Coastal Waves Program

Office of Oceanography

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U.S. DEPARTMENT OF COMMERCE
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INTRODUCTION

This report describes the Coastal Waves Program (CWP)* of the National Oceanic and Atmospheric Administration (NOAA). The CWP is designed and planned as one component of a cooperative national effort by Federal and state agencies and the private sector to provide mutually needed wave information. The prime tasks of the CWP are to provide large-scale, long-term data and statistics for all U.S. coastal waters; wave information affecting public safety (especially to navigation); and overall coordination of wave programs. Other Federal agencies will provide wave forecasts, some measurements, archival services, and other environmental data needed to support wave studies. The private sector and Federal agencies generally use their own and other data to provide site specific forecasts and statistics to meet particular needs. A high degree of cooperation is expected in measurements, hindcasts, exchange of data, evaluating accuracies, and developing models and improved methods of measurement.

Waves are a never-ending ocean phenomenon which have both fascinated and terrorized man since his existence. With the potential for exerting enormous forces, waves lap and pound everything in their path--ships, structures in the water and on the coast, and the coast itself. To survive, structures must be designed, built, maintained, and operated to withstand the extreme wave conditions that may occur. Everyone in the marine community--from the holiday fisherman, the offshore oil operator, the supertanker naval architect, to the beach house owner--must deal with waves. No one is immune.

Waves and wave information availability impact initial costs, operational costs, safety of life and property, and efficiency of working in the oceans. Thus, it is no wonder that a great variety of individuals and groups in Federal, state, and local government and in the private sector need and use wave data in making decisions. The success of their endeavors depends on reliable information about waves--past, present, and future.

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*Funds were appropriated by Congress to begin this program in Fiscal Year 1980.

The responsibility for implementation of the CWP must fall on the Federal Government for many reasons: (1) the large-scale and long-term measurements and models required--very long-term measurements over a total ocean area are required to achieve the statistical accuracy and reliability needed for a typical single site; (2) the wide range of users--many small firms and organizations in the private sector and local governments who need essentially the same wave data as the Federal Government and major corporations would not be able to afford the data otherwise; (3) the interdisciplinary character of the program--the CWP must interact with other Federal programs including weather and storm surge forecasting, bathymetric mapping, and tides and currents to provide good wave information; and (4) the broad impact of the program--wave information to be provided by the CWP impacts public safety, environmental quality, national defense, and protection of the coasts.

USER REQUIREMENTS

Figure 1 identifies major users and the activities requiring knowledge of waves. Federal agencies need information and data for an array of missions ranging from defense to resources development. State and local government groups need wave data to carry out planning, develop policies, and provide services. Private industry and all levels of government need wave data for engineering designs and marine operations.

The efficient and safe design of coastal and offshore structures depends on highly accurate wave data. The analysis of sedimentation/erosion rates and design of harbors and systems to deal with coastal erosion also require highly accurate wave data. Wave data obviously are needed for wave energy development and wave phenomenon investigation. Wave forecasts and historical statistics are critical to fishing operations, marine construction, recreational boating, operations on offshore platforms, workboat activities, dredging, salvage, merchant shipping, and other marine operations.

Users require wave data, information, and services in a variety of forms and time frames for both specific locations and large areas. Parameters needed include spectra, directional spectra, extreme heights, significant heights, mean periods, mean directions, periods of maximum wave variance,

USERS \ APPLICATIONS	Structures and Equipment Engineering	Facility and Ship Construction and Operations	Coastal Erosion and Shore Protection Planning	Coastal Hazards Preparedness/Rescue	Conservation/Regulation	Wave Energy Development
FEDERAL						
National Oceanic and Atmospheric Administration	x	x		x	x	
U.S. Army Corps of Engineers	x	x	x		x	
U.S. Coast Guard		x		x	x	
U.S. Navy	x	x		x		
U.S. Geological Survey	x				x	
Nuclear Regulatory Commission	x				x	
Department of Energy	x					x
Maritime Administration	x					
Federal Emergency Management Administration				x		
TYPICAL STATE AND LOCAL GOVERNMENT						
Port Authorities	x	x		x		
Coastal Planning Organizations			x	x	x	
Recreational Organizations	x	x	x	x		
Civil Defense Directors			x	x		
Public Works Departments	x	x	x			
TYPICAL INDUSTRY AND PUBLIC						
Contractors and Builders	x	x				
Fishing		x				
Marine Recreation	x	x				
Offshore Oil and Gas	x	x			x	
Dredging	x	x				
Salvage	x	x				
Coastal Utilities/Refineries	x	x	x	x	x	
Marine Transportation	x	x				

Figure 1. Users of Wave Information and Applications

groupiness factors, nonlinear shapes and characteristics, directional spreading factors, and spectral width parameters. Many users will want raw data that they can process in their own special way. Others will want completely analyzed information.

