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Wave Monitoring in The Southern California Bight

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Abstract

An overview of recent research by the Coastal Data Information Program (CDIP), aimed at effectively monitoring wave conditions in the Southern California Bight, is presented. The topographic and bathymetric complexity of the Bight presently limits the utility of *in situ* measurements to the immediate vicinity of the observations. A long-term goal of the CDIP research program is to provide useful estimates of the wave and wind field throughout the southern California region from a limited number of *in situ* observations. Ongoing and planned CDIP research projects, involving numerical wave models, deep ocean directional wave measurements, and regional wind data are described.

Introduction

Numerous wave measurements have been made within the Southern California Bight over the last decade by NOAA and the Coastal Data Information Program (CDIP). However, shoreward propagating surface gravity wave energy is focussed and diffused by offshore banks and blocked by islands in this bathymetrically complicated coastal region. Wave energy can therefore be very different at sheltered sites separated by only a few kilometers, and a prohibitively large number of *in situ* instruments would be required to monitor all locations of interest for engineering, boater safety and other purposes.

Determining the wave climate within the Bight is further complicated by locally generated waves. Although the incident deep ocean wave field is usually the

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dominant source of wave energy within the Bight, there are important exceptions. Intense local storms with strong and spatially variable winds can generate energetic seas on large pre-existing swell (Seymour, 1989). Many wind measurements throughout the Bight will be required to study local wave generation in these cases, and present wind-wave generation models may be inaccurate.

Wave conditions within the Bight can be conceptually divided into swell waves arriving from outside the islands and local seas generated inside the Bight. One approach to estimating swell conditions in coastal regions is to initialize a numerical wave propagation model with the offshore (unsheltered) frequency-directional spectrum, $S_o(f,\theta)$. However, for complex bathymetry, the model simulations can be highly sensitive to the details of $S_o(f,\theta)$. This may degrade model predictions which are based on input conditions specified with conventional (fundamentally low resolution) measurement systems, such as the ubiquitous pitch-and-roll buoy.

The Southern California Wave Experiment (Aug. 91 - Feb. 92), jointly sponsored by The California Department of Boating and Waterways, Sea Grant, and The Army Corps of Engineers, was designed in part to test methodologies for predicting swell conditions within the Bight from directional buoy measurements of S_o. Preliminary results from this experiment are encouraging; however, the expected sensitivity of wave conditions in the Bight to small errors in the peak direction of S_o is clearly seen.

Geographical Setting

The Southern California Bight extends from approximately 32°N to Point Conception (34.5°N) on the west coast of the U.S. (Figure 1). The topography and bathymetry of the Bight are characterized by numerous offshore islands and shallow banks, a narrow continental shelf, and coastal submarine canyons.

The complex bathymetry results in an equally complicated regional wave field. The islands block a significant amount of the incident deep water wave energy and the wave field is influenced by offshore banks, the irregular shaped continental shelf, and numerous coastal submarine canyons. The spatial variability of the resulting nearshore wave field is often dramatic, with large changes in wave energy taking place over only a few kilometers.

The wind field in the Bight is profoundly affected by the rugged topography of both the offshore islands and the coastal mainland. However, a very limited number of wind measurements are presently available to define these spatially varying winds. Therefore, properly initializing wave generation models in the Bight remains a difficult and poorly understood problem.

