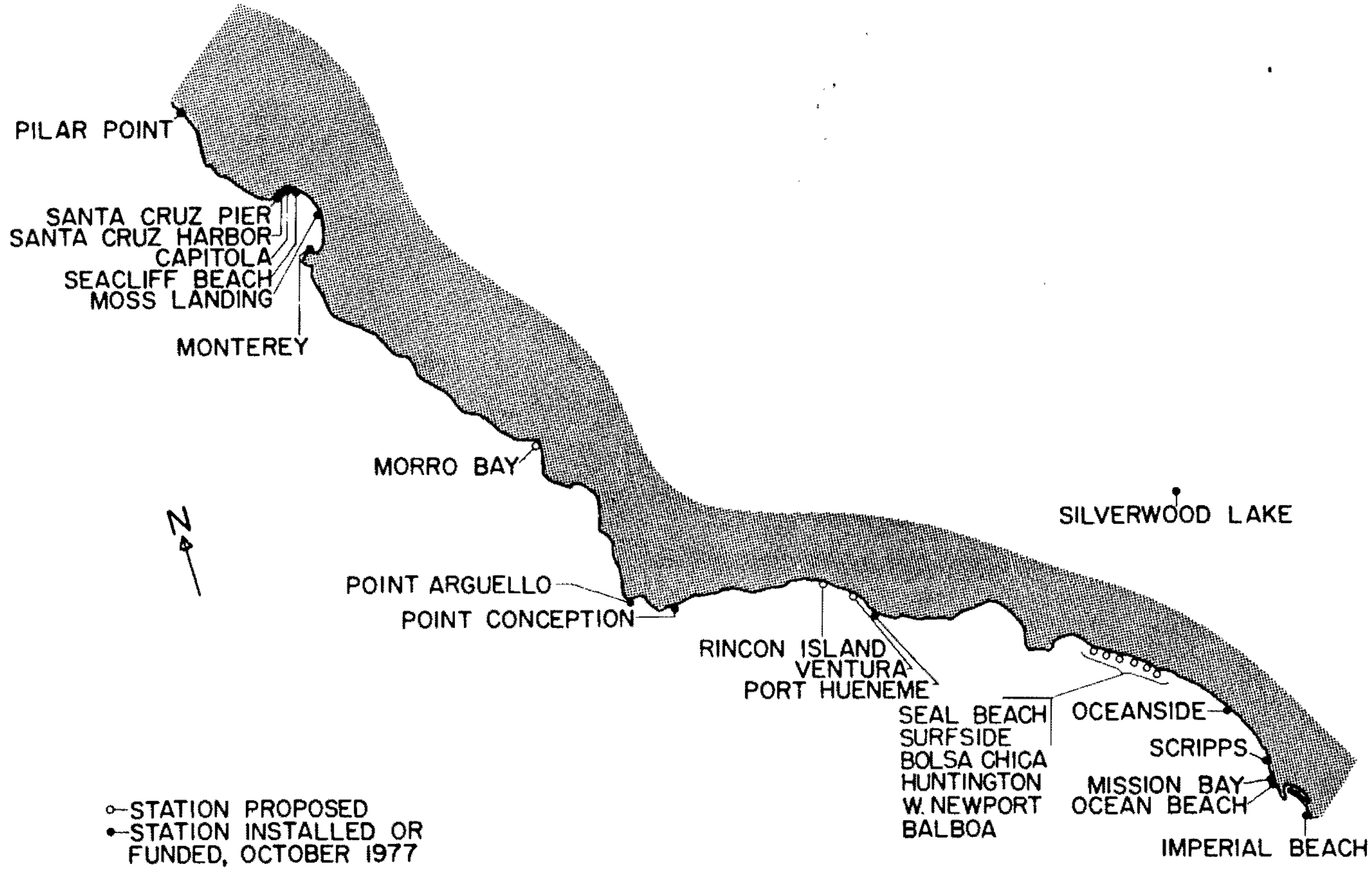


Fig. 1. California Coastal Engineering Data Network wave measurement stations. The indicated stations were installed or proposed as of October 1977.