The accuracy and quality of wave information affect safety, cost, and efficiency of offshore and coastal activities. Consider, for example, the design of a typical large offshore platform. The designer of such a structure includes a safety factor in his design to compensate for the lack of reliable wave information. This can be costly for large structures since, for each foot of increase in the design wave height criterion, the cost goes up $1 million or more. The cost to the operator could be much greater if the structure fails because of underestimating the design waves. Design of breakwaters and other coastal protection devices is even more dependent on the accuracy and quality of the wave information since it is often more difficult to add safety factors to them.

Other marine operations are similarly affected. The decisions a ship master makes are critically dependent on confidence in the wave forecasts received as well as on the forecasts and waves themselves. Short routes are only attempted if the forecasts are reliable enough to assure no untoward danger.

LIMITED AVAILABILITY OF WAVE DATA

Presently available wave information is not adequate to meet the needs of users. Relatively few long-term wave measurements are available for U.S. waters, and accuracies of these measurements are unknown. There are no operational measurements of directional spectra being made now.

Although models are available for hindcasting* deepwater wave conditions, these models do not have the capability to consider all factors which

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*Hindcasting is the use of forecast type models to estimate the wave conditions that occurred in the past based on historical wind data.

influence the waves such as currents, small-scale effects, and the location of islands. The available models for shallow water, where wave conditions are more complex, are even less well developed than the deepwater models. There is no consensus among professionals regarding the accuracies of data coming from these models or which models are the most accurate.

While users must make do for now with the limitations of available wave information, they require additional information and a higher degree of accuracy than previously required. The high cost of marine structures demands that designers can no longer use arbitrary safety factors. Design must carefully match expected wave conditions. With much ocean development moving into frontier areas, it is impossible to achieve optimum design because adequate wave data do not exist.

To meet immediate needs, major private sector and Federal organizations have established expensive programs to gather available wave information and make relatively short-term measurements. However, these short-term programs are inadequate. For example, the Director of Civil Works of the U.S. Army Corps of Engineers (COE) stated:

> ". . . the Corps needs comprehensive and detailed wave data along every coast of the United States. When we perform a specifically authorized study, we do not have time to collect adequate wave data. We should have . . . data . . . collected over a sufficient number of years to be statistically significant to supplement the data collected . . . at the time of investigation."*

In this need, the COE is typical of most engineering users.

PROGRAM GOAL AND OBJECTIVES

Goal: Support the growth, safety, and efficiency of marine activities including national defense operations, erosion mitigations, transportation, fishing, offshore oil and gas recovery, seafloor mineral recovery, construction, recreation, and coastal zone development by providing historical, real-time, and statistical data and information on waves in U.S. waters.

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*Letter from Major General Ernest Graves to the Administrator of NOAA dated July 19, 1976.

Objectives:

1. Develop, deploy, and operate wave measurement and data processing systems as needed to assure adequate geographic coverage.

2. Develop and operate wave hindcasting models as needed to fill voids in measured wave data.

3. Provide statistics of the large-scale wave "climate."

4. Prepare descriptions of important local wave phenomena which are hazardous to navigation for inclusion in the "Coast Pilots."

5. Provide wave data in real time to support forecasting and other operational needs.

6. Evaluate and improve the accuracy of wave data and information.

7. Provide a national focus for coordination of wave-related activities.

8. Advance wave science and measurement technology.

In terms of geographic coverage, the program will provide data and statistics on waves in all ice-free U.S. waters out to the edge of the Continental Shelf (or 200-mile economic zone whichever is larger) and ocean-wide data sufficient to compute coastal swell conditions. Emphasis will be placed on the region seaward of the breaker zone (approximately 7 meters of depth for large waves). Although waves in shallow water can be computed for specific sites using data from deeper water, the program will not attempt to meet the specific needs of individual private users since that task is the province of private firms and consultants. However, the nonspecific products of the CWP will meet some of their requirements.

Figure 2 shows the long-term accuracy objectives of the CWP in terms of field measurements, models, and statistical products. A more immediate objective is to determine the true accuracy of presently available wave data.

Parameters Derived from Measurements (not including statistical confidence)	
Individual Heights	±5%**
Significant Heights	±2%**
Period (Mean or Period of Maximum Variances)*	±0.5 sec
Mean Direction	±5°
Variance Spectral Density	±10%
Parameters Derived from Models	
Directional Spectra Density	±25%**
Significant Height	±10%**
Period of Maximum Variance*	±0.5 sec
Directional Resolution	±15°
Output Products (including 80 percent statistical confidence and representativeness)	
Nonextreme Significant Height Statistics	±10%
Nonextreme Spectral Statistics	±15%
Extreme Significant Height for 100-Year Return Period	±15%

*Or equivalent frequency.

**For waves with significant height greater than 3 meters.

Figure 2. Initial Long-Term Accuracy Objectives of Coastal Waves Program (At Three Standard Deviation Levels).

To meet these accuracy objectives, a long-term statistical wave data base for the Continental Shelf is required. The most feasible approach to establish this data base for the immediate future is by hindcasting with some testing of the models by short-term measurements. Since hindcasts have been made by the U.S. Navy, the U.S. Army Corps of Engineers, and others, the CWP would not repeat their work. However, these hindcasts are limited in reliability by the present state of the science and have unknown accuracies.

