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Waves for Coastal Design in the United States

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ABSTRACT

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Information on waves is critical to the designers of coastal projects. Unfortunately, data are usually sparse. This dichotomy was recognized and addressed in the U.S. Army Corps of Engineers (CE) when the Coastal Field Data Collection Program (CFDCP) was created in 1977. This national data collection program is intended to provide the information designers require through two efforts, the Field Wave Gaging Program (FWGP) and Wave Information Studies (WIS). These efforts, through wave measurement and hindcasting, respectively, aid the designer through increasing the available data base. Because of the nature of hindcasting, the WIS data base has been developed much more quickly than that of the FWGP. In addition to the FWGP and WIS, the CFDCP funds efforts to acquire oceanographic and meteorological data during episodic events, such as northeasters and tsunamis; measure damage to coastal structures and projects and the alteration of coastal areas; conduct Littoral Environmental Observations (LEO) in areas of interest; and develop a data base management system for the archiving of coastal data that have been and continue to be collected. The CFDCP, therefore, provides the mechanism through which valuable coastal data are collected, analyzed, distributed, and archived.

ADDITIONAL KEY WORDS: *Wave data, wave gaging, hindcasting.*

FIELD WAVE GAGING PROGRAM

Introduction

While the timely collection and reporting of climatological and environmental data have become routine in many countries, a similar capacity for waves, currents, and coastal winds has not. The need for long-term, high quality wave data, in particular, has long frustrated the coastal engineer. In 1974, both Prof. Robert Wiegel and Dean Morrough P. O'Brien of the University of California at Berkeley commented publicly on the need for information on the nearshore wave climate comparable to data routinely available on many other natural phenomena. O'Brien further expressed his concern for improving the accuracy of wave forecasting and hindcasting techniques through comparison with reliable measurements (EDMISTON, 1978).

The need for characterizing the nearshore wave climate is much like the experience of conventional meteorological measurement programs. Along coastlines with high population densities, usage of the resource is intense. Ignorance of the processes at work carries a significant penalty. Past programs either have emphasized the collection of deepwater wave climatology or have been too regional or even site specific. With the Field Wave Caging Program (FWGP), the CE intends to collect the long-term, nearshore wave data that are necessary for planning, design, construction, operation, and maintenance of coastal projects, as well as for the verifications of numerical hindcast and forecast models.

History and Objectives

In 1974, the American Society of Civil Engineers (ASCE) sponsored a Conference on Ocean Wave Measurement and Analysis. As a direct result of that conference, Scripps Institution of Oceanography installed a regional wave monitoring network for the state of California in 1975. The network began modestly, with only four stations operating by mid-1976, supported by the California Department of Boating and Waterways (Cal Boating) and the National Oceanographic and Atmospheric Administra-

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tion (NOAA) Sea Grant Program. In 1978, the Corps of Engineers' South Pacific Division (SPD) became involved and provided funding to begin the expansion of this network throughout California. The Coastal Data Information Program (CDIP) became a cooperative effort between the CE and Cal Boating, with Scripps acting as a contractor for data collection, analysis, and reporting (SEYMOUR, 1979).

In 1977, the CE established a nationwide Coastal Field Data Collection Program (CFDCP), one element of which was the FWGP. The goals of the FWGP are to collect nearshore and relatively deepwater wave data to satisfy the immediate needs of the coastal planner, designer, and project operator; to support the Corps' efforts to develop wave hindcast/forecast models; and to provide a long-term data record for all of the nation's coastlines.

The existence of the CDIP was beneficial to starting the FWGP in two ways: (1) by having begun development on an automated data collection, analysis, and reporting system, and (2) by establishing a network of CDIP gages from which the national wave gaging system could expand.

Gage Network

The FWGP is expanding from its beginning on the west coast and will acquire wave data along each of the nation's coasts. Primary data for the program will be collected at a number of deepwater, or index sites (Figures 1–5). These stations will be operated continuously to satisfy the goals of the program. They are located in water sufficiently deep to minimize bathymetric effects on the measured waves, often as deep as 200 m (650 ft). An additional and unfortunately critical consideration in siting the index gages is to find locations not in commercially fished areas. Commercial fishermen using bottom-dragging equipment can break a deepwater mooring with their nets. This is an all-too-frequent occurrence in commercial fishing grounds even though instruments are reported in the U.S. Coast Guard "Notice to Mariners."

Augmenting the index stations are nearshore gages located in areas generally representative of long stretches of coastline. These nearshore gages are, on occasion, single pressure gages or, more often, slope arrays. Data are to be collected from these stations for five years to provide nearshore wave information necessary to coastal projects and to assist in verification of wave propagation models. Site selection for slope arrays requires reasonably straight, parallel offshore contours and, like the index stations, consideration of commercial fishing activity.

Until recently, Datawell Waverider buoys have been used in all of the index station installations, since the depth at these installations precludes the use of bottom-mounted sensors. The Waverider buoy is a proven instrument which uses a vertically stabilized accelerometer to sense the vertical component of the buoy's motion. Heave data from the buoys are transmitted by radio link up to 50 km (31 miles) to shore.

A recent decision not to require time series wave data at all stations immediately expanded the gage network dramatically. Now satellite-reporting buoys operated by the National Data Buoy Center (NDBC) of the National Oceanic and Atmospheric Administration (NOAA) can be included in the system where appropriate. Figures 1–5 show the NDBC buoys considered to be index stations. In the Atlantic Ocean and Gulf of Mexico, the use of NDBC buoys helps avoid the radio transmission distance restrictions associated with Waverider buoys.

Nearshore wave measurements, in depths of up to 15 m (50 ft), are made using a bottom-mounted, semiconductor, strain gage pressure transducer. The transducer and its circuitry are housed in a plastic pressure case mated to an underwater cable by a plastic underwater connector. The cable is used both to supply power to the sensor and to carry the signal ashore. Sufficient cable is stored in a service loop to allow the sensor housing to be brought to the surface for servicing, thereby increasing the system's reliability (SEYMOUR *et al.*, in press).

A slope array of four pressure sensors was developed by Scripps under CDIP to infer sediment transport from a measure of radiation stress. Data analysis procedures have been modified to provide wave direction for the FWGP. This array is 6 m (20 ft) square and uses a specially designed armored underwater cable for data and power transmission. The cable has effective abrasion resistance, waterblocking integrity, tensile strength, and resistance to cutting which greatly enhance the system's

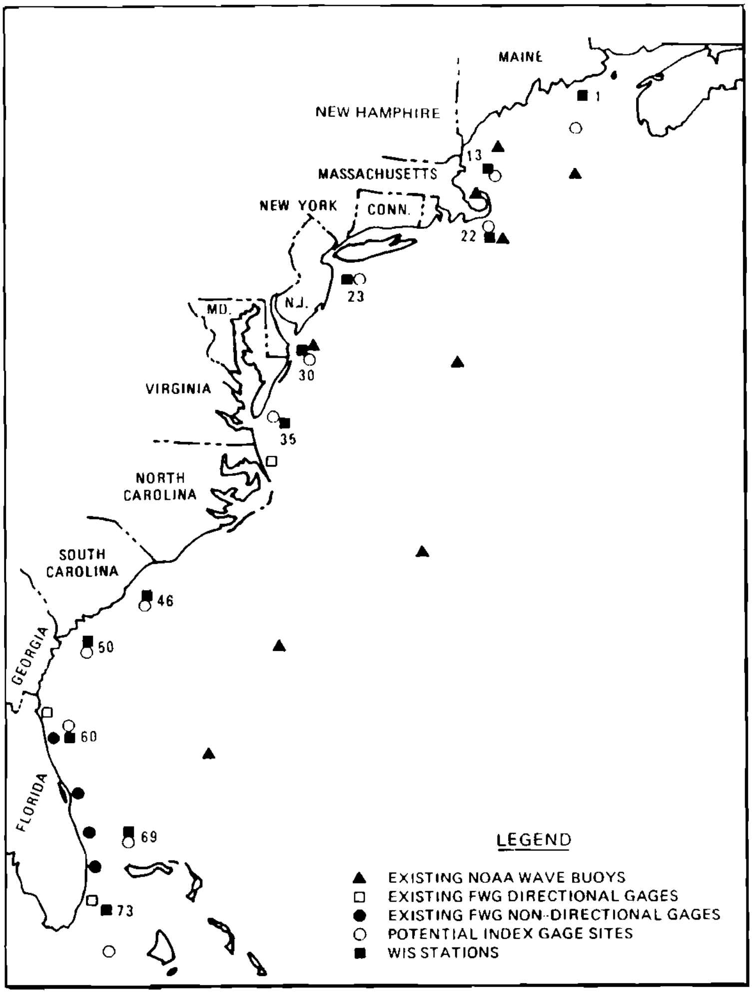

Figure 1. Actual NDBC, FWGP, FCDN, and proposed index sites (approximate), Atlantic coast.

reliability. Details of the array are described by SEYMOUR and HIGGINS (1978), and results of laboratory and field tests and discussed by HIGGINS *et al.* 1981).

Installation of a Waverider buoy or a single pressure sensor gage is fairly straightforward, requiring only a small craft. The standard Datawell mooring has been employed successfully with few modifications. A tripod or jetted pipe is most often used for the single pressure sensor installation. Some innovation is needed when installing a slope array because of its size. When available, an amphibious vehicle can be effectively used to deploy the array and lay the cable from offshore across the surf zone and beach to the shore station. On several occasions when an amphibious vehicle was unavailable, an array was carried as a sling load beneath a U.S. Army Reserve Chinook helicopter. The cable spool was carried inside its cargo area.

