New Technology in Coastal Wave Monitoring

Richard Seymour [1], Member ASCE, David Castel[1],
David McGehee [2], Member ASCE, Juliana Thomas[1], and
William O'Reilly[1]

Abstract

The Coastal Data Information Program (CDIP) is an extensive network for monitoring waves along the Pacific coastlines of the US. The system has evolved substantially since its inception in 1975. The technological innovations in instruments, system control and management, quality control, software, computer hardware, field equipment and installation techniques, data archiving and analysis are described. Some further developments, underway or planned, are also defined.

Introduction

What is now called the Coastal Data Information Program had its beginnings in the mid 1970's with a modest, one node, field wave data collection station. The station was installed at Imperial Beach in San Diego county. This technology development was partially in response to a plea by a keynote speaker in the Waves 1974 conference. In his address, Prof. Robert Wiegel stressed the need for acquiring a nearshore wave climatology for the United States to allow coastal practitioners to make more rational design decisions. Data from the Imperial Beach station, transmitted over normal dial up phone lines, was recorded at a Scripps Institution of Oceanography central facility in La Jolla, CA., on a Nova mini computer. Recorded data were archived for later analysis. The project was supported by the State of California Department of Boating and Waterways and the California Sea Grant program.

Shortly after its inception, the program expanded and added the US Army Corps of Engineers (USACE) as a co-sponsor. As the steward of the nation's coastal infrastructure, the Corps requires reliable, long-term wave measurements for use in planning, designing, and operating coastal projects. Design wave conditions, usually expressed in terms of return intervals, are obtained through extremal analysis of wave histories. The confidence in these projections drops as the desired return interval

---

[1] Scripps Institution of Oceanography, UCSD, La Jolla, CA 92093.
[2] Coastal Engineering Research Center, USACE, Vicksburg, MS 39180

exceeds about twice the length of the historical record. However, there is seldom time between the inception of a project and the point when design details are finalized to collect sufficiently long wave histories. Wave hindcasts, which are made possible by long-term meteorological observations, are one approach to this requirement. Wave measurements are critical to hindcast validation. Another application for wave data is accurate quantification of conditions during specific events that result in structural damage or operational delays. Finally, laboratory and analytical research into the physics of wave generation, propagation, and transformation requires measurements for calibration and verification. The USACE Field Wave Gaging Program (FWGP) was established with the goal of collecting wave data at sufficient spatial and temporal density to meet and satisfy these requirements for the entire US coastline.

With time, the data collection system grew and evolved into what has become known as the Coastal Data Information Program (CDIP). In its present form, the CDIP has collected data from many field stations, on both the east and west coasts, the Great Lakes and the islands of Hawaii. In 1991, recognizing the value of wave measurements to a broad range of federal, State and local interests, the US Army Corps of Engineers and the California Department of Boating and Waterways entered into a watershed Cooperative Agreement (CA) between the two agencies.

The CA formally recognized that the impact of ocean waves, and the utility of wave information, transcends agency jurisdictions and missions. The data needs of the various State and federal partners overlap, but each agency brings its own set of requirements for the data products. Through the CA, CDIP has evolved technically and procedurally, not only to improve the quality and reduce the costs of wave measurements, but to meet a growing demand for enhancements in capabilities.

Many data user needs can be satisfied by the original thrust of the CDIP - collecting, analyzing, and compiling a database of analyzed wind and wind-wave parameters and statistical permutations of the accumulated histories. Some researchers require special sampling schemes, for example, extended time series to observe long wave phenomena. Harbor oscillation studies can benefit from multiple data sets synchronized in time. Alternately, a separate class of users make operational decisions based on current conditions, and thus require near realtime data access. The early history of the system and a more detailed description of the technology initially utilized is contained in Seymour and Sessions (1976), Seymour (1979), and Seymour et al (1985).

While the original emphasis of the CDIP was wave, current and wind measurements, the system of instrument platforms, telemetry links, and computers can be adapted to obtain other types of data. The benefits of establishing a climatic perspective of the baseline and extremal conditions apply to any coastal environmental parameter. With the collection and processing infrastructure in place, the cost of CDIP monitoring of other physical and chemical processes, such as currents, turbidity, temperature, salinity, water quality, to name a few, is dominated by the constraints of the individual sensor technology.

Historically, this cooperative agreement was based upon a very successful mechanism management of the CDIP in the Scripps Institution of Oceanography, UCSD. As an example, in 1992, the CDIP, using advanced and state of the art technology through a memory-distributed, multi-node network, recorded in excess of one million words of data every day. These environmental data were collected, in

Appendix. References:

Herbers, T.H.C., and R.T. Guza, 1989. Estimation of wave radiation stresses from slope array data, J. of Geophys. Res., 94(C2), pp 2099-2104.