PROGRAM TASKS

The CWP consists of five major tasks: measurements, hindcasting, quality assurance, data management, and local hazards. Each of these is described in the following subsections.

Measurements. Although existing wave measurement systems cannot meet all the objectives of the CWP, they must be used while new technology is being developed, especially for directional variables. The CWP has sponsored several new system developments including modifying Waveriders to communicate via satellite, Coastal Ocean Dynamics Radar (CODAR), and pitch-roll-heave directional buoy systems. The CWP has operated a pilot network off Maryland, Delaware, and New Jersey. Also, it was a coleader of the Atlantic Remote Sensing Land Ocean Experiment (ARSLOE) in the fall of 1980. ARSLOE was conducted to (1) test and compare performance of all available wave measurement systems (including buoys, radar, aircraft, wave staffs, and bottom-mounted devices); and (2) test shallow water wave theory.

The first large-scale CWP measurement effort will be the establishment of a network of buoys in the Mid-Atlantic Bight, scheduled for deployment in Fiscal Year 1982. The buoys and their locations are shown in figure 3. This network will provide practical experience in network operations and data for developing and testing hindcast models. After 2 years of operation, the plan calls for removal of selected stations, leaving a more sparse long-term network. After this, the plan is to install measurement networks in other coastal regions. These deployments will depend on user priorities, experience with the Mid-Atlantic Bight Network, budgets, availability of hardware and systems, and progress in model development. All CWP measurements will be

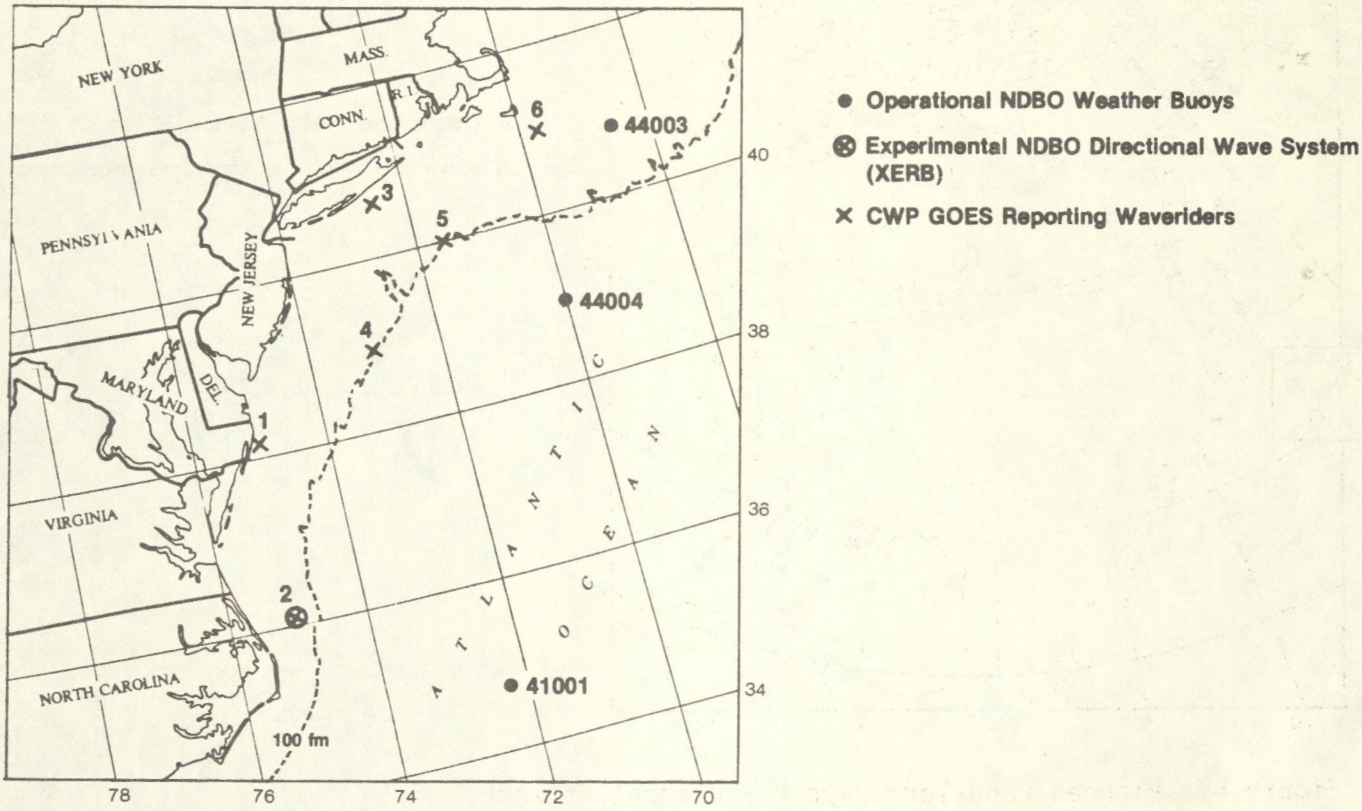

Figure 3. Mid-Atlantic Bight Network.

communicated and made available in real time to forecasters and others who need these data.