Nearshore gages installed in support of specific projects supplement data collection under the FWGP. On the Pacific coast, project-supported gages are operated through the CDIP network and data reported by Scripps in the program's reports. The program, therefore, provides an existing system through which project-specific data can be collected, analyzed, and

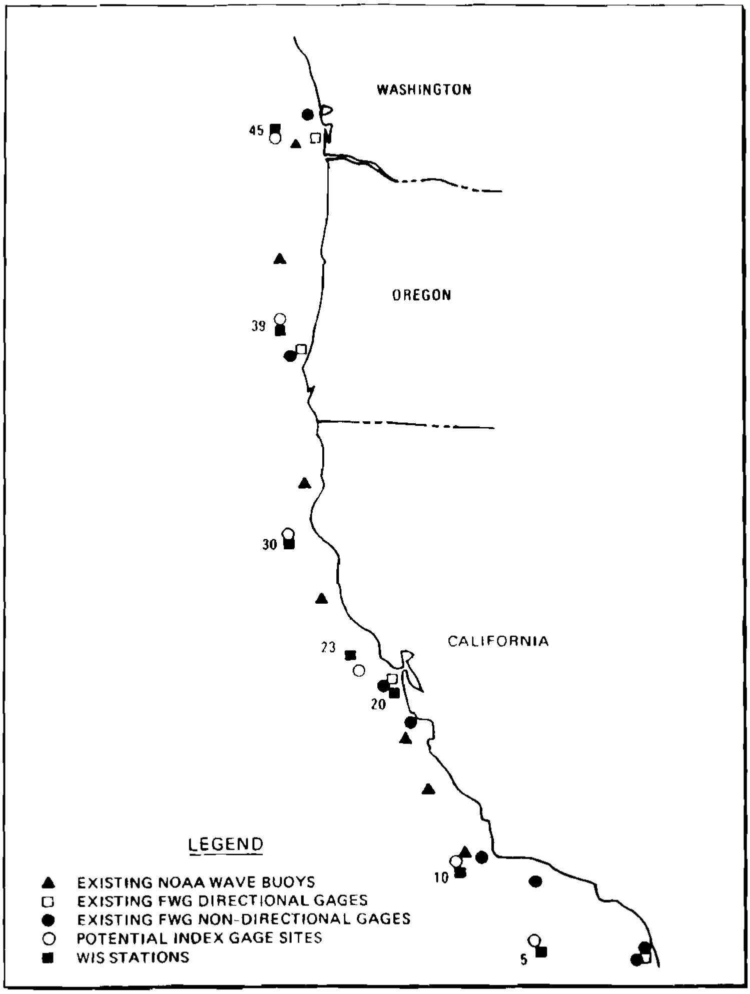

Figure 2. Actual NDBC, FWGP, and proposed index sites (approximate), Pacific coast.

reported, taking advantage of CDIP computers at Scripps. The CDIP system provides the considerable capability and flexibility needed for coastal data collection and can accommodate any continuously reporting instrument. Tide, surge, current, wind, and wave data are being or have been collected on the system.

Related Data Collection Programs

Alaska's coastal data needs are unique. The state has approximately 54,500 km (33,900 miles) of coastline with a climate varying from temperate to arctic. With communities heavily dependent on the sea scattered along the entire coast, the state needed a planned approach to its coastal data collection efforts. In 1982, a cooperative agreement was signed between the state of Alaska and the Corps of Engineers to collect coastal wind and wave data under the Alaska Coastal Data Collection Program (ACDCP). The goals stated in that agreement were, briefly, to collect, analyze, report, and archive coastal data collected by either party; to develop a plan for the collection of coastal data; and to develop instruments, telemetry

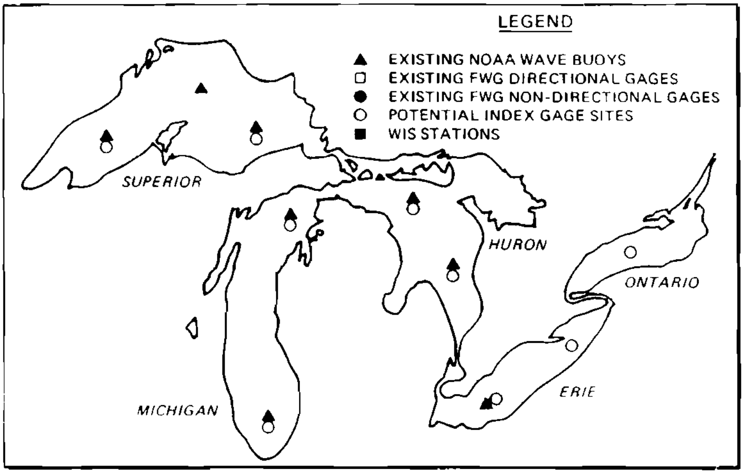

Figure 3. Actual NDBC, FWGP, and proposed index sites (approximate), Great Lakes coasts.

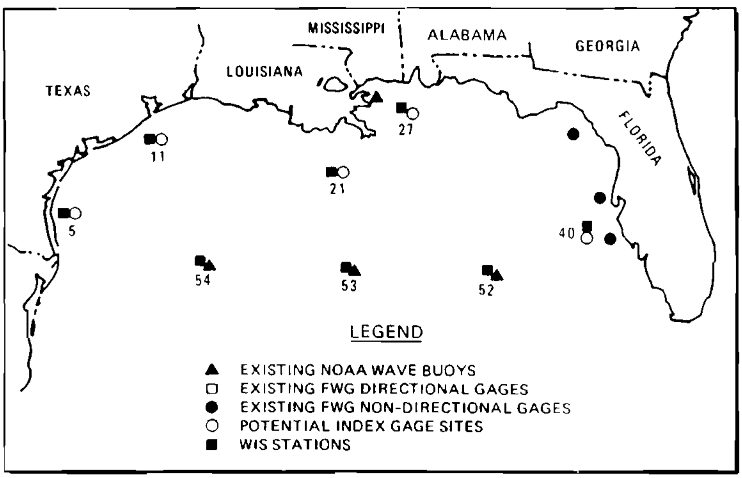

Figure 4. Actual NDBC, FWGP, FCDN, and proposed sites (approximate), Gulf of Mexico coast.

systems, and analysis procedures suited to the needs and environment of Alaska (BALES, 1984).

Conduct of the program in Alaska has been reduced somewhat from the original scope, but data collection, archival and distribution are still being supported. The Alaska District, Corps of Engineers, publishes periodic data reports. The data reports provide average wind speed and direction, maximum wind speed, and standard deviation of the wind speed and direction for each data collection. Both wind and wave data are reported every three hours. Wave data reported include the significant wave height, total energy in the spectrum, and the percent of the energy in frequency bands of 0.02148 Hertz (Hz) width.

Another cooperative effort that receives support from the FWGP involves a contract with the University of Florida to collect, analyze, and report wave data along the Florida coast. The gaging effort, called the Florida Coastal

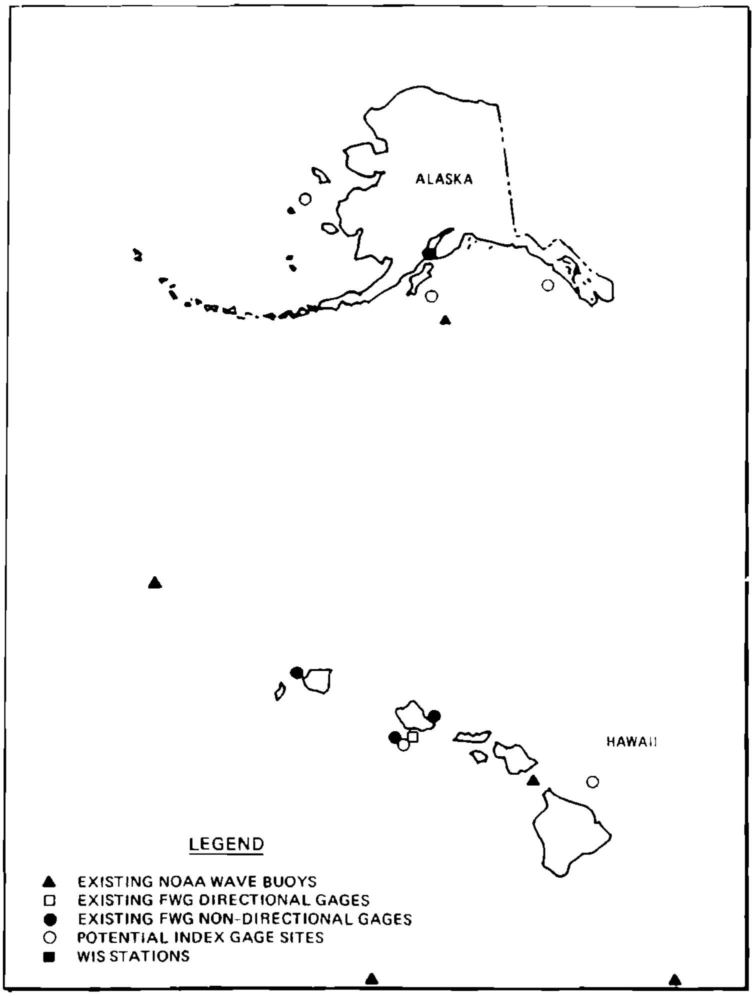

Figure 5. Actual NDBC, FWGP, ACDCP, and proposed index sites (approximate), Alaska and Hawaii coasts.

Data Network (FCDN), funded by the Corps of Engineers through the FWGP and by the state of Florida. Eight sites in Florida are operated by the University using bottom-mounted single pressure transducers. The system is presently being upgraded to provide directional wave data.

Data reports are produced monthly by the University of Florida for each of the sites operated under the contract. Both tables and plots are used to report the wave data, which are collected every 6 hours. Plots of maximum period and significant waveheight versus time are included in the reports. The tables provide significant wave height, total energy in the spectrum, and the percent energy in various period bands from 4 to 22+ seconds for each data collection (HOWELL, 1980).

Data Collection, Analysis, and Reporting

The data collection system developed by Scripps and used by the CDIP is based on burst rather than continuous sampling. While sampling frequency is field selectable, depending on the data to be collected, it is typically set at 1 Hz for ocean waves measured for the CDIP. The sample size is 1024 points, yielding 17 minutes of data. Normally each instrument is interrogated once every 6 hours, although certain critical stations are called every 3 hours and the data transmitted to the National Weather Service.

A block diagram of the collection and analysis system is shown in Figure 6. Signals from as many as eight input channels are received by a weatherproof shore station near the sensors. This station, which contains the data conversion and storage capability, control and power systems, and telephone interfaces, is modular. All electronics are on plug-in cards to facilitate the replacement of faulty components and minimize a station's down-time. Current incoming data are maintained in a digital buffer memory which deletes the oldest words on a first-in first-out basis, ensuring that the most recent data set is in the buffer.

A control computer (an IBM located at Scripps) initiates a telephone call to the shore station using an autodialer and normal telephone lines. The shore station, when called, locks the most current words in memory and transmits the data in a special 1200 baud synchronous format to a digital data receiver at Scripps. Once all the data are transmitted, typically in slightly over one minute for four data channels, the shore station disconnects itself from the telephone line. Header information is then added, and the record is written on magnetic tape. During data transmission from the shore station, signal quality tape checks are performed. Failure of a quality check results in a second call causing the immediate retransmission of the original data from the shore station. This protocol is important in the correction of transmission errors (SEYMOUR *et al.*, in press).

After the quality check, the raw data are put onto disks in a large mini-computer (a Prime which serves as the central processing computer) for quasi-real-time analysis. The Prime and the PC are connected with a bi-directional serial link, allowing data and command flow in both directions. The PC can be remotely accessed through the Prime to make functions such as test calls, status checks, and raw statistics available from remote terminals.

Data analysis is composed of three phases. The first phase involves receipt of the raw data from the PC and extensive data verification and editing in preparation for the second phase. An analysis phase performs the fast Fourier transform operations of the edited time series. The final phase operates on the analyzed data to produce the end products, monthly and annual reports.