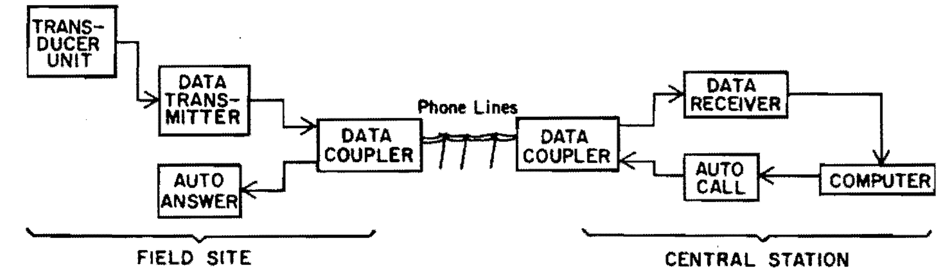


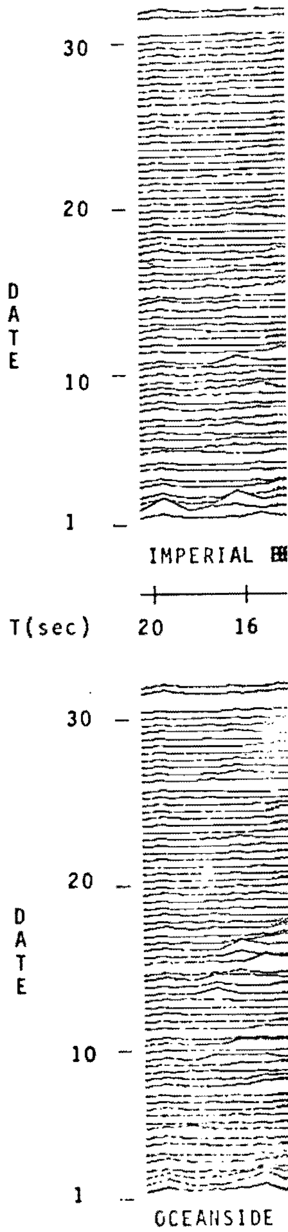
Fig. 2. Wave measurement system. The transducer can be a bottom-resting pressure transducer or an offshore buoy which telemeters data to a shore terminal. The central station is at Scripps Institution of Oceanography and the field sites are shown in Fig. 1.

groups and maximum height and period can be extracted. Multiple channel capability exists at each station so that any other analog signal can be digitized and transmitted to the central station in addition to the wave records.

DATA REPORTING

Monthly reports are mailed to users within a few days after the end of every month. For each ten-hour period and for each station, these reports contain: the time of observation, the significant wave height, the total energy, and an energy spectrum expressed as a percent of the total energy within period bands of approximately two seconds width. In addition, for each station, tables are shown of the maximum significant wave height for each day in the month and of height persistence which is the number of consecutive days that a particular wave height is exceeded.

One of the most useful data displays is illustrated in Figure 3. It shows a pictorial representation of the spectra for a month at each station so that relative energies can be evaluated and the decay of swell following a storm can be readily observed. Although the energy relationships shown are largely qualitative, they provide a concise representation of many pages of tabular data and can rapidly direct the attention of a user to significant events. For direction measuring stations, representative directions are reported for each period band using the methodology described below.