Figure 4 shows one possible configuration for a national wave measurement network which would be cooperatively operated by several agencies. Measurement stations are tentatively spaced approximately 500 km apart because of the scale of the wind systems generating the waves. Most measurement stations are located sufficiently offshore to eliminate bottom effects, and thus provide data which are representative of large areas. Relatively small-scale measurement systems will be operated on a short-term basis for site specific studies, model testing, and research.

Hindcasting. A wave hindcasting model provides estimates of wave conditions that occurred in the past based on estimates of the wind fields which occurred in the past. Past wind fields are usually determined from a combination of synoptic atmospheric pressure and wind data through a boundary layer wind model. In the hindcast model, waves build as a function of the winds and

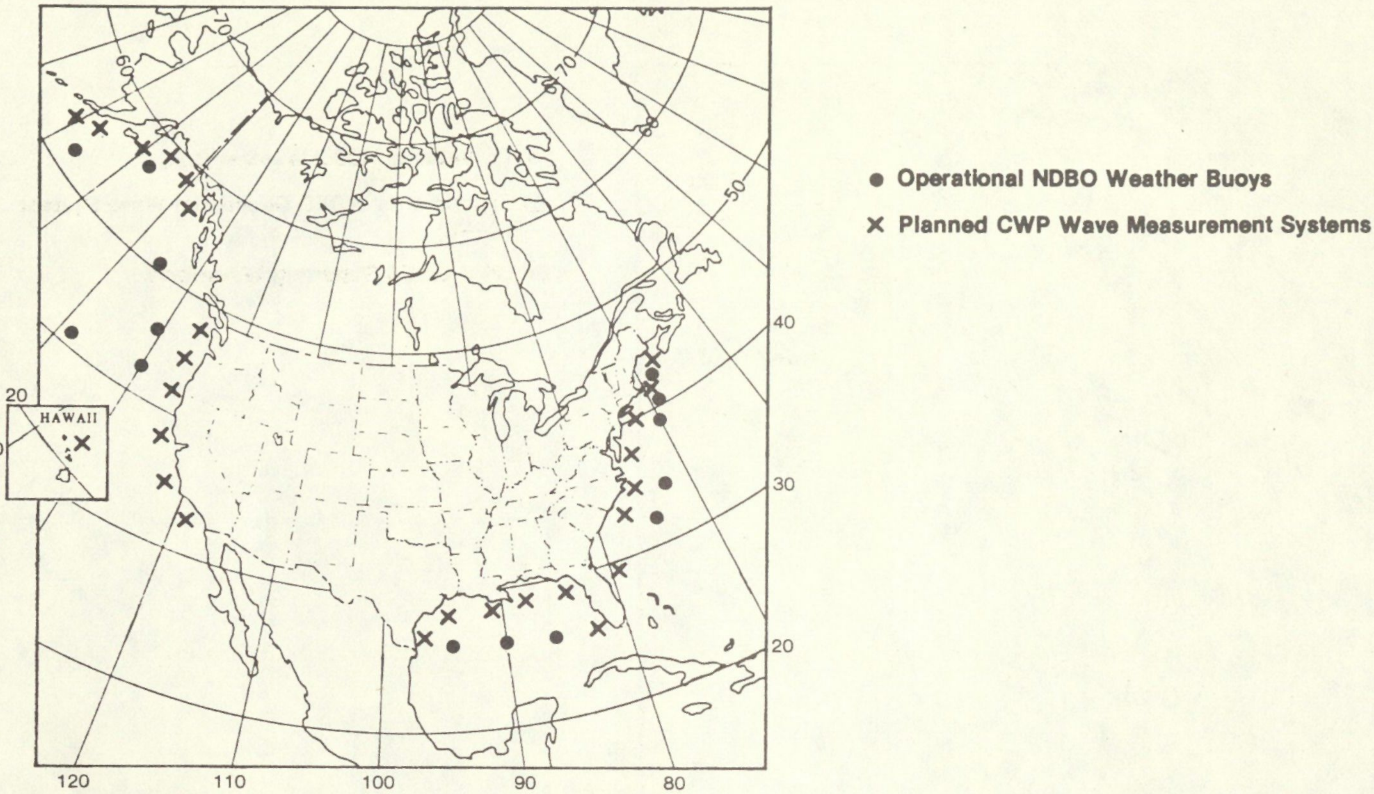

Figure 4. Planned Long-Term Wave Measurement Network.

propagate as a function of water depth, currents, and their own characteristics. Through interaction with each other and with outside forces, these waves will change and dissipate. The output of modern models is usually directional spectra. Hindcasts for waves in most coastal areas must utilize models which cover essentially the entire ocean, since waves generated in distant locations propagate into coastal areas as well.