In the first phase, an editing routine provides an automated data assurance scheme operating on the massive daily influx of data after their acceptance by the central computer. The editor is programmed to objectively recognize certain anomalies, to correct the more obvious ones, and to reject the others as bad data. It also compiles daily summaries and monthly statistics on the frequency and type of errors. The types of errors are spikes (the most frequent cause of data rejection), flat spots, mean shift exceedence, absence of zero crossings, and maximum

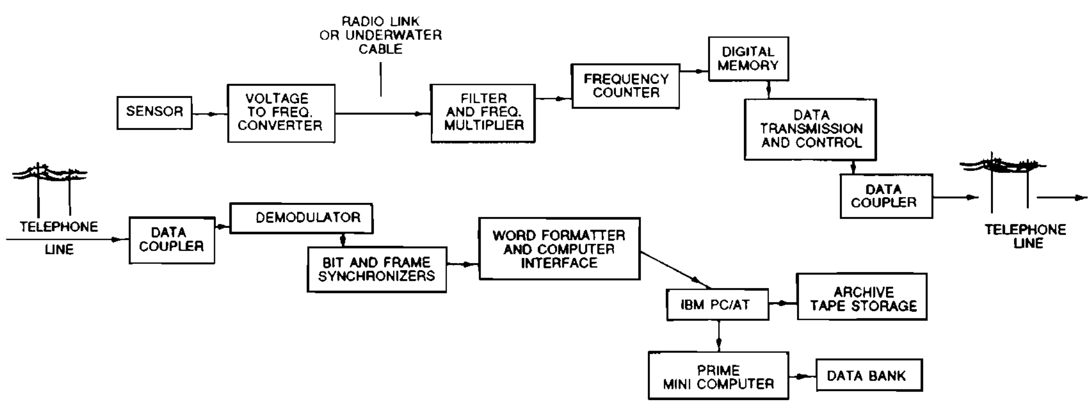

Figure 6. CDIP data collection and analysis system.

and minimum wave height exceedence. Additionally, the editor filters the time series to remove tidal components and intercompares hem2the individual sensor variances to evaluate acceptability of data for determining wave direction from the arrays.

Edited data for both gravity and infragravity waves are then Fourier transformed and the energy spectra calculated. Spectral values are grouped into period bins and summed to yield the variance. From the variance, the significant wave height is determined and the period band containing the maximum energy in the spectrum is identified. The data analysis routine also determines the percent of energy in each of nine period bands ranging from 4 to 22+ seconds

HIGGINS *et al.*, (1981) describes the analytical method for extracting wave directionality from the sea surface slope components measured by the array. The method developed by LONGUET-HIGGINS *et al.* (1963) for use with a pitch-and-roll buoy is adapted for use with the array. An estimate of the longshore component of radiation stress, S_{xy}, can be extracted when surface elevation and components of sea surface slope are known at a point. The components of the slope are determined from differences between a pair of sensors. While only three sensors are required for this analysis, four are used for redundancy.

> "Routine analyses of wave direction involve calculation of spectrum of the long shore component of shoreward-directed radiation stress, which, with the energy spectrum, allows the estimation of an apparent arrival direction for each band of periods. Summing the radiation stress components over all frequencies yields total S_{xy}. From this, and the total energy, a significant angle of arrival for all the wave energy can be estimated." (SEYMOUR *et al.*, in press).

In addition to the products previously discussed, the distribution of S_{sy} in the period bands is reported.

The significant data collected under the FWGP are available to users in four forms: direct access via remote terminals; through the Coastal Engineering Information Management System; data archives at the University of Florida, Alaska District, Scripps and the U.S. Army Engineer Waterways Experiment Station (WES); and monthly and annual reports. CDIP data processed since the program's inception are directly available to any authorized user with a computer terminal capable of remote telephone access of the Prime at Scripps. A user-friendly program has been developed to obtain tabular and plotted data, including data for single or multiple stations on a single day, a single station on multiple days or overplotted spectra to allow visualization of a storm's passage. Edited raw data are archived on tape at the University of Florida, Alaska District, Scripps, and WES and can be made available to users under certain conditions.

Monthly and annual reports produced by Scripps, monthly reports from the University of Florida, and periodic reports from Alaska District provide the widest dissemination of wave data collected within the FWGP. After the first month of operation of the original CDIP program in 1975, a report was issued showing spectra and other wave parameters for Imperial Beach, California. Every month since, analyzed data have been provided through these reports to a large group of public and private users. These data are summarized in an annual report which includes descriptive statistics on wave height and period as well as longshore sediment transport.

Table 1 lists the sites, both program and project supported, where data have been collected. The location of the instrument (to include depth), its type, length of deployment, and percent data collected are also given.

Future Effort

A nationwide network of index sites, including the Great Lakes, is the goal of the FWGP, and that goal will be pursued during the next few years. Growth of the program will be gradual, but the importance of obtaining long-term wave data should ensure that expansion.

Data Available

Considerable data of interest to coastal engineers and scientists are available. To obtain any of these data, contact Mr. David D. McGehee at the Coastal Engineering Research Center.

Table 1. *Station directory.*

Station Name	Type	N. Lat.	W. Long.	Location (m)	Date	Depth Percent
Barking Sands, HI	Buoy	22 10.0′	159 47.0′	109.0	10/87-Pres	84
Makapuu Point, HI	Buoy	21 17.5′	157 34.0′	168.0	06/81-Pres	87
Imperial Beach, CA	Array	32 35.0′	117 8.2′	10.2	07/83-Pres	88
Ocean Beach Pier, CA	S.P.	34 44.9′	117 15.6′	6.7	03/76-10/79	90
Mission Bay, CA	Buoy	32 44.8′	117 22.3′	192.0	02/81-Pres	76
Mission Bay Entrance, CA	Array	32 45.4′	117 15.7′	10.0	08/78-Pres	68
Scripps Pier, CA	S.P.	32 52.0′	117 15.4′	8.0	06/76-Pres	90
Del Mar, CA	Array	32 57.4′	117 16.7′	10.7	07/83-03/88	100
Oceanside Beach, CA	Array	33 11.4′	117 23.4′	9.1	12/78-Pres	77
San Clemente, CA	Array	33 24.9′	117 37.8′	10.2	07/83-03/88	100
Begg Rock, CA	Buoy	33 24.4′	119 40.1′	110.0	10/82-Pres	100
Sunset Beach, CA1	Array	33 42.5′	118 04.2′	8.2	11/80-Pres	71
San Pedro Channel, CA	Buoy	33 35.0′	118 14.9′	117.0	02/81-03/82	100
Santa Monica Bay, CA	Buoy	33 53.0′	118 38.0′	185.0	03/81-06/81	100
Santa Cruz Island, CA	Buoy	33 58.3′	119 38.5′	54.8	09/83-11/85	100
San Cruz Canyon, CA	Buoy	33 55.0′	119 44.0′	366.0	01/86-Pres	90
Point Mugu, CA	Buoy	34 05.4′	119 06.8′	18.0	10/82-07/83	89
Channels Islands, CA	S.P.	34 10.0′	119 14.2′	6.0	12/76-10/83	100
Santa Barbara, CA	Array	34 24.1′	119 41.5′	9.0	09/79-01/83	100
Santa Barbara Point, CA	Array	34 24.1′	119 41.6′	9.0	09/79-01/83	100
Pt. Conception, CA	Buoy	34 25.3′	120 25.2′	201.2	06/78-12/79	61
Pt. Conception, CA	Array	34 26.8′	120 25.7′	16.8	02/78-06/79	75
Point Arguello, CA	Buoy	34 40.0′	120 50.8′	219.0	06/78-09/86	63
Diablo Canyon, CA	Buoy	35 12.5′	120 51.7′	22.9	06/83-12/87	100
Capitola, CA	S.P.	36 57.9′	121 56.9′	6.1	12/77-10/79	44
Seacliff, CA	S.P.	36 57.1′	121 55.1′	8.2	08/78-06/71	27
Santa Cruz Harbor, CA	Array	36 57.8′	122 00.7′	7.0	08/77-12/82	81
Santa Cruz Harboro, CA			Surge		(see Santa Cruz Harbor array)	
Santa Cruz Pier, CA	S.P.	36 57.4′	122 01.0′	7.0	01/78-07/81	100
Santa Cruz, CA	Buoy	36 53.4′	122 04.3′	70.0	05/78-08/81	97
North Monterey Bay, CA	Buoy	36 55.0′	122 19.5′	320.0	10/79-Pres	77
Pacifica, CA	Array	37 38.0′	122 30.0′	10.0	08/80-01/83	100
Farallon Island, CA	Buoy	37 34.0′	122 53.0′	91.4	01/82-Pres	96
Stinson Beach, CA	Array	37 53.8′	122 38.9′	10.0	05/80-07/82	100
Pt. Reyes, CA	Buoy	37 56.3′	123 03.8′	73.2	04/81-05/83	96

WAVE INFORMATION STUDIES FOR U.S. COASTLINES

Introduction

The U.S. Army Engineer Waterways Experiment Station's (WES) Coastal Engineering Research Center's (CERC) Wave Information Study (WIS) has the task of estimating the wave climate for U.S. coastal waters through numerical hindcasts. WIS has been designed to provide a data base of the most commonly used wave characteristics, such as significant wave height, peak wave period, mean wave direction, and wave spectra, both directional and nondirectional. The wave climate hindcasts were accomplished in three phases for the Atlantic and Pacific oceans (Figure 7) and a single-phased hindcast was performed for the Gulf of Mexico. The hindcasts for each of the Great Lakes also will be done in a single phase. All three phases for the Atlantic and Pacific coasts of the United States and the one phase for the Gulf of Mexico have been completed for the 20-yr period 1956 through 1975. The Great Lakes hindcasts, beginning with Lake Michigan, have been initiated. The purpose of this section is to present an overview of the extensive information generated by WIS and discuss methods used to provide the wave data to potential users. A brief review of the WIS hindcasting procedure also is presented. Tropical storms were excluded from the studies mentioned above and were hindcast separately for the