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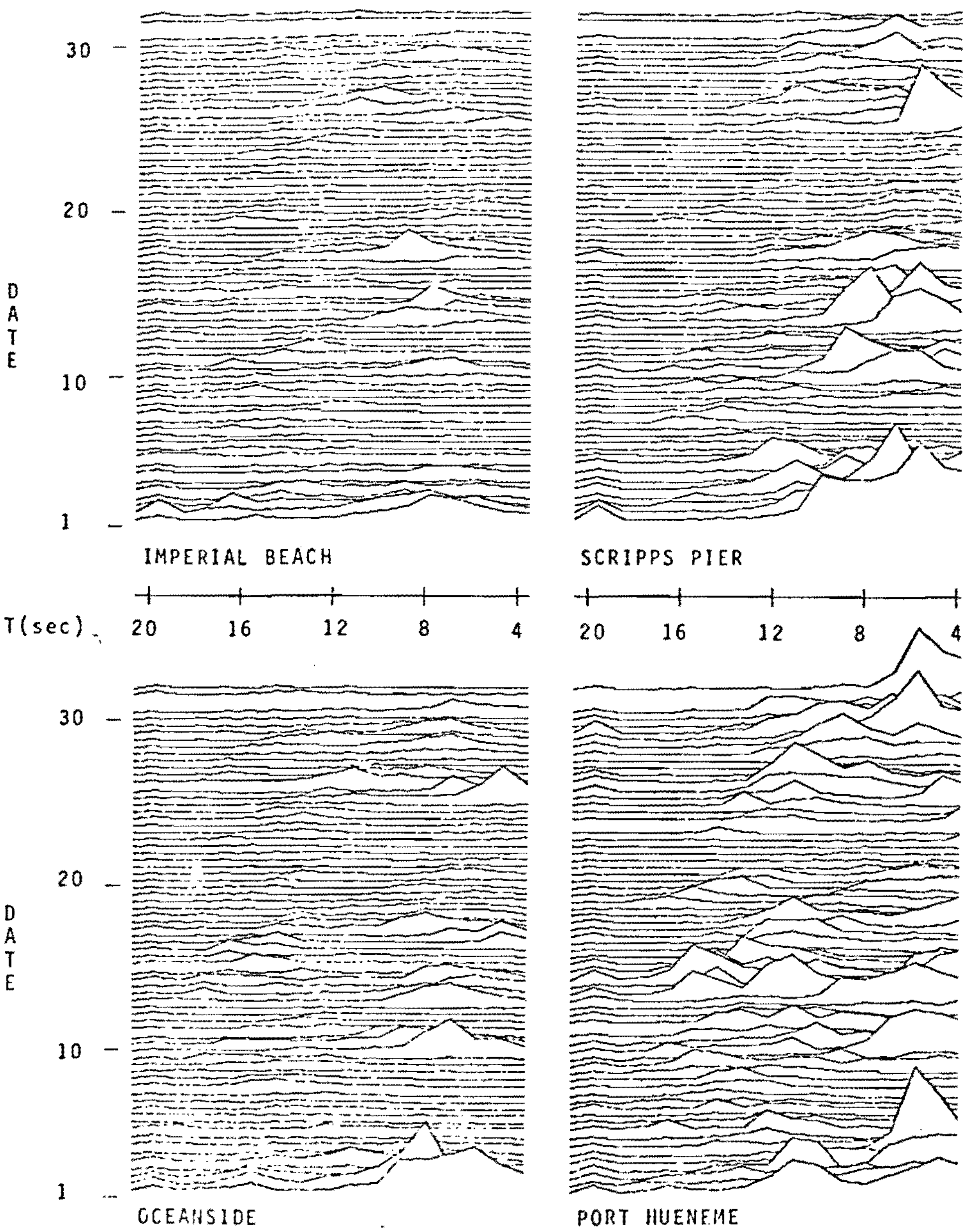

Fig. 3. Qualitative energy spectra for four stations during the month of March 1977. Each line represents a measurement taken every ten hours. Time moves upwards in the figure. The ordinates of each plotted line are proportional to the wave energy at the indicated period. Note that plots are linear in period, rather than frequency.

The monthly reports have been collected for a six-month or one-year period and then reissued under a single cover with a progress report for the system covering the same period. These reports (*Seymour et al.*, 1976, 1977, 1978) contain details of the system configuration and operation.

WAVE DIRECTION MEASUREMENT

Although the spread in wave arrival direction in shallow water is much diminished by refraction compared to deep water waves, the need for accuracy in determining direction is much greater in certain important applications. As an example, for small angles the longshore transport of sediment by oblique waves is proportional to the magnitude of the angle the crests form with the shoreline. Thus, direction estimation errors of only a few degrees can result in very significant errors in the estimate of transport. In many cases of interest, the approach angles are characteristically only a few degrees, so that small errors can actually result in the improper sign for the transport -- i.e., failure to predict the proper direction.

The present method for acquiring directional nearshore data is to use arrays of wave gages and to construct directional spectrum estimates from the cross-correlations between pairs of gages. These arrays are large and expensive to install because of the accuracy required in the relative placement of the gages. Because of their size (hundreds of meters for linear arrays to measure periods up to 18 secs) there is also a serious question of the spatial homogeneity of the wave field over the length of the array. The finite number of cross-correlations available in any reasonable sized array also limits the resolution of the directional spectrum estimate so that determination of direction to the accuracy required for sediment transport estimates is questionable under many conditions. In this volume, *Borgman* (1978) discusses the determination of directional wave spectra from wave sensor arrays and the directional resolution of various methods. However, even if good resolution of the central approach angle is obtained, the estimate of sediment transport requires the calculation of the longshore component of momentum flux, S_{xy}, and the smearing of the directional spectrum always produces an S_{xy} estimate smaller than the actual quantity by an error of unknown magnitude. *Higgins, Seymour, and Pawka* (1978) show the analytical proof for this and describe a series of verifying field experiments.