The CWP hosted a wave modeling workshop in June 1980 with internationally recognized scientists in attendance. The workshop concluded that present models of shallow (i.e., about 15 to 20m depth) water waves provide significant wave heights* within ±50 percent of actual conditions. For deepwater wave models, the experts did not agree on the accuracy of hindcasts. Further, there are no models available which include important factors such as currents or which use available wave measurements. Obviously, there is a great need to improve the models.

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*Significant wave height is defined as the average of the highest third of the individual wave heights.

The CWP will use hindcasting models to interpolate between measurement locations, to determine shallow water wave conditions, and to determine extreme wave conditions until a long-series of measurements can be completed.

Many engineering applications require the probability of extreme wave conditions occurring over periods ranging from 25 to 100 years which require long periods of measurement. However, since long-period measurements of waves are not now available, hindcasting, based only on winds, must be the primary method for determining the probability distribution of extreme wave conditions for the near future. For developing such statistics in the future, hindcast type models will be used in conjunction with wave measurements in an interpolation mode. The measurements will constrain the model computations to assure accuracy at grid points between measurement sites. This method will allow the measurement sites to be widely spaced without significant degradation in accuracy.

Quality Assurance. The quality assurance task has two parts. The first is an effort to determine the accuracy of various elements in the total system--from data acquisition to product preparation. The second is to establish standards of data quality and monitor program operations for adherence to these standards.

The evaluation of accuracies is complicated because of the many potential sources of errors in measurements, data processing, modeling, data analysis, and the natural sampling variability in measurements which causes relatively wide confidence intervals for realistic record lengths. Wave measurement system accuracies will be determined by both laboratory and field tests. The ARSLOE is providing important intercomparisons of most of the available wave measurement systems including CODAR, Waverider buoys, wave staffs, directional buoys, and a large NOAA Data Bouy Office buoy along with a number of aircraft-based remote sensing systems. Preliminary results have shown discrepancies between different buoy systems as high as 25 percent in significant wave height.

A laboratory calibration system has been developed by the CWP which tests the dynamic performance of sensor electronics in accelerometer buoys. This is the only such system in the United States. Most of the buoy sensors calibrated with this system have been found to have an output as much as 10 percent lower than actual in terms of wave height and 20 percent lower in terms of spectral amplitude. These errors are being corrected with improved circuits.

Data Management. This task will cover the design, deployment, and implementation of a data management system which encompasses the entire flow and manipulation of data--measurements, transmission, processing, analysis, product preparation, storage, retrieval, and distribution. The effort includes coordination with users to determine technical requirements, content, format, delivery, and accuracy.

The basic data flow for CWP measurements begins at an internal microprocessor in the buoy which is programmed to provide either (a) wave spectra at 3-hour intervals or (b) 1-second sampled time series of the surface elevation at 1-hour intervals, depending on preset thresholds. For very high waves, an internal tape recorder will be used for longer records and better resolution. These data are telemetered via GOES and landline to the National Meteorological Center (NMC) where initial processing and quality checks are made. NMC then: (1) prepares and transmits bulletins of wave conditions over the weather communication system within 1 hour, (2) prepares a tape of all data for later CWP analyses, and (3) flags system malfunctions for corrective action. After more careful quality control and formatting, all data are archived at the National Oceargraphic Data Center (NODC).

The CWP products will be based on all data available--not just that which it gathers itself. Most of these will come via the archives of NODC and the National Climatic Center.

To accomplish the objectives of the program, complex statistical analyses are required. Initial CWP studies have shown that, contrary to generally accepted practice, innate uncertainties in basic data result in the estimated extreme significant wave heights being biased much too high. The program is developing methods to represent and to use spectra more efficiently and to reconstruct more accurately the actual shape of larger waves.

Local Hazards. The CWP will perform special studies to describe, explain, and warn against dangerous local wave conditions. These conditions include such phenomena as waves breaking on harbor entrance "bars" which have been repeatedly called out for study and reporting by the National Transportation Safety Board in various accident investigations. The studies will be directed toward giving practical guidance to commercial and recreational navigators and to weather forecasters, as well as adding to the available base of scientific knowledge. Emphasis will be on possible precursor signs of danger such as change of tide or swell. Study sites will be selected by establishing priority according to factors such as degree of danger, history of accidents, level of traffic, complexity of the investigations required, and revision schedule of the "Coast Pilots."

Individual studies will be made of each hazardous local condition. Investigations may involve detailed measurements, local "lore" of waves, currents, winds, topography, or other critical parameters which impact the waves. Research will be needed to improve the basic scientific understanding of such phenomena.

PRODUCTS AND SERVICES

The CWP will provide data and information in both real time and nonreal time. Nonreal-time historical and statistical wave products are designed to support engineering and planning. Real-time data products will support forecasters and operational decisionmakers.

Real-time products will be made available to users within 1 hour of acquisition via NOAA satellites and landline telemetry. This will include such parameters as wave height, period, mean direction, and spectral density.