Table 1. *Continued.*

Station Name	Type	N. Lat.	W. Long.	Location (m)	Date	Depth Percent
Noyo, Ft. Bragg, CA	Buoy	39 26.3′	123 53.3′	94.0	05/81-06/82	69
Humboldt Bay (Inner), CA	Buoy	40 52.5′	124 13.3′	50.0	03/80-09/82	60
Humboldt Bay (Outer), CA	Buoy	40 56.9′	124 24.8′	180.0	03/80-05/81	36
Crescent City, CA	Array	41 44.2′	124 10.7′	7.6	09/75-01/83	100
Barbers Point, HI	Array	21 19.5′	158 07.5′	9.1	06/86-Pres	90
Barbers Point, HI	Buoy	21 20.1′	158 09.0′	183.0	06/86-Pres	100
Harvast Plafform, CA	S.P.	34 28.2′	120 40.9′	204.0	01/87-Pres	100
Marina CA	Array	36 42.0′	121 48.9′	15.0	12/87-Pres	86
Santa Cruz, CA	Array	36 57.0′	122 0.2′	13.1	12/87-Pres	100
Montara, CA	Array	37 32.8′	122 31.1′	15.5	12/87-Pres	100
Coquille River, OR	Buoy	43 06.7′	124 31.5′	70.0	11/81-Pres	61
Coquille River, OR	Array	43 07.4′	124 26.4′	16.0	08/83-Pres	100
Umpqua River, OR	Buoy	43 40.6′	124 14.3′	42.0	05/84-06/85	100
Ocean Park, WA	Array	46 23.5′	124 04.7′	11.3	09/83-Pres	100
Grays Harbor, WA	Buoy	46 48.7′	124 35.4′	119.0	11/81-Pres	59
Silver Bay, MN	S.P.	47 20.0′	91 15.0′	7.9	09/80-01/82	88
Silver Bay, MN	S.P.	47 20.0′	91 15.0′	8.8	09/80-01/82	88
Rudee Inlet, VA	Array	36 49.3′	75 57.8′	6.4	06/81-07/83	48
CERC Duck, NC	Array	36 11.3′	75 44.7′	6.4	09/80-Pres	93
Jacksonville, FL	S.P.	30 18.0′	81 22.92′	9.5	1985-Pres	88
Marineland, FL	S.P.	29 40.05	81 12.28′	10.0	1977-Pres	86
Cape Canaveral, FL	S.P.	28 24.70	80 34.60′	8.0	1978-Pres	89
Vero Beach, FL	S.P.	27 40.50′	80 21.25′	7.5	1979-Pres	90
West Palm Beach, FL	S.P.	26 42.12′	80 01.70′	9.0	1980-Pres	88
Miami Beach, FL	S.P.	25 46.10′	80 07.38′	6.5	1978-Pres	85
Clearwater, FL	S.P.	27 58.73′	82 51.00′	5.0	1979-Pres	90
Venice, FL	S.P.	27 04.43′	82 27.38′	7.2	1986-Pres	91
Steinhatchee, FL	S.P.	29 42.00′	83 46.05′	9.2	1986-1987	88
Kodiak, AK	Buoy	57 20.00′	152.10.00′	unk	10/81-10/84	89
Homer, AK	Buoy	59 30.00′	151.50.00′	unk	06/85-Pres	50

Atlantic and Pacific Coast and Gulf of Mexico for the same 20-yr time period. The Atlantic Coast and Gulf of Mexico hurricane hindcasts have been completed and the Pacific Coast hindcasts are currently in production.

WIS Methods

Several WIS reports have been published which discuss in detail how WIS performs and verifies its hindcasts (BROOKS and CORSON, 1984; CORSON and RESIO, 1981; CORSON *et al.*, 1980; JENSEN *et al.*, draft; MCANNEY, 1986; RESIO, 1982; RESIO and TRACY, 1983; RESIO *et al.*, 1982; TRACY, 1982). The WIS deepwater wave model is a discrete spectral model, which requires a time series of wind speeds and directions as input. In the Phase I hindcast, the land-sea boundaries of the wave generation area were determined and a grid which effectively covered this area was defined. Each cell of both the Atlantic and Pacific Phase I oceanic grids is approximately 120 nautical miles (220 km) square (Figures 8 and 9). For the Gulf of Mexico Phase I (the only phase) hindcast, each grid cell is approximately 30 nautical miles (55 km) square (Figure 10). Surface atmospheric pressure fields were reconstructed in the Atlantic, Pacific, and Gulf of Mexico using two sources of sea-level pressure data (CORSON *et al.*, 1980). The fundamental gridded pressure information was supplied by Meteorological International, Inc. (MII) (HOLL and MENDENHALL, 1971), with supplemental data taken from National Weather Service (NWS) synoptic surface charts. Estimates of the quasi-geostrophic wind speeds and directions were calculated at each grid intersection by analyzing the pressure gradients. Through an additional analysis of the vertical variation of the wind in the planetary boundary layer, the quasi-geostrophic winds were reduced to a 19.5

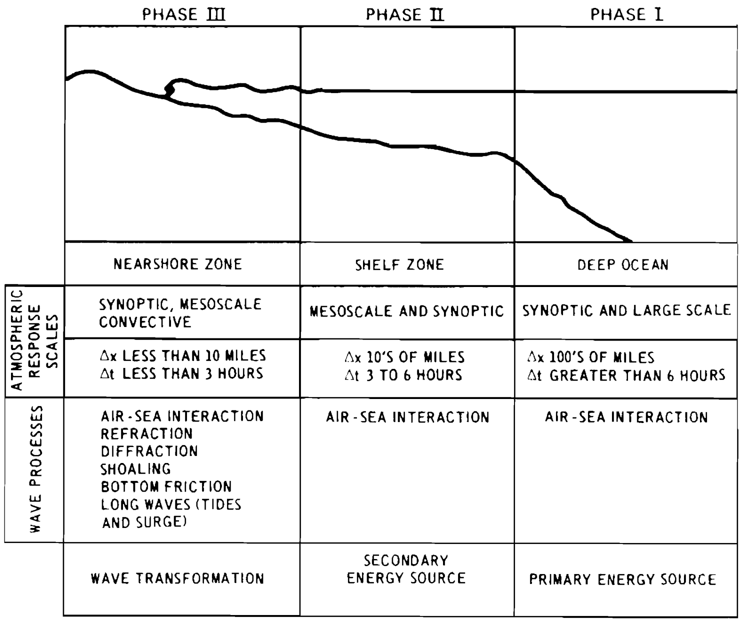

Figure 7. The three phases of WIS.

m level and blended with available ships observations (RESIO *et al.*, 1982). Finally, the 19.5 m surface winds were input into a numerical model which simulated wave generation, propagation and decay on the grid (RESIO, 1982; RESIO and TRACY, 1983).

Input for the Phase II wave calculations were the Phase I wind fields which had been interpolated onto a finer resolution grid, with grid cells approximately 30 nautical miles (55 km) square, to better represent the shoreline geometry effects near the coast (Figure 11). Phase II wind interpolations were blended with available ships observations at this finer scale. The more representative shortline geometry and increased data density provided by Phase II were prerequisites for the fine scale Phase III calculations.

The Phase III wave hindcast assumed straight and parallel bathymetric contours and no additional energy sources and simulated refraction, shoaling, breaking, sheltering, and wave-wave interactions in a transformation of the Phase II wave data into a 10-meter depth at points approximately 10 nautical miles (18 km) apart along the entire U.S. Atlantic coast (Figure 12). As part of Phase III Atlantic, water-level statistics were calculated from available tidal reference stations (Table 2) (EBERSOLE, 1982). For Phase III of the Pacific coast hindcast, the WIS Phase II wave hindcast data were transformed into a 10-meter depth at points approximately 10 nautical miles (18 km) apart along the coast from Cape Flattery, Washington to the Mexican border (Figure 13). As shown, the last WIS Pacific Phase III station is Point Conception, California. A much finer resolution grid is being used to hindcast wave data for the U.S.

Pacific coast south of Point Conception for the southern California Bight (Figure 14). The Gulf of Mexico is a small water body, relative to the Atlantic and Pacific Oceans; therefore, the single-phased hindcast (Phase I) for the Gulf was performed on a Phase II-sized grid (one-half deg latitude by one-half deg longitude) (Figure 10).

WIS Data

There are four major types of gridded meteorological and oceanographic data sets produced during the WIS hindcasts:

(a) Pressure fields for Phase I

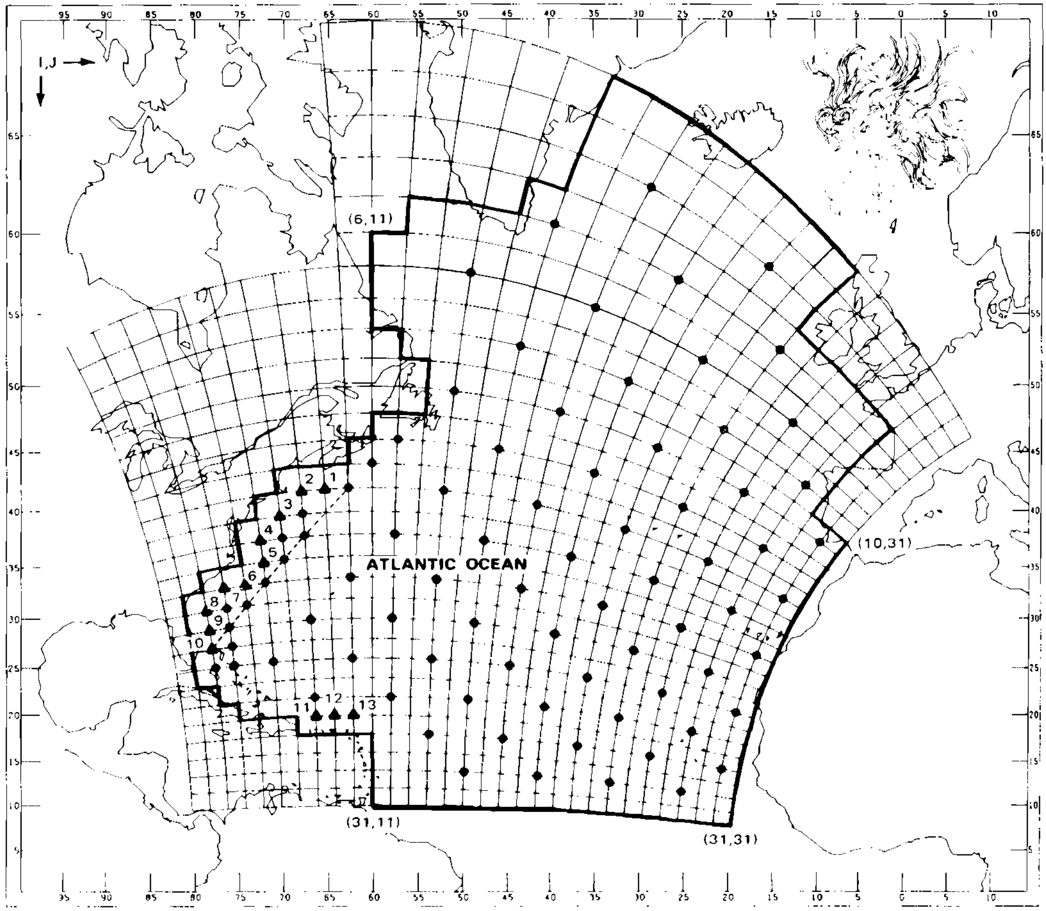

Figure 8. Atlantic Phase I SOG (spherical orthogonal grid).

(b) Wind fields for Phases I and II
(c) Wave data for Phases I, II, and III
(d) Water-level data as part of Phase III

Table 3 presents a summary of the data sets and some of their pertinent characteristics produced from the Atlantic, Pacific, and Gulf of Mexico WIS hindcasts. As noted in Table 3, the basic time interval for all completed WIS hindcasts is 1956 through 1975. The surface pressure fields, wind fields, and wave parameters data sets are described in more detail in the subsequent sections.