Lygre, A., and H.E. Krogstad, 1986. Maximum entropy estimation of the directional distribution of ocean wave spectra, JPO, 16, 2052-2060.

Seymour, R. J., 1979. Measuring the nearshore wave climate: California experience. In: Ocean Wave Climate, M. D. Earle and A. Malahoff, eds., Plenum Press, New York, Marine Science, 8: 317-326.

Seymour, R. J. and M. H. Sessions, 1976. Regional network for coastal engineering data. In: Proc. 15th Coastal Engineering Conf.,ASCE, Honolulu, HA, July, Vol. 1, Chap. 5, pp. 60-71.

Seymour, R. J., M. H. Sessions and D. Castel, 1985. Automated remote recording and analysis of coastal data. J. Waterway, Port, Coastal and Ocean Engineering, Proc. ASCE, 111(2): 388-400.

However, during periods when utilities fails, wave data can be lost. Not surprisingly, electrical outages are more frequent during storm events, when wave data is often of the greatest interest. Over the last several years, CDIP has developed a Smartstation whose function is to collect and store wave data in the field. CDIP is developing a backup power unit for the Smartstation. In the planning stages is a system allowing data to be acquired and stored during a power outage lasting up to several days. This will require modifying the existing Smartstation so that it can recognize a power outage and operate in a low power mode. The Smartstation will be equipped with a series of trickle-charged automotive batteries as the backup power source.

Central Facility Upgrading And Expansion

Conversion to a UNIX-based SUN system is in progress. A SPARC 1 workstation will replace the PC-based data acquisition system. This workstation will allow greater flexibility and accessibility to the data. Station polling cycle time will be reduced. 1.3 gigabyte 4mm DAT tapes will replace 40 megabyte 9 track tape storage. Networked to the SPARC 1 is a 630 multi-processor server. The FFTs and analysis programs will be performed on the server. Condensed statistics will be archived on disk. At the completion of each data run, the processed data will to be transmitted to the National Weather Service office in San Diego for distribution across their AFOS network. A similar file will also be sent via TCP/IP network to other computers at Scripps and Waterways Experiment Station (WES). These data will be accessible to interested government agencies via modem or TCP/IP network. Optical storage of raw data is under investigation and will be integrated into the system at some future date.

Conclusions

Harsh environmental conditions, the rapid evolution of improved communication and computation technologies, and the special needs of specific coastal engineering projects have driven the development of a variety of new concepts, facilities and techniques for the reliable and economical gathering, archiving and analysis of wave and other coastal data. The experience of the CDIP program, which is approaching the 20 year mark, may provide valuable guidance to other networks with similar objectives.

Acknowledgments

The continuing support of the Coastal Engineering Research Center of the U.S. Army Corps of Engineers and the California Department of Boating and Waterways is gratefully acknowledged. In addition, we wish to thank the U.S. Navy, the National Weather Service, the City and County of San Francisco, Pacific Gas and Electric Company, Texaco USA, and the many others who have provided cooperation, support and services. We would like to offer particular recognition to some of the pioneers of the CDIP concept, including Meredith Sessions, Robert Wiegel, Orville Magoon, George Armstrong, George Domurat, Douglas Pirie and Michael Hemsley.

realtime, from rugged, high energy nearshore ocean locations, as well as sheltered inland waterways and harbors. Throughout its 18 year history, CDIP reported data from close to 80 separate locations. Most of these are shown in Figure 1.