The great bulk of the products will be in the nonreal-time mode. Besides statistics, this will include data that are also available in real time but enhanced by special analysis and quality control, data too voluminous to be transmitted by real-time telemetry, unprocessed field data, and output of hindcast models.

To meet the previously specified user requirements for wave information in engineering, management, navigation, forecasting, etc., the CWP will provide the following products:

o Teletype bulletins in real time of wave parameters such as significant heights, periods of maximum energy, and spectra.

o Tapes of unprocessed and processed measured time histories of wave heights.

o Tapes and reports of spectra computed by hindcasting.

o Plots and tabulations of the probability and joint probability distributions of wave parameters such as extreme heights, significant heights, mean periods, mean directions, periods of maximum wave variance, groupiness factors, and spectral width parameters at measurement and hindcasting locations.

o Plots and tabulations of the distribution of persistence of favorable and unfavorable wave heights at these locations.

o Representations of directional and nondirectional spectra at these locations.

o Plots and tabulations of joint probabilities of wave parameters with other parameters such as winds and current which jointly impact engineering and other user activities.

o Reports describing and warning against dangerous wave conditions near harbor entrances and abstracts of these for the "Coast Pilot."

o Reports of waves and other environmental parameters in major storms where the data may be of significant scientific or engineering interest.

o Reports describing methods of computing and simulating wave characteristics such as individual wave heights, periods, directions, height distributions, orbital velocities, subsurface pressures, and nonlinear effects.

o Atlases describing spatial and temporal variations of wave parameters.

o Reports evaluating accuracies and capabilities of models, measurement systems, measured data, and statistical products.

o Reports of scientific and engineering research and development performed under CWP auspices.

o Reports providing guidance and instructions for use of wave data and information products.

Figures 5a through 5c show examples of products. Figure 5a shows the reconstruction of a typical 17-minute record of the waves. Figure 5b is a plot of a variance spectrum of the waves with 90 percent confidence intervals during ARSLOE. Figure 5c shows the distribution and cumulative distribution of significant wave height measured at Ocean City, Maryland.

Dissemination of these products will be as follows:

o Bulletins of real-time wave data provided through the NOAA National Weather Service within 1 hour after completion of the measurement.

o Processed and unprocessed field data archived and made available through the NOAA Environmental Data and Information Service within 6 months after the time of the observation.

o Descriptions and warnings of important local wave problems disseminated through both program reports and the "Coast Pilot" which is published by the NOAA/National Ocean Survey.

o All other data and information such as statistics and reports made available through the Office of Oceanography of the NOAA/ National Ocean Survey.