Surface Pressure Data

Figure 15 diagrams the procedure for the surface pressure fields development for the WIS Atlantic Phase I hindcast. Basically, this same procedure, with slight modifications, was used to develop the pressure fields for the Pacific and Gulf of Mexico Phase I hindcast. After extensive comparisons, it was determined that the fundamental pressure data from MII did not suffice for a synoptic-scale representation of pressure gradients (CORSON *et al.*, 1980). Therefore, supplemental data from NWS synoptic surface charts were used to augment MII's data in areas with steep pressure gradients. By respecifying these central pressures, where MII's data were usually less intense, input wind fields for the numerical hindcast model could then be adequately computed. Considerable effort was expanded to find the most efficient method to reconstruct accurate pressure fields

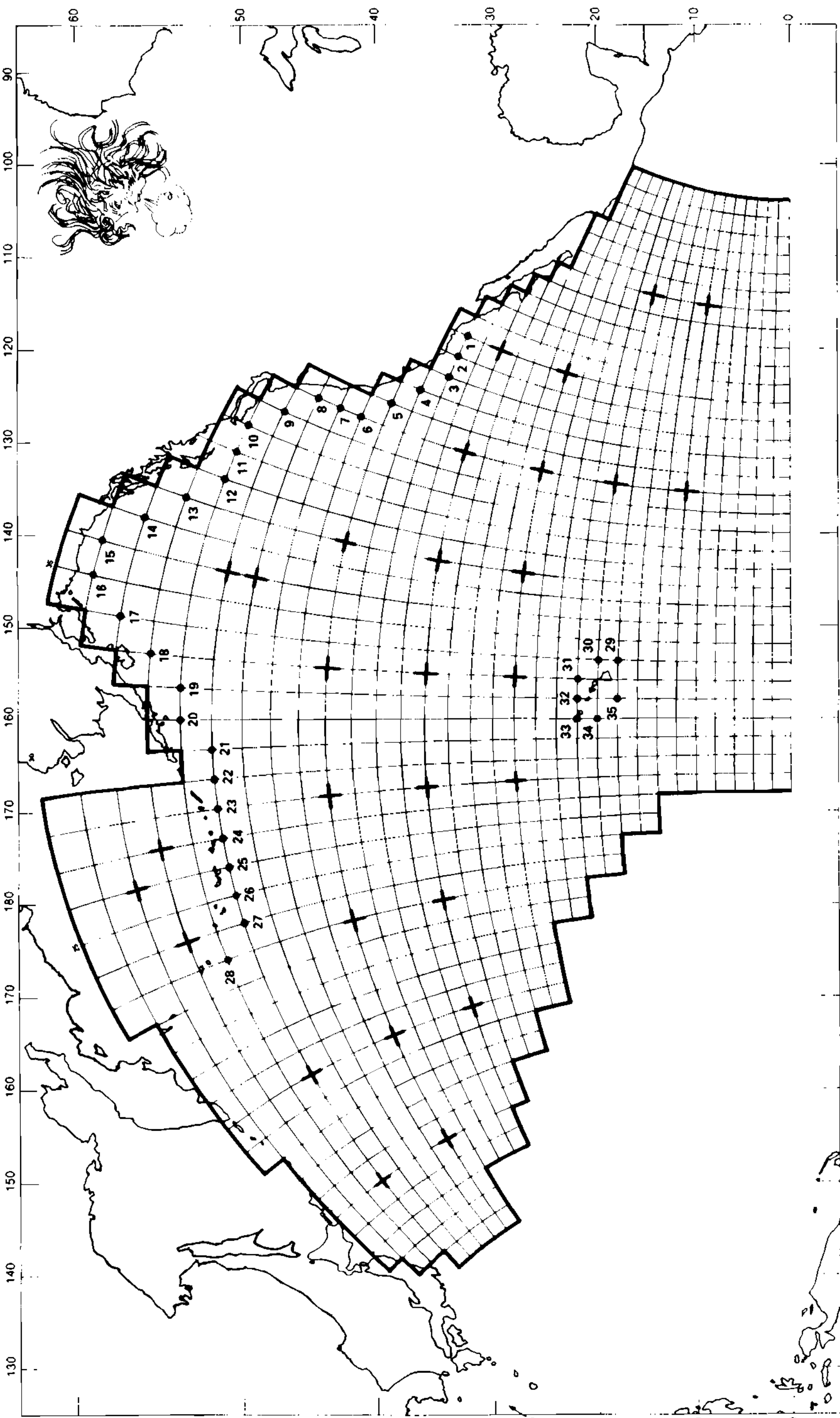

Figure 9. Pacific Phase I SOG.

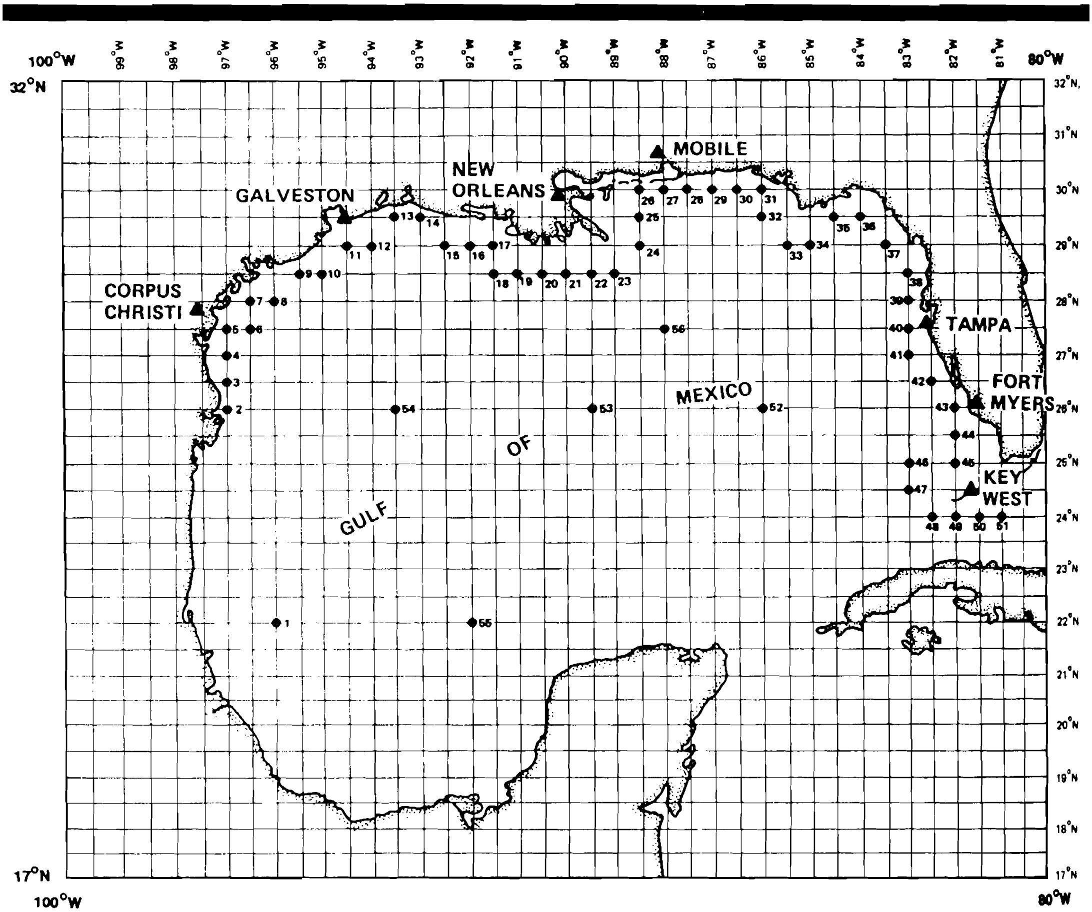

Figure 10. Gulf of Mexico Phase I grid.

for this initial phase of the Atlantic coast hindcast. It was decided that the NWS pressure fields would be digitized, and this digitized information would be overlaid on the MII data, with blending on the edges to achieve continuity between the two fields.

The Atlantic and Pacific surface pressure fields were calculated on grids generated by latitude-longitude values computed in a coordinate system of great circle paths for quasi-east/west lines and orthogonals to the great circle paths for quasi-north/south lines. These spherical orthogonal grids (SOG) were used to facilitate great circle paths for wave propagation toward the coasts of the United States. The generation of a SOG in the Gulf of Mexico was not necessary, since the Gulf's latitude-longitude lines coincide with great circle paths. The surface pressure fields for the WIS Atlantic hindcast were constructed and stored at 6-hr intervals on a 61 × 61 SOG, which is approximately twice as dense as the 31 × 31 grid shown in Figure 8. For the Pacific hindcast, WIS constructed and stored surface pressure fields at 6-hr intervals on a 64 × 123 SOG, which is about twice as dense as the 32 × 61 grid shown in Figure 9. The surface pressure fields for the Gulf of Mexico were constructed and stored 6-hr intervals on the 31 × 41 grid. On the three pressure grids, there exist pressure data at each intersection point at 6-hr intervals throughout the entire 20-year period of record. Note that Figures 8 and 9 were drawn to depict the grid characteristics as used in the numerical wave model; small portions on the fringes of the full grids, which were not used in the wave model, have been omitted in the drafting. SOG spatial separations for surface pressure field recon-