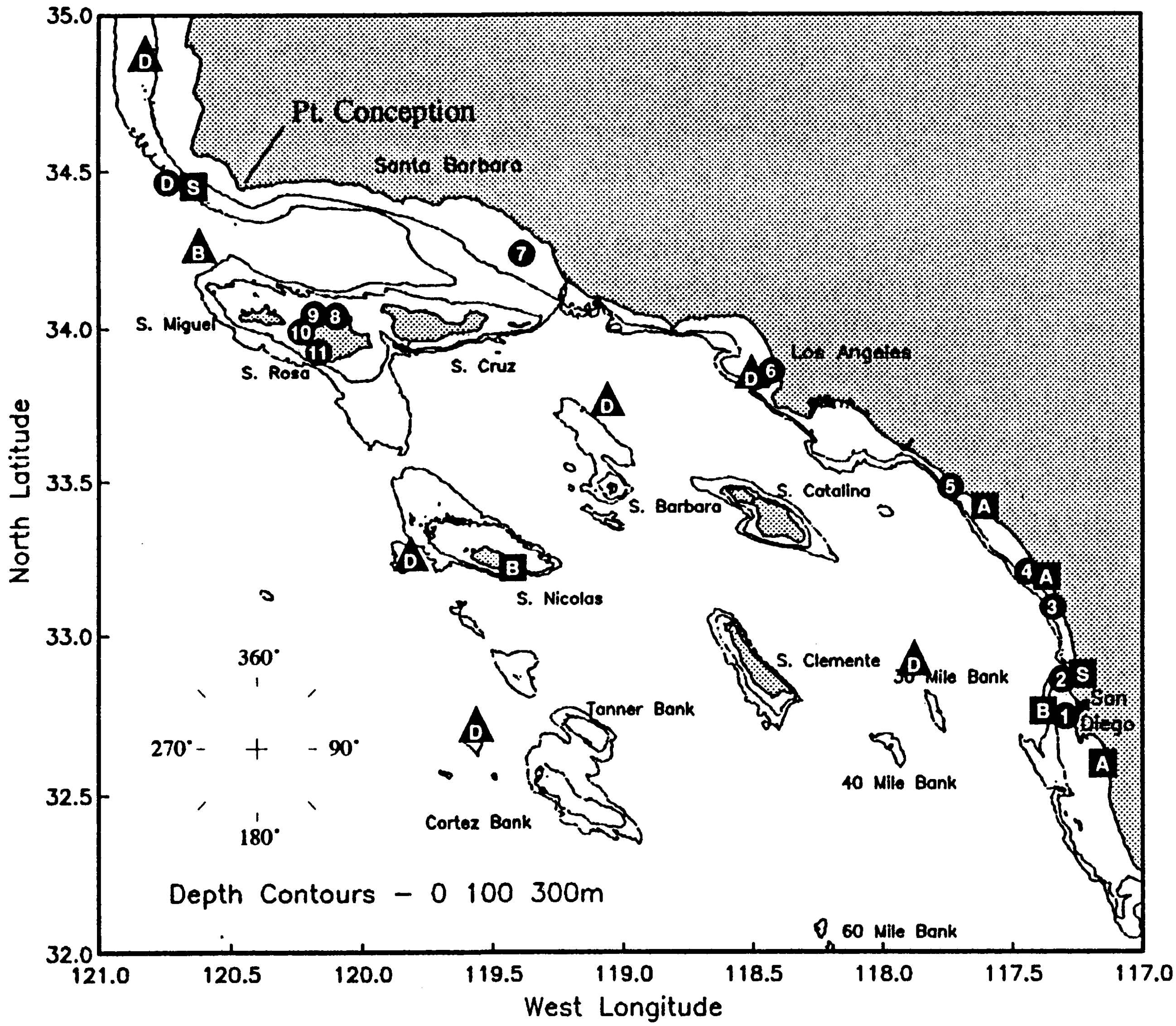

Figure 1. Locations of measurement stations in the Southern California Bight during the winter 1991-1992. "B" represents nondirectional buoys, "D" directional buoys, "S" single-point pressure gages and "A", directional arrays. The triangles are gages maintained by NOAA or the Navy, squares, the Coastal Data Information Program, and the numbered circles are for single-point gages deployed as part of the Southern California Wave Experiment.

Utilizing Historical Wave Measurements

Since the mid-1970's, routine wave measurements have been made in the southern California region. Most of this data has been collected by the CDIP, NOAA, and the U.S. Army Corps of Engineers (see the paper by Seymour et. al. in these conference proceedings). The purpose of these measurements is to provide quasi real-time and historical wave information to engineers, coastal planners, and mariners. Over the past decade, the number of wave gaging stations has grown considerably, and the Bight is arguably the most heavily monitored wave climate in the U.S..