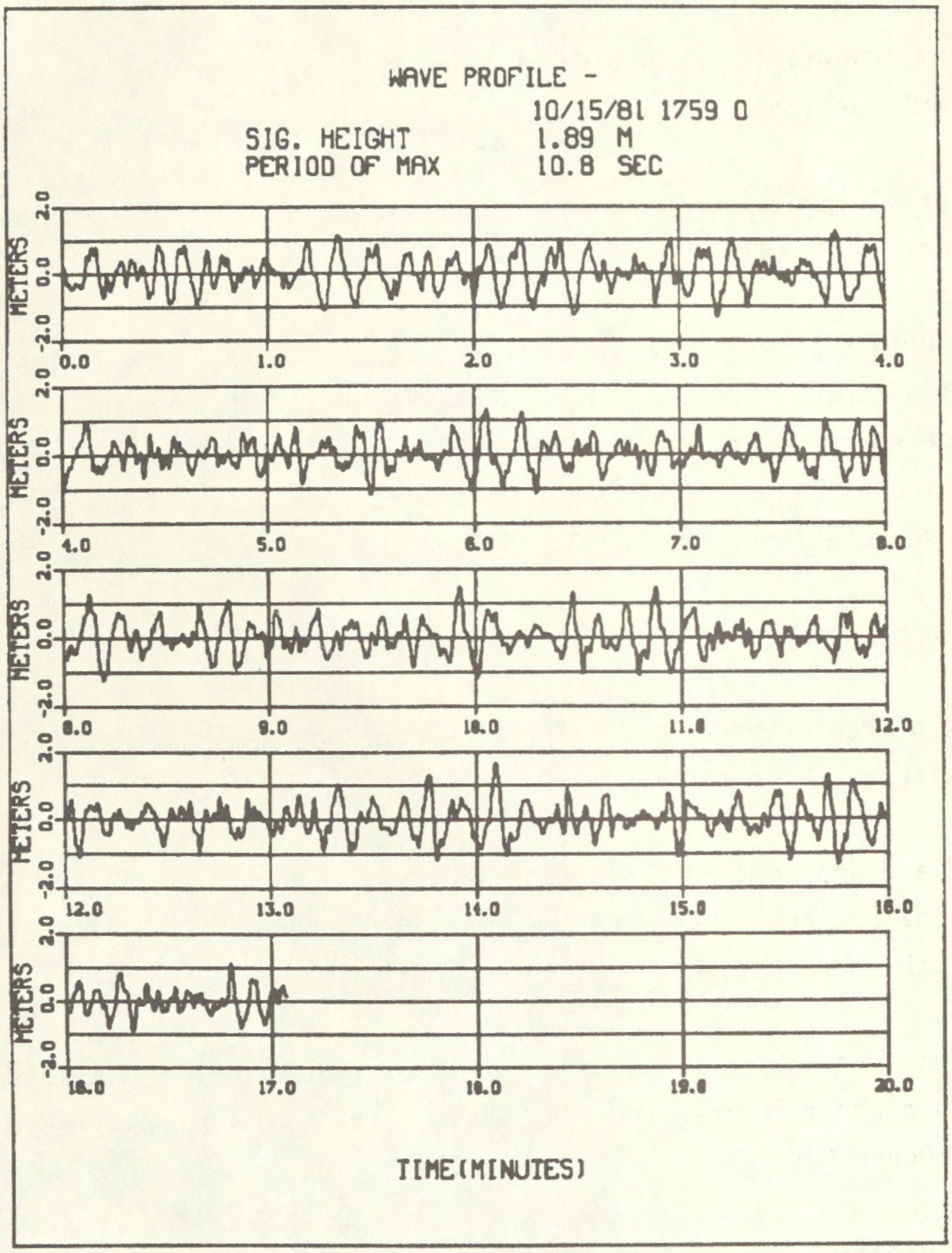

Figure 5a. Example of Data Product: Time History of Sea Level Surface Elevations Measured off Ocean City, Maryland, 1759 GCT, October 15, 1981.