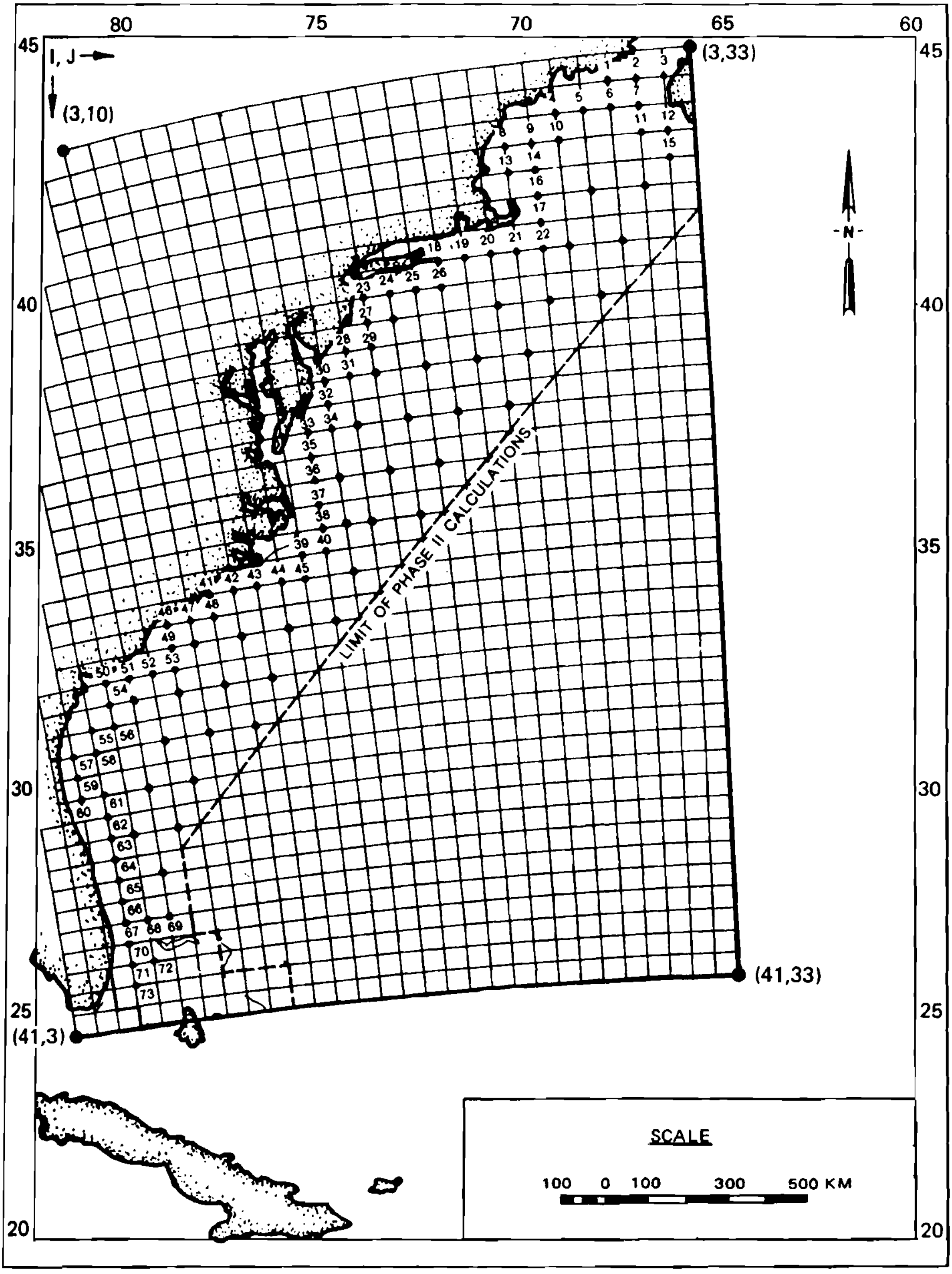

Figure 11. Atlantic Phase II SOG.

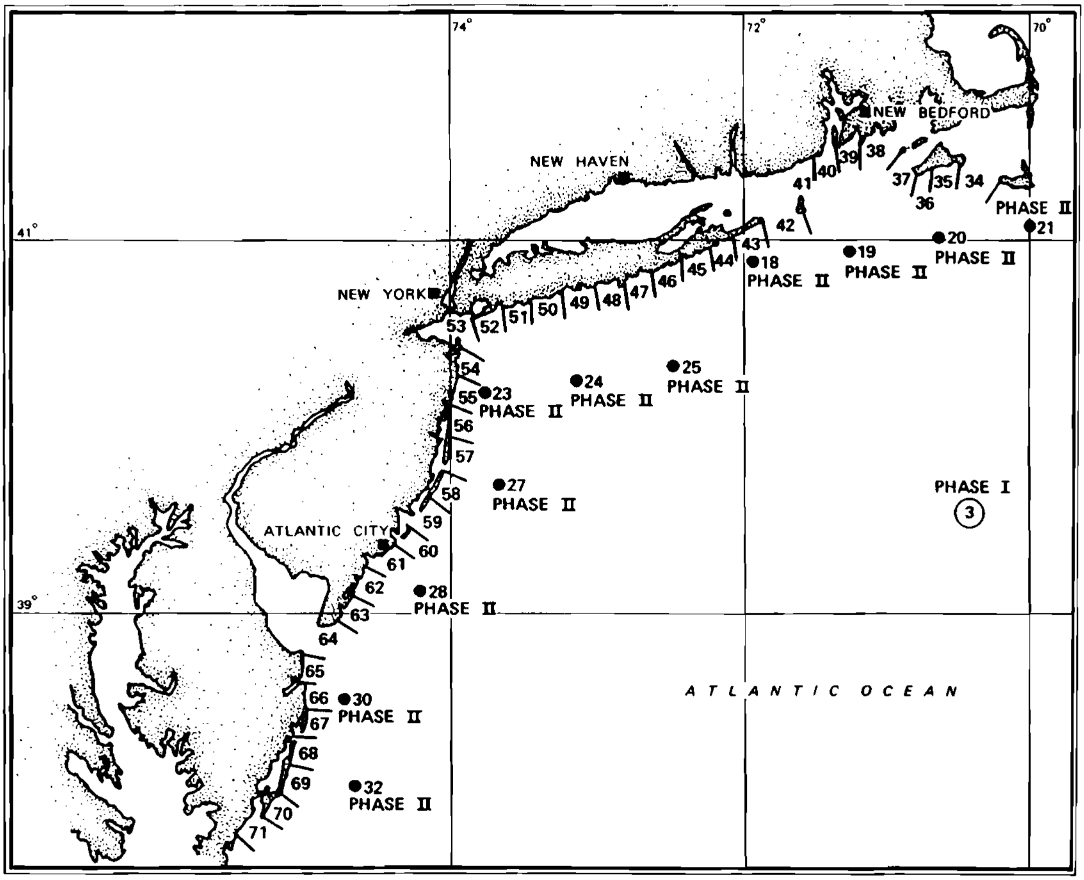

Figure 12. Atlantic Phase III coastal segment.

structions represent approximately 110 km for the Atlantic and Pacific, and approximately 55 km for the Gulf of Mexico. WIS Report 1 describes the methods used in the pressure field analyses and the verification of these methods (CORSON *et al.*, 1980).

Hindcast Wind Data

An integral part of the 20-yr hindcast was the reconstruction of surface wind fields from available historical meteorological data. Three primary sources of information were used during the reconstruction process for these wind fields:

(a) Gridded Northern Hemisphere pressure fields (HOLL and MENDENHALL, 1971)
(b) North American Historical Weather Map Series (NCDC)
(c) Surface Marine Observations (NCDC)

Basically, two independent types of information in the three data sets were considered—pressures and winds. First, the pressure data converted by means of an analysis of pressure gradients into estimates of quasi-geostrophic winds. Then, these approximations were transformed into estimates of wind vectors at a reference level of 19.5 m above the surface for the Atlanta and Pacific and 10 m for the Gulf of Mexico (RESIO *et al.*, 1982). After the geostrophic-level winds were reduced to near-surface winds, independent observations from ships were blended into the wind fields. For the 20-yr hindcast period, a total of over 16 million

Table 2. *National Ocean Services, east coast tidal stations.*

Station No. Longitude		Location		Available Data
		Station Name	Latitude	
841-0140	Eastport, ME	40°54.2'N	66°59.1'W	1940-1967
841-3320	Bar Harbor, ME	44°23.5'N	68°12.3'W	1947-1967
841-8150	Portland, ME	43°39.4'N	70°14.8'W	1940-1967
841-9870	Seavey Is., ME	43°04.9'N	70°44.7'N	1940-1967
844-3970	Boston, MA	42°21.3'N	71°03.0'W	1936-1965
844-7930	Woods Hole, MA	41°31.5'N	79°40.4'W	1932-1964
845-2260	Newsport, RI	41°48.4'N	71°24.1'W	1940-1966
846-1490	New London, CT	41°21.5'N	72°05.5'W	1938-1954
851-0560	Montauk Pt., NY	41°02.9'N	71°57.6'W	1947-1967
851-6990	Willets Pt., NY	40°47.6'N	73°46.9'W	1940-1967
851-8750	The Battery, NY	40°42.0'N	74°05.5'W	1936-1968
853-1680	Sandy Hook, NJ	40°28.0'N	74°00.1'W	1940-1967
853-4720	Atlantic City, NJ	37°21.3'N	74°25.1'W	1955-1960
				1971-1981
855-7380	Lewes, DE	38°46.9'N	75°07.2'W	1950-1973
863-8610	Hampton Roads, VA	38°56.8'N	76°19.9'W	1927-1971
865-9084	Southport, NC	33°54.9'N	78°01.1'W	1933-1954
866-5930	Charleston, SC	32°46.9'N	79°55.5'W	1940-1966
867-0870	Fort Pulaski, GA	32°02.0'N	80°54.1'W	1935-1967
872-0220	Mayport, FL	30°23.6'N	81°25.9'W	1940-1969
872-3170	Miami Beach, FL	25°46.1'N	81°07.9'W	1972-1981

ships observations were blended into the final wind fields for the Atlantic Ocean, the Pacific Ocean, and the Gulf of Mexico (BROOKS and CORSON, 1984). The wind fields over the ocean were verified at each stage during their production. To reduce the computation time and cost of the wind hindcasts, wind speed and direction estimates over land were calculated without going through the complete planetary boundary layer sub-routine of the WIS model. Also, the topography of the land (mountains, *etc.*) and its effects were not included in the hindcasts, as they were expected to be negligible at a great majority of grid points. The WIS hindcast overwater winds are considered to be valid representations of open-ocean conditions at the 19.5-m level (10.0 m for the Gulf of Mexico). The WIS hindcast surface winds for the Atlantic Ocean were calculated and stored for each intersection point on the Phase I grid (Figure 8) at 3-hr increments for the 1956-1975 period of record. The Phase I Pacific Ocean and Gulf of Mexico Phase I wind fields exist at each intersection point of the grids shown in Figures 9 and 10, respectively. These surface winds were hindcast and stored every 6 hours for the same 20-yr interval. The spatial separation of the Phase I grids on which hindcast wind data were archived is approximately 220 km for the Atlantic and Pacific, and approximately 55 km for the Gulf of Mexico (Table 3, Figures 8, 9, and 10). WIS Report 4 presents the methods and verification of the wind hindcast procedures (RESIO *et al.*, 1982).

Both the Atlantic and Pacific Phase II wind fields were developed by interpolating Phase I winds from the 220-km grids onto finer resolution grids with spatial separations of about 55 km, such as shown on Figure 11. Each Phase II grid is a subset of, and approximately four times as dense as, its respective Phase I grid. The Atlantic Phase II wind speeds and directions (3-hr time-steps) were interpolated and stored on a 41 × 33 grid (Figure 11); the Phase II Pacific winds (6-hr time-steps) were interpolated and stored on a 31 × 32 grid.