A common problem facing coastal engineers is translating historical wave data collected at one more sites in a coastal region to a study site where there are few or no direct measurements. While a wave measurement made along an open coastline may be relevant for a large section of coast, measurements made in areas with complex bathymetry are often quite site specific. Under these conditions, simple interpolation methods will not accurately predict waves at uninstrumented sites.

In an attempt to effectively utilize wave data collected along complex coastlines, data interpretation schemes based on inverse mathematical methods are presently being studied by CDIP. Inverse methods encompass a wide range of techniques from linear programming (solving simple sets of linear equations) to more sophisticated forms of inverse theory which have found important uses in such fields as geophysics and medical tomography. The inverse techniques being applied in southern California borrow heavily from a branch of oceanography known as acoustic tomography, where acoustic sources and receivers are strategically placed in the ocean for the purpose of mapping, for example, the mesoscale sound speed field (Munk and Wunsch, 1978).

The goal of a southern California inverse model is to estimate the entire regional wave field using a network of wave gages. In addition, by applying analogous procedures to those developed for designing acoustic tomography experiments (Barth and Wunch, 1990), the best future gaging locations can be selected in an objective manner.

The inverse approach is being used to study swell waves from distant sources. Locally generated seas are also important to the overall southern California wave climate and can be incorporated into the inverse methodology. However, for the purpose of evaluating the viability of the inverse approach, we have limited our present scope to wave propagation and avoided the additional uncertainties of wind-wave generation models.

Linear Wave Propagation Models

The inaccuracy of simple interpolation schemes between measurement stations in southern California means that some other "model" must be used to relate the measurements to each other and to wave conditions throughout the region.

Two well known linear wave propagation methods, spectral refraction (Longuet-Higgins, 1957) and spectral refraction-diffraction (Izumiya and Horikawa, 1987), have been adapted for use in southern California. These models assume S_o is homogeneous in deep water outside the islands and no local generation of wave energy. A comparison of these two models (O'Reilly and Guza, 1993) in southern California, using simulated incident directional spectra, showed that they predict surprisingly similar results across most of the Bight. The agreement generally is best between the models when S_o is broad in direction and frequency. Simulated southern hemisphere swell, which are narrow in both frequency and directional upon their arrival in California, produced the largest differences between the model predictions.

The Southern California Wave Experiment

In the fall and winter of 1991-92, an extensive field experiment was undertaken to test the accuracy of the spectral wave propagation models and assess the viability of using inverse methods to improve estimates of the Bight-wide wave field. The existing wave monitoring stations were supplemented with 11 additional single-point pressure gages (i.e. nondirectional), deployed throughout the Bight as part of the Southern California Wave Experiment (Figure 1). In addition, a Datawell directional waverider buoy was deployed by the U.S. Navy in deep water west of Pt. Conception.

Preliminary results indicate that a linear model which includes island blocking and spectral refraction yields useful predictions of wave energy across most of the region. The exception was the east end of the Santa Barbara Channel (Site 7, Figure 1) where both the spectral refraction and refraction-diffraction wave models underpredicted significant wave heights of swell from the northwest by 50%. The reasons for this are still being studied and CDIP hopes to redeploy instrumentation at this site in the future.

The month of January, 1992 was suitable for a field verification of models because the deep water wave conditions were often dominated by swell from a single, distant source, which are optimal conditions for estimating directional spectra with low-resolution directional buoy data. Figure 2 shows the hourly measurement of wave energy in the 10-20*s* period band (swell wave energy) at Batiquitos Lagoon (Site 3 , Figure 1), for January, 1992. Also shown is the predicted wave energy based on the spectral refraction model (Figure 2, lower panel). This model was initialized using hourly, iterative maximum likelihood estimates (IMLE, Oltman-Shay and Guza, 1984) of S_o from an unsheltered, deep ocean directional buoy. The total wave energy is significantly overpredicted by the wave model in this case. However, if the hourly estimates of S_o are rotated 8 degrees to the North (e.g. deep water wave energy which was originally