Since the principal motivation of wave direction measurement in this program is to predict sediment transport, it was decided to measure S_{xy} as a function of frequency directly. Following *Longuet-Higgins* (1970)

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$$S_{xy}(f) = \sum^{\theta} E(f,\ \theta)\ n\ \sin\theta\ \cos\theta \qquad (-90° \leq \theta \leq +90°) \tag{1}$$

where S_{xy} = longshore component of shoreward directed momentum flux

$E(f,\ \theta)$ = energy as a function of frequency f and direction θ

n = ratio of group and phase velocities

θ = angle between wave arrival direction and the normal to the shoreline

Equation (1) provides a conceptual picture of the longshore component of momentum flux showing its dependence upon approach angles. However, in longshore sediment transport calculations using current models, the transport rate is proportional to the magnitude of S_{xy} and its direction is determined by the sign of this quantity. Therefore, the component approach angles need not be measured if a means exists for direct measurement of S_{xy}. An estimate of S_{xy} is obtained from this system using the approach suggested in *Longuet-Higgins et al.* (1963) of utilizing the time averaged value of the product of the orthogonal sea surface slope components.

$$S_{xy}(f) = \frac{n}{k^2} \langle n_x n_y \rangle \tag{2}$$

where k = wave number

and $\langle n_x n_y \rangle$ = time average of slope components in the offshore and alongshore directions

The averaging of the slope components is done in frequency space by computing the cospectrum between the slope component time histories. The slopes are measured by using the difference between the two pairs of bottom-mounted pressure transducers. The Fourier coefficients are corrected by standard linear wave theory for the pressure attenuation effects.

A more complete treatment of the theory and a discussion of the magnitude of the errors inherent in this estimation scheme are found in *Seymour and Higgins* (1978A) and *Higgins, Seymour, and Pawka* (1978).

Measurement of S_{xy} for ocean waves to acceptable engineering accuracy can be made with relatively small arrays -- on the order of six meters on a side. This allows the array to be built into a single rigid frame. The alignment of the frame is established within approximately one-half degree by divers using a waterproof magnetic compass. Coordinate rotation is employed to correct the slopes to be referenced to the local trend in bottom contours. The estimation of longshore sediment transport using data obtained through this system is described in *Seymour and Higgins* (1978B). It can be seen that employing the values of $S_{xy}(f)$ from Equation (2) in Equation (1) allows the estimation of a representative approach angle for each frequency interval.

INTERACTIONS WITH DEEP WATER MEASUREMENT PROGRAMS

Since the principal concern with wave statistics is their application to the nearshore environment, any scheme for producing deepwater statistics -- either using direct measurement or hindcasting techniques -- requires a test of its ability to allow projection into shallow water. Synoptic data from large numbers of nearshore measurement stations provides the ultimate test for any deep water system. The usefulness of deep water statistics to the coastal engineer depends upon using refraction analyses and upon being able to predict the nearshore wave environment to reasonable accuracy.

If comparisons of nearshore measured climates and climates predicted from deep water data show that the deep water directions cannot be measured or inferred with sufficient accuracy to allow such projections into shallow water, nearshore measurements can possibly provide a reasonable means for estimating deep water direction. This approach, suggested by M. P. O'Brien of Berkeley, is based upon using non-directional nearshore wave gages spaced many kilometers apart along a coastline as an array to determine deep water wave direction. This large-scale array could be used in two modes. For a given frequency band, each deep water wave approach direction can produce a unique fingerprint of spectral intensities at the various elements in the array, provided that the intervening bathymetry is sufficiently irregular to cause non-homogenous refraction, so that a deep water direction can be assigned. The second mode of operation would be to use the shore stations as a directional array which could be considered coherent for events of sufficiently long time and space scales. *Thompson and Smith* (1974) show that swell trains have well-defined maxima in group heights that would have phased arrival times measured in hours over an array on the order of a hundred kilometers in length. A more complete treatment of these array concepts and the results obtained are contained in *Seymour and Higgins* (1978C).

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SUMMARY AND CONCLUSIONS

A reliable system for sampling the coastal wave climate has been demonstrated. A compact representation of wave directionality is contained in the spectrum of the longshore component of momentum flux obtained routinely with this system and this has been shown to be useful in predicting longshore sediment transport. Wave statistics obtained from this system have been used for the design of harbor entrance improvements, shoreline erosion protection structures and for a large number of scientific investigations, including large-scale island shadowing experiments and providing ground truth for evaluating techniques for the remote sensing of waves. The effectiveness and usefulness of the system has led to plans to expand it to cover the entire coastline of California.

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