Hindcast Wave Data

Although the primary purpose for the hindcast was not to generate the surface pressure data and wind data discussed in the previous sections of this article, these steps and the deep water hindcasts to be discussed next were necessary to properly simulate a coastal wave climate. Also, they provided valuable data sets which may be used by others in investigations independent of WIS (CORSON, 1982; CORSON,

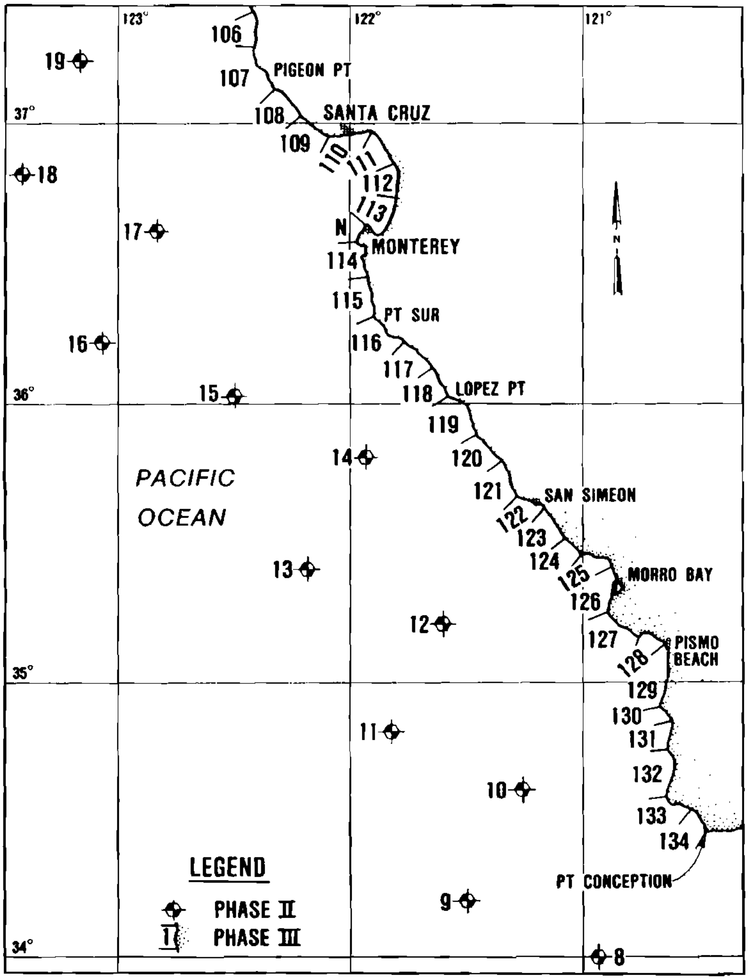

Figure 13. Pacific Phase III coastal segment.

1983). The Phase I hindcasts for the North Atlantic and North Pacific were performed on the grids shown in Figures 8 and 9, respectively. For the wave hindcasts, as for the wind hindcasts, the spatial separation for these grids is about 220 km. The Phase II wave hindcasts for the Atlantic and Pacific coasts were performed on grids such as shown in Figure 11. The grid shown in Figure 10 was used for the Phase I Gulf of Mexico wave hindcast. The present wind and wave hindcasts do not include hurricanes, however, hurricane winds and waves will be added to the data sets in the near future.

The basic output of the Atlantic and Pacific Phases I and II and the Phase I Gulf of Mexico numerical wave models is two-dimensional (2-D) wave spectra for selected locations at 3-hr intervals from 1956 through 1975 (58,440 time-steps). The 2-D spectral arrays are composed of energy density for sixteen 22.5-deg direction bands and twenty frequency bands approximately 0.01 Hz in width. For the Atlantic Phases I and II, the frequency bands range from 0.033 to 0.16 Hz (6–30 sec). For the Pacific Phases I and II the frequency bands have a range of 0.03 to 0.22 Hz (4–33 sec.). The frequency bands for the Gulf of Mexico range from 0.06 to 0.24 Hz (4–16 sec).

Due to the extensive amount of wave data generated during the wave hindcasts, wave

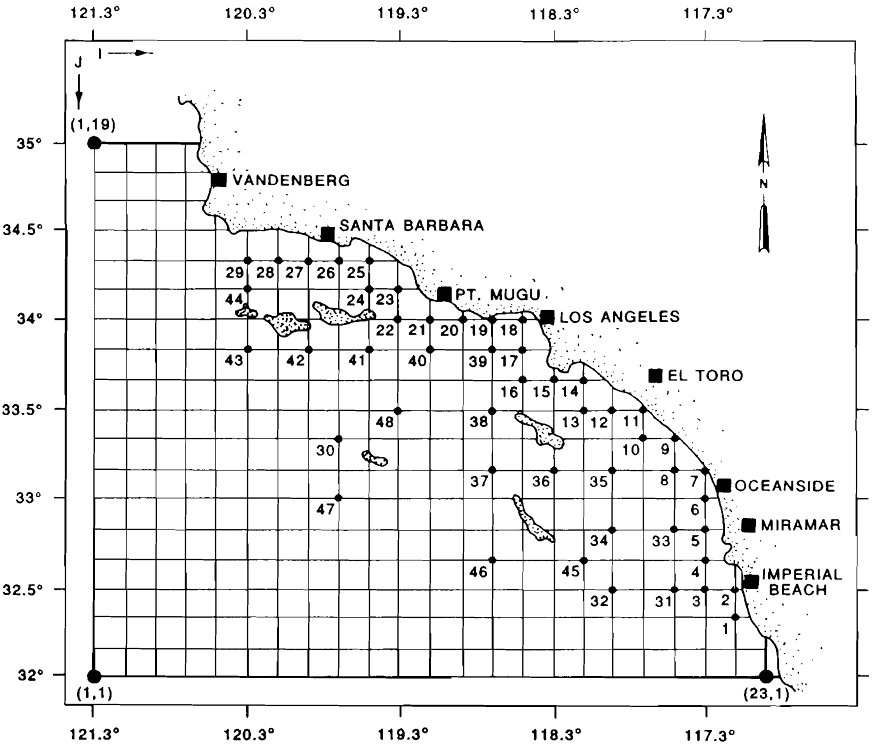

Figure 14. Southern California Bight 10 nautical mile grid.

data were not stored for all intersections of the grids as was done for the hindcast pressure fields and wind fields. Instead, Phase I and Phase II wave data were stored for selected sites throughout the North Atlantic and North Pacific Oceans. The sites for which Atlantic Phases I and II hindcast wave data were generated are shown in Figures 8 and 11, respectively. The Atlantic Phase I 2-D spectra for the 83 locations marked with solid dots and the 13 numbered sites marked with solid triangles (called "stations" in WIS reports) in Figure 8 are no longer available due to the age and unavoidable deterioration of the magnetic tapes on which these data were archived. Future data will be archived on optical disk to avoid aging problems. The Atlantic Phase II 2-D spectra were stored for the 73 numbered stations which are marked with solid dots in Figure 11. Again, due to the deterioration of the magnetic tapes on which these data were archived, two years in this 20-year data set have a small "gap" where the continuous period of record is broken. The magnetic tapes containing the 2-D spectra for the 40 un-numbered locations in Figure 11 were also a casualty of time and are no longer available. Currently, there are plans for an update of the North Atlantic hindcast using a revised version of the deep-water numerical wave model, with the same grids and Phase I input wind fields.

For the 13 Phase I and the 73 Phase II Atlantic stations, the 2-D spectra were processed to generate wave parameters most often needed in coastal design applications: significant wave height (H_s), peak wave period (T_p), and mean wave direction (θ) of sea and swell (Figures 8 and 11). These parameters were reorganized, so the data for each numbered station can be retrieved as a function of time, without reading the data for all stations. Complete listings of the latitude-longitude coordinates and corresponding SOG I-J locations for each Phase I and Phase II grid point are available (BROOKS and CORSON, 1984). The 2-D spectra have not been sorted by station; however, these data can be

Table 3. *Summary of WIS data sets.*

WIS Data Set	Period of Record	Time-Steps (GMT)	Grid or Stations	Spatial Separation
		ATLANTIC HINDCAST		
Surface Pressure Fields	1956-1975	6-Hr	61 x 61	110 Km
Phase I Wind Fields	1956-1975	3-Hr	31 x 31	220 Km
Phase II Wind Fields	1956-1975	3-Hr	41 x 33	55 Km
Phase I Wave Data				
Parameters	1956-1975	3-Hr	13 Sites	Variable
2-D Spectra	1956-1975	3-Hr	96 Sites	Variable
Phase II Wave Data				
Parameters	1956-1975	3-Hr	73 Sites	Variable
2-D Spectra	1956-1975	3-Hr	113 Sites	Variable
Phase III Wave Data	1956-1975	3-Hr	166 Sites	18.5 Km
Water Level Data	1927-1981	1-Hr	20 Sites	Variable
		PACIFIC (NORTH) HINDCAST		
Surface Pressure Fields	1956-1975	6-Hr	64 x 123	110 Km
Phase I Wind Fields	1956-1975	6-Hr	32 x 61	220 Km
Phase II Wind Fields	1956-1975	6-Hr	31 x 32	55 Km
Phase I Wave Data				
Parameters	1956-1975	3-Hr	35 Sites	Variable
2-D Spectra	1956-1975	3-Hr	64 Sites	Variable
Phase II Wave Data				
Parameters	1956-1975	3-Hr	53 Sites	55 Km
2-D Spectra	1956-1975	3-Hr	53 Sites	55 Km
Phase III Wave Data	1956-1975	3-Hr	134 Sites	18.5 Km
		PACIFIC (SOUTH) HINDCAST		
Phase III Wave Data				
Parameters	1956-1975	3-Hr	48 Sites	10 NM
2-D Spectra	1956-1975	6-Hr	48 Sites	10 NM
Phase III Wave Data	1956-1975	3-Hr	23 Sites	5 NM
Parameters				
2-D Spectra	1956-1975	6-Hr	23 Sites	5 NM
		GULF OF MEXICO HINDCAST		
Surface Pressure Fields	1956-1975	6-Hr	41 x 31	55 Km
Phase I Wind Fields	1956-1975	6-Hr	41 x 31	55 Km
Phase I Wave Data				
Parameters	1956-1975	3-Hr	56 Sites	Variable
2-D Spectra	1956-1975	3-Hr	56 Sites	Variable

processed as needed (CRAWFORD, 1987). Similar parameter data and spectra were processed and stored from the Phase I and II North Pacific hindcasts. The 2-D spectra were stored for the 29 cross-marked sites and the 35 numbered stations which are shown in Figure 9. The Pacific Phase II 2-D spectra were stored for 53 stations along the coast. The Pacific Phase I and Phase II 2-D spectra were processed to provide an overall significant wave height from the spectrum, a spectral peak wave period, and the mean wave direction of the spectrum. The same three parameters also were provided separately for the sea and swell regions of the spectrum for the numbered stations marked with solid dots in Figure 9 for Phase I. For more efficient data access, the Pacific wave parameters were reorganized by station as a function of time. As for the Atlantic, complete listings of the latitude-longitude coordinates and the corresponding SOG I-J locations for each Phase I and Phase II grid point are available. The 2-D spectra have not been sorted by station; however, these data can be processed as needed (CORSON, 1983).