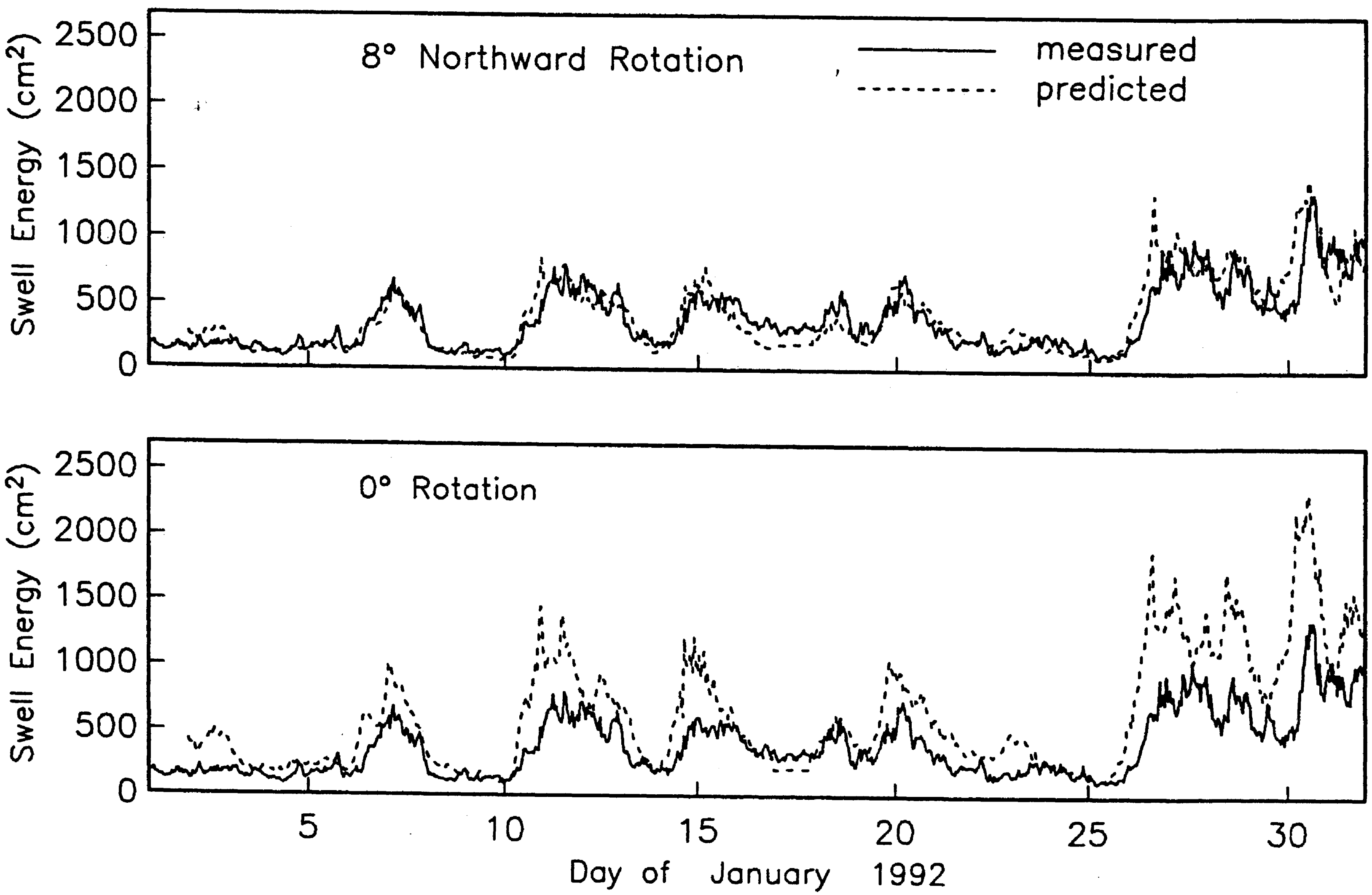

Figure 2. Measured (solid line) and predicted (dashed) swell energy (total energy between 10 and 25s periods) in 30m depth near Batiquitos Lagoon (Site 3, Figure 1). Predictions are based on spectral estimates from a deep water directional buoy. The upper panel is for predictions based on the same deep water spectra that have been rotated to the north by 8 deg.. (From O'Reilly, 1993)