Parameters measured include wave height, wave period, wave direction, current velocity and wind velocity. In cooperation with the National Weather Service Marine Advisory Program, CDIP provides essential and timely coastal weather information to mariners, fishermen and recreational boaters. Through published and widely distributed monthly and annual reports, the program furnishes coastal engineers and others in the oceanographic community with long-term wind and wave statistics.
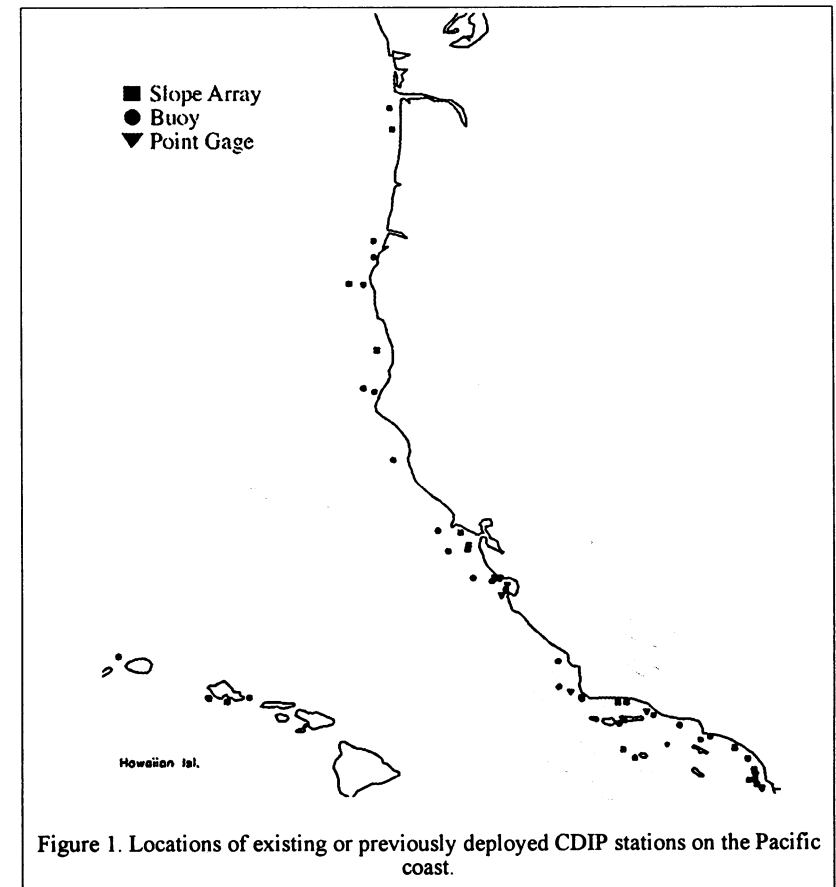

Figure 1. Locations of existing or previously deployed CDIP stations on the Pacific coast.

Data Acquisition And Processing

Data Acquisition

The program's mission and mandate have, for the most part, remained unchanged. The program's primary responsibilities are:

1) Accept input from any sensor type that has an electrical signal as its output,

2) Automatic end-to-end operation of the complete system. Data sampling, transmission, recording, validation, analysis and dissemination, without operator intervention.

3) Data recording in one central location at the Ocean Engineering Research Group's facility in La Jolla, CA.,

4) Quasi realtime availability of analyzed data, and

5) Data links and system costs that allow economical operation with inputs from any location equipped with phone service.

With time, increasing data acquisition requests imposed new demands on system capabilities. The requirement for longer, up-to-continuous data records, severely strained the existing network storage limits. The perceived need for flexible data sampling protocols led to a requirement for a communicative, intelligent field station. The very real requirement for field backup data storage dictated an uninterrupted power supply to assure data integrity when utility services are disrupted. The above concerns, coupled with significant increases in computing capabilities, communication advances and component miniaturization, accompanied by promised cost reductions, suggested a re-evaluation of the programs tools and methodology. In response to the above issues, a new, PC based data acquisition system was designed as the next generation CDIP autonomous field data collection system.

The next generation field data logging system, or Smartstation, was designed and developed as a software driven, autonomous, data acquisition system. The system's primary function is to locally acquire, log, and in response to a call from a host computer, upload the stored data. Bi-directional communication between host and client computers is accomplished via modem connections, through normal phone service. The field station is designed to operate independently, under locally resident program control. However, the dual direction communication capability allows for significant flexibility in the PC execution routines. The field data acquisition unit is a commercially built, rugged and hardened, industrial off-the-shelf PC.

The data acquisition system is typically connected to the sensing elements through electro-mechanical cables or via radio telemetry links. Reporting sensors may have a source output of analog, digital or frequency modulated signals. Data sampling configurations are a function of the observed parameters and of the particular phenomenon studied. Nominally, sampling frequencies for ocean waves, currents and winds measurements are one Hz. Sample length can vary from approximately 34 minutes for ocean directional wave measurements to continuous data for infragravity type wave studies. Typically, a field station is polled eight times daily. At the normal

instrumentation and a CDIP field station could increase the effective data collection range to approximately 50km.

The CDIP is developing a radio telemetry system designed to transmit 10 channels of continuously sampled data. Sampling frequency will be selectable from between 0.5 to 2 hz. The system will be self-contained with enough battery power to last 1 year between service calls. The radio transmitter will reside in a buoy tethered to an instrumentation package via an electro-mechanical mooring cable. Information will flow from the package to the radio transmitter, to be received at a shore side station for storage on board a Smartstation. From there, information will be processed through normal CDIP procedures. This configuration will permit bottom mounted slope arrays, as an example, to be deployed in areas relatively far from shore (e.g. shoals and banks). Alternately, instrumentation can reside along sections of coastline where a shore based field station is impossible or impractical.