In Phase III, Atlantic Phase II wave data were transformed into wave data representative of 10m-depth conditions for stretches of coastline approximately 18 km (10 nautical miles) in length (JENSEN, 1983b). There are a total of 166 Phase III stations (coastal segments) along the Atlantic coast (JENSEN, 1983a). Figure 12, shows an example section of the Atlantic coast with the Phase III, Phase II, and Phase I stations marked. For each 3-hour

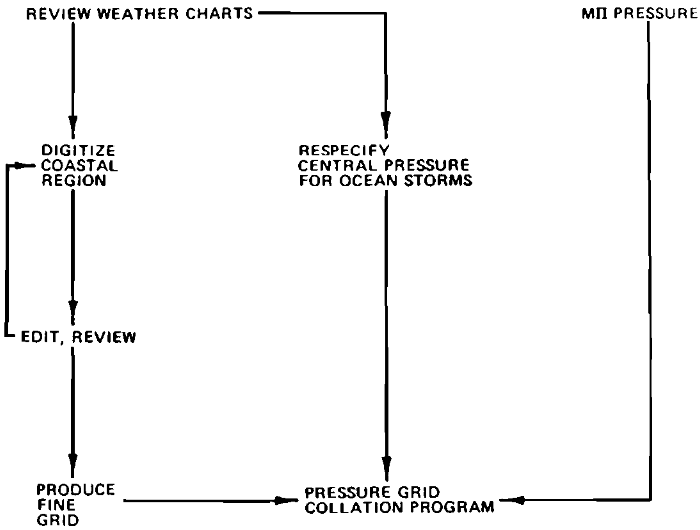

Figure 15. Pressure field development procedure.

increment of the 1956-1975 20-yr hindcast interval, H_s, T_p, and θ for the sea and swell regions of the spectrum were stored for all 166 Phase III sections.

Pacific Phase II wave data were transformed into Phase III wave data representative of 10-m depth conditions for coastal segments approximately 10 nautical miles (18 km) in length. An example of the 134 Pacific Phase III stations (coastline sections) and the relative locations of the Phase I and Phase II Pacific stations are shown in Figure 13. H_s, T_p, and θ for the sea and swell regions of the spectrum were stored for all 134 Pacific Phase III stations at 3-hr time-steps throughout the 20-yr hindcast interval (JENSEN *et al.*, draft-a).

Phase III-type wave transformations were not calculated in the Gulf of Mexico due to the small size of this water body and the Gulf's intricate coastline topography. However, site-specific Phase III-type wave characteristics can be generated using the Gulf Phase I data as input, if assumptions of straight and parallel bottom contours and no additional energy sources are appropriate. H_s, T_p, and θ for the sea and swell regions of the spectrum were stored for the 56 Gulf of Mexico stations at 3-hr intervals throughout the WIS 20-yr hindcast period (Figure 10).

Data Availability and Presentation

WIS has generated far more data than can be distributed in standard data reports which simply list data values. Three approaches have been taken to present and make the data available in a usable form. First, summarized wave data reports which contain the results of the most often used analyses have been prepared and published (CORSON *et al.*, 1986; CORSON *et al.*, 1987; CORSON *et al.*, 1981; CORSON *et al.*, 1982; CORSON and TRACY, 1985; EBERSOLE, 1982; JENSEN, 1983a; JENSEN *et al.*, draft-a; JENSEN *et al.*, draft-b). WIS experience indicates that percent occurrence tables, wave rose diagrams, mean and maximum summary tables, and tables (or diagrams) of extreme wave estimates are most often requested and can be conveniently provided in published reports. Each of the data products summarize 20 years of hindcast wave data for the specified WIS stations. Thus, the information in 58,440 3-hr hindcast wave records for each station is reduced to more useful concise forms. By publishing the data products in reports, the analyzed and summarized WIS hindcast information can be distributed to potential users relatively quickly.

For data display and presentation, most of the attention in WIS has focused on the wave hindcasts because WIS's primary task is to provide coastal wave data. However, some CE studies and requests have involved other WIS data sets (CORSON, 1982; CORSON, 1983). Figure 16 portrays schematically how the various hindcast data sets can be provided to potential users. A second approach to making WIS data available to more effectively serve CE needs is the Sea-State Engineering Analysis System (SEAS) (MCANEY, 1986). WIS has stored selected portions of the hindcast wave data and programs which process/display the data on a computer-based analytical system. There are three major parts of SEAS:

(a) Data base.
(b) Retrieval system.
(c) Program library.

Currently, the SEAS data base includes sea and swell wave parameters (H_s, T_p, θ) for the 13 Atlantic Phase I stations, 73 Atlantic Phase II stations, 166 Atlantic Phase III stations, 35 Pacific Phase I stations, 53 Pacific Phase II stations, 134 North Pacific Phase III stations, and 56 Phase I stations in the Gulf of Mexico. The SEAS data base is continually being updated. Current augmentation efforts are focused on the wave parameters generated in WIS's most recent hindcasts of selected hurricanes in the Atlantic Ocean and Gulf of Mexico. All 2-D spectra generated by all production hindcasts to date, the Atlantic water-level data, and all WIS hindcast wind data are being considered for integration into SEAS. The SEAS retrieval system has been designed to allow extraction of any subset of the SEAS data base through a user-friendly interactive question and answer procedure. The SEAS system guides the user by asking what location (by station number) and time interval is of interest, and then creates a file or tape for further processing.

Although some SEAS users create data files to be analyzed by their own programs, the SEAS program library has been designed to include those data processing and statistical programs most often required by CE districts and divisions. Data reports currently available from SEAS program library include:

(a) Wave parameter listings.
(b) Time history plots of wave parameters.
(c) Percent occurrence tables.
(d) Histograms for H_s, T_p and θ.
(e) Probability tables for maximum wave height and associated period.
(f) Probability tables for individual wave height and associated period.
(g) Latitude and longitude lists for WIS stations, including water depth, if applicable.
(h) Precomputed 20-yr percent occurrence tables for WIS stations.

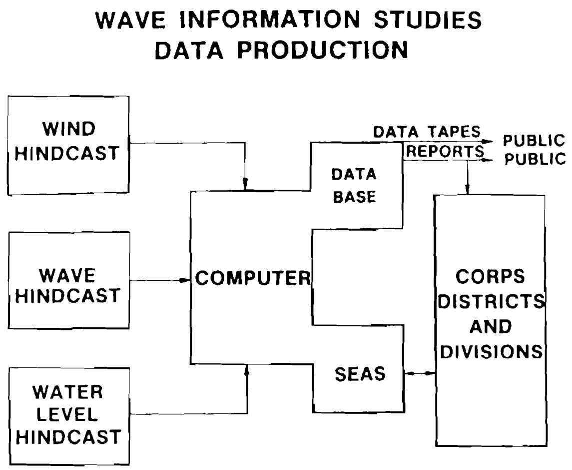

Figure 16. Wave information studies data productions.

(i) Precomputed 20-yr mean and maximum summary tables for WIS stations.
(j) Precomputed 20-yr return period tables for WIS stations.

Like the SEAS data base, the program library has been designed so that new programs may be added easily to SEAS as required.

As a final means of assuring that WIS data are available to all potential users, the WIS wind data and wave parameter data are transferred to NOAA's National Climatic Data Center (NCDC) once verification has been completed. To date, data tapes containing Atlantic Phase I, Atlantic Phase II, and Pacific Phase I wind fields have been forwarded to NCDC. Water parameter data for Phases I, II, and III of the Atlantic, and Phases I and II of the Pacific have also been transmitted to NCDC. The wave parameter data for Phase III of the North Pacific and Phase I of the Gulf of Mexico are scheduled to be transferred to NCDC, upon publication of the respective data reports. The WIS data transmitted to NCDC have been integrated into their master library. To request these data from NCDC, contact their Customer Service office, Federal Building, Asheville, North Carolina 28801, and reference WIS data from Tape Deck 9787. By transferring its data to NCDC, WIS has made it possible for persons requiring more detailed information than available in the WIS reports, and not having access to SEAS, to obtain WIS data. Since WIS wind and wave data are archived on magnetic tapes and optical disks at WES, outside users can contact the WIS staff directly with their data requests. Standard "tape to tape" data requests or requests for copies of tables from current, out-of-print, or draft reports are easily filled. Most requests for data are subject to nominal processing charges. WIS has the capability to process data for site-specific requests, including 2-D spectral analysis and customized Phase III-type wave transformations. The output data can be provided on magnetic tape, IBM-compatible diskettes, standard print-out listings, or camera-ready tables.

Summary

The primary task of WIS is to provide a long-term data base of hindcast wave data for the Atlantic, Pacific, Gulf of Mexico, and Great Lakes coasts of the United States to be used by CE district and division offices in the design and operation of coastal projects. A major part of the WIS task is development and operation of the numerical models and procedures used to generate the hindcast wave data. WIS has completed all phases of its 3-phase approach for the Atlantic and Pacific coasts, its single-phase production for the Gulf of Mexico, and the production portion of its hurricane hindcasts for the Atlantic and Gulf of Mexico. The post-production data processing for both the Atlantic and Gulf of Mexico hurricane hindcasts is very near completion. The 30-yr (1957-1985) wave hindcasts for the Great Lakes, beginning with Lake Michigan, have been initiated.

The data sets WIS has generated during its 20-yr (1956-1975) hindcasts include:

(a) Gridded surface pressure data
  1. Phase I North Atlantic Ocean
  2. Phase I North Pacific Ocean
  3. Phase I Gulf of Mexico
(b) Gridded hindcast wind data
  1. Phase I Atlantic Ocean
  2. Phase II Atlantic Ocean
  3. Phase I Pacific Ocean
  4. Phase II Pacific Ocean
  5. Phase I Gulf of Mexico
(c) Hindcast 2-D wave spectra for selected sites*
  1. 13 Phase I Atlantic stations*
  2. 83 additional Phase I Atlantic sites*
  3. 73 Phase II Atlantic stations*
  4. 40 additional Phase II Atlantic sites*
  5. 35 Phase I Pacific stations
  6. 29 additional Phase I Pacific stations
  7. 53 Phase II Pacific stations
  8. 56 Phase I Gulf of Mexico stations
(d) Wave parameters (H_s, T_p, θ) for sea and swell
  1. 13 Phase I Atlantic stations
  2. 73 Phase II Atlantic stations
  3. 166 Phase III Atlantic stations
  4. 35 Phase I Pacific stations
  5. 53 Phase II Pacific stations
  6. 134 Phase III Pacific stations
  7. 56 Phase I Gulf of Mexico stations
(e) Water-level statistics for the Atlantic coast

*Data missing or no longer available

Another major portion of WIS is the presentation and preservation (archival) of the data generated during the hindcast so pertinent data are readily available to potential users, including CE, other Government agencies, and the public. Sea-surface pressure fields, which are rarely needed by others, are archived at WES. WIS hindcast wind, wave, and water-level data have been (or are scheduled to be) made available through publication of reports, integration into the computer-based SEAS, transmittal to NCDC, and archival onto optical disks at WES.

CONCLUSION

Both the FWGP and WIS are progressing toward the accomplishment of their objectives. Both are providing needed information for design. Instrument deployments under FWGP have been coordinated with WIS so that, as the hindcast period is expanded, verification of the numerical models will be possible. Where NOAA or other data have been available, the hindcast has been checked and has shown excellent correlation with the measured wave data. These efforts are being expanded both geographically and temporally to satisfy the needs of the coastal planner and engineer.

ACKNOWLEDGEMENT

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