estimated to arrive from 270° now arrives from 278° etc.), then much better agreement is obtained with the measurements (Figure 3, upper panel). In addition, the fit to most other study sites improved, although not as dramatically, from this slight directional rotation. To illustrate this point, concurrent predictions of swell wave energy were made at 14 different measurements sites throughout the Bight. The overall accuracy of these predictions was quantified as a predictive skill,

$$PREDICTIVE\ SKILL = \frac{<m^2>-<(m-p)^2>}{<m^2>} \tag{1}$$

were $<>$ = all the hourly predictions at the 14 sites, m = measurements, and p = model predictions. Three different directional estimators were used with the buoy data; A maximum entropy method (MEM, Lygre and Krogstad, 1986) and a maximum likelihood estimator (MLE), and the IMLE method. The most significant difference between MEM, MLE, IMLE estimates of S_o during January was in the directional widths. MEM generally makes the narrowest, and MEM the broadest, estimates of S_o.

When the Bight-wide predictive skill of the model is calculated as a function of the rotated S_o (Figure 3), significant improvement in the overall predictive skill is seen for a small northward rotation (≈5°). This result shows how sensitive sheltered sites can be to errors in S_o. In addition, for unidirectional wave events, measuring the mean direction correctly appears to be more important than choosing a particular directional spectrum estimator.

Rotating all the estimates of S_o, in order to be more consistent with the wave measurements made *within* the Bight, is a simple example of an inverse model. O'Reilly and McGehee (1993) consider how best to combine sheltered and unsheltered wave measurements to improve estimates of the true deep ocean directional wave spectra. These "improved" estimates can be used with wave propagation models to estimate the wave field at uninstrumented sites throughout the Bight.

Present and Future Research at CDIP

In addition to developing wave models and inverse prediction methods for southern California, CDIP is engaged in a number of other research activities.

- Deep Water Directional Data from Harvest Platform

In November, 1992, Harvest Platform, an oil drilling platform in 200m water depth west of Pt. Conception, was equipped with an array of 6 pressure transducers. CDIP hopes to use this data to initialize the linear wave models and make real-time predictions of Bight-wide swell conditions during the winter months (when swell approach California from the west-northwest). In addition, the