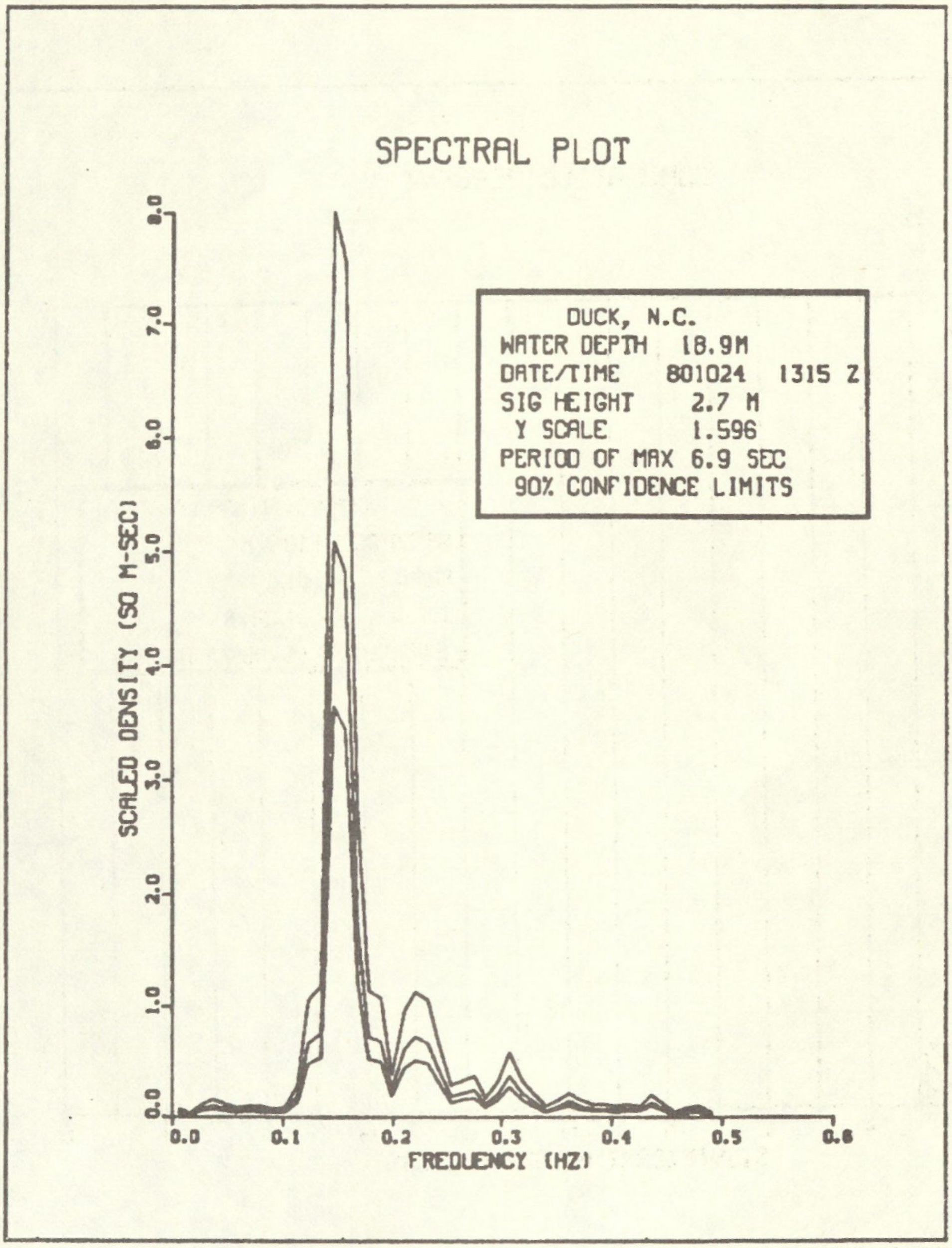

Figure 5b. Example of Data Product: Variance Spectrum with 5 Percent and 95 Percent Confidence Bands of Waves Measured off Duck, North Carolina, 1315 GCT, October 24, 1980. Ordinate is relative, conversion to M^2 - sec is achieved by multiplying by 1.596.

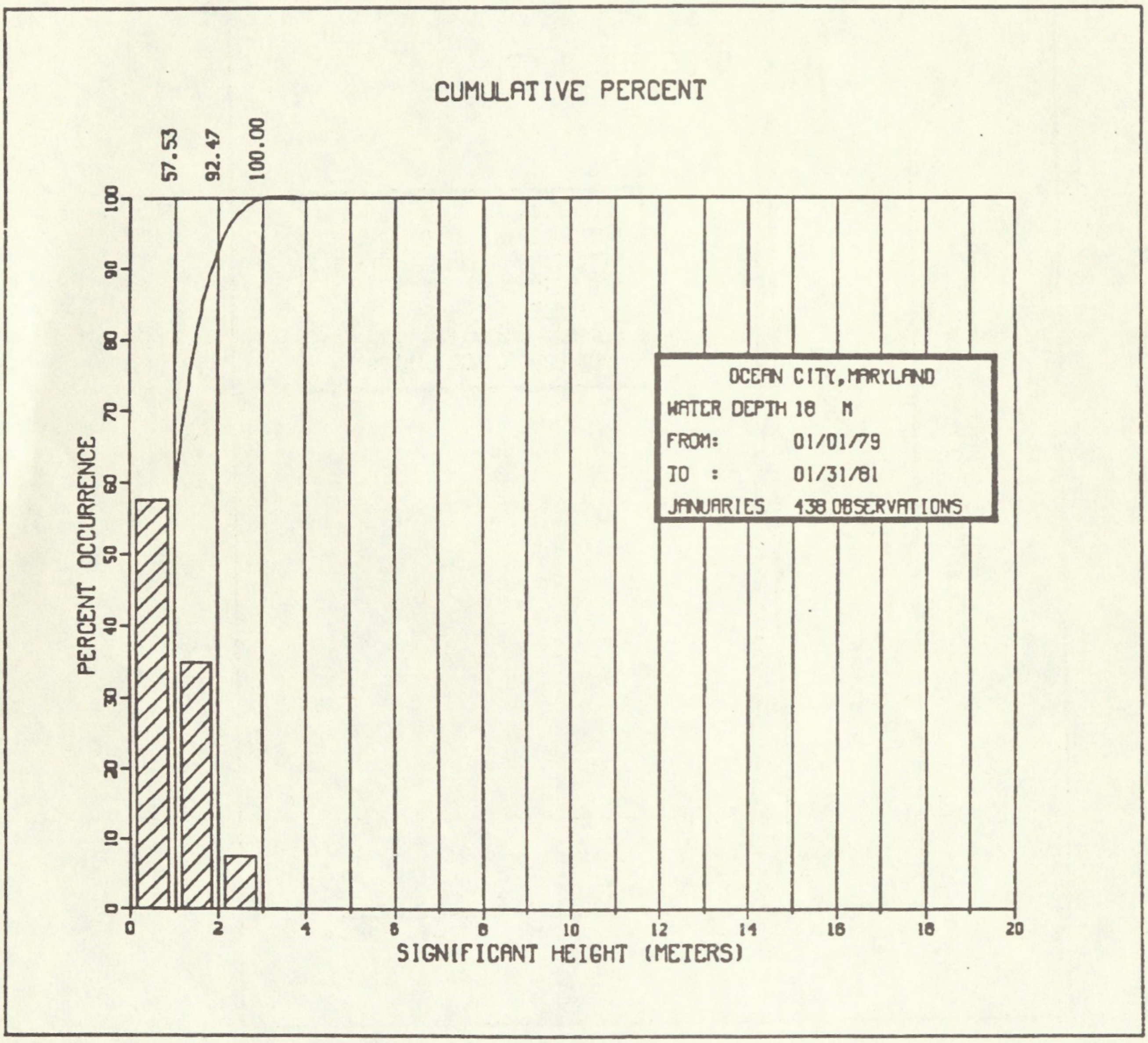

Figure 5c. Example of Data Product: Histogram and Cumulative Distribution Of Significant Wave Height Occurring in January off Ocean City, Maryland (Based on Measurements from 1979 through 1981).

For further information about the program or products contact the Program Manager:

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