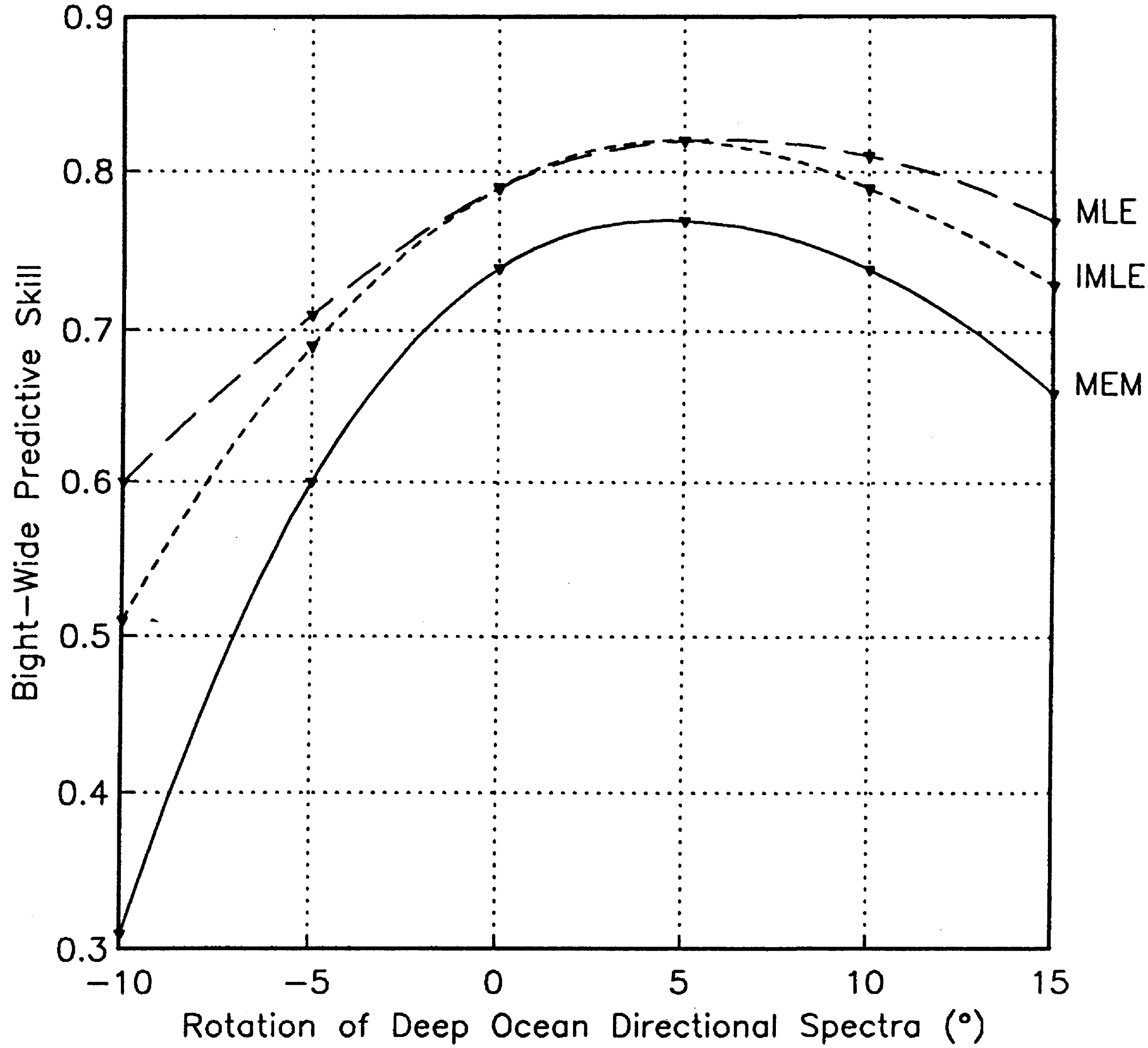

Figure 3. Variation in overall skill of spectral refraction model predictions when the deep water directional spectra are rotated to the south (-) and north (+). The skill value is averaged over 744 hourly predictions and 14 different measurement sites during the month of January, 1992.

directional data from the platform is an ideal ground-truth for testing other types of deep water wave measurement systems. Presently, the Harvest data is being used to verify the accuracy of a NOAA 3-m discus buoy and a Datawell directional waverider buoy.

- Wind-Wave Generation on Pre-existing Swell

A very common condition in the southern California is to have local winds generating seas on existing swell waves as they propagate through the Bight. A detailed study of this process is presently being planned for the Pt. Conception region. Several wind measurement buoys (presently under development) will be deployed to complement the existing oil platform instrumentation and NOAA buoys presently operating in the area.

- Swell Propagation Across Broad Continental Shelves

Preliminary results from the Southern California wave experiment suggest that linear propagation models, initialized by buoy data, can provide useful estimates of swell wave energy along coastlines with narrow continental shelves. The question remains as to whether or not similar swell predictions could be made on a broad continental shelf like the U.S. east coast. CDIP plans to join in an upcoming field experiment at Duck, North Carolina in 1994 by deploying a Datawell directional waverider buoy at the edge of the continental shelf. Wave model predictions will be compared to shelf-wide swell wave data.

Summary

The Southern California Bight is one of the most intensely monitored wave climates in the world. However, the topography and bathymetry of the region produce spatially complex wind and wave fields. Therefore, a combination of numerical wave models and inverse mathematical methods are being developed to fully utilize the historical wave data. Preliminary results from a recent field experiment indicate that linear wave propagation models are a viable method for predicting swell wave conditions across narrow continental shelves. The field results also demonstrate that wave predictions at highly sheltered sites are sensitive to small directional errors ($\approx 5°$) in estimates of S_o. Ongoing CDIP research includes the field verification of deep water wave measurement instrumentation, the development of inexpensive wind monitoring buoys, the study of wind-wave generation on existing swell, and the verification of linear wave propagation models on broad continental shelves.

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