Wind Measurements

Offshore winds can be highly variable and unpredictable. This is especially so in storms events off the Pacific coast. Lack of offshore wind observations a a critical, unknown in marine forecasts and reports. Absence of this vital information has, at times, resulted in the damage to boats with accompanying boater injuries and occasional loss of life. This lack of information is of significant concern to the coastal partner states of the CA. CDIP has historically focused on the collection of wave data. However, in regions such as the Southern California Bight, locally generated seas can play a major role on the regional wave climate. A more complete understanding of the spatial variability of winds in the Bight is required for useful now casts and hindcasts of local sea conditions. Thus, the collection of over-water wind conditions is a natural extension of the CDIP database.

To that end, the CDIP is engaged in a development program that will collect, and send to shore, in real time using the concurrently developed telemetry transmission package, data observed by offshore wind buoys.

Self-contained Directional Array

The telemetry system will allow CDIP to expand its real-time wave gaging into areas where the present shore cabling method is not possible. In conjunction with the development of the telemetry package, it is proposed to develop a prototype directional array which uses this module instead of the traditional shore cable. This will permit bottom mounted arrays to be deployed in areas relatively far from shore. The wave data will be transmitted from a surface buoy moored above the slope array. The array will be somewhat larger than the typical 6m square CDIP slope array, and will contain additional sensors in order to test the ability of the telemetry system to transmit large data sets. The prototype will be tested in an appropriate setting within Southern California.

Smartstation Backup Power

In order to economically and efficiently collect wave data in real-time, CDIP uses telephone lines to retrieve data from storage devices at the various wave gage locations. The field storage systems are placed where electricity and phone service is available. This has proven to be a generally reliable method for data acquisition.
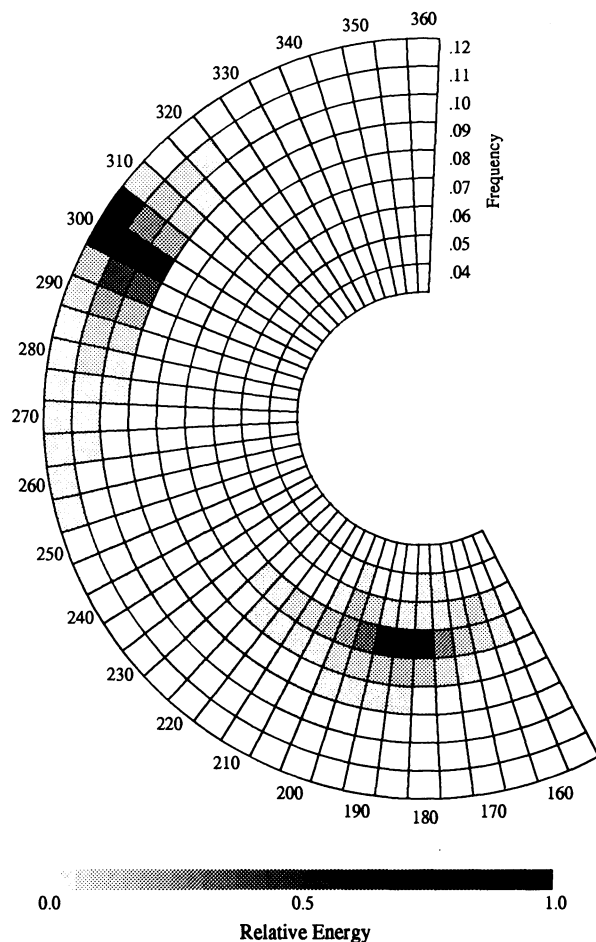
Figure 12. Directional spectrum from the Harvest Platform array spectra of Figure 10.

Future Plans

Nominally, with the exception of buoy information, the CDIP receives data from offshore gauges through telemetry cables. This methodology has been remarkably successful and robust. Unfortunately, cable costs and logistical considerations limit cable lengths to no more than three km. at best. This arbitrary limitation is unnecessarily restrictive. A cable-free telemetry system for data transmission between

8192 samples collected for non-directional wave measurements a 43.5 minute data gap is introduced into the three hour cycling period.

The physical functional specifications for the smart station emphasize rugged construction, dependability and reliability. To that end, the system is built to withstand field environmental conditions, insulated from electrical noise, mechanical vibrations and temperature extremes. The single moving component in the system is a hard disk. A removable floppy is an optional feature. Disks are included for long term data storage. However, the system is configured to ignore disk functions in the event of a disk failure. Maintenance is reduced to board level change out functions by unskilled, local field contacts.

Software specifications include a DOS operating system, RS232 or equivalent inputs, minimum 512K ROM disk, a system watch dog timer and up to four megabytes of RAM disk storage. A key component in the data acquisition system is a 16 bit counter-timer board, capable of latching, holding and registering the incoming frequency modulated data signal without altering or interrupting the input signal. Up to 16 signals can be interrogated by one Smartstation. The data lag between the first and last signal is less than 1000th of the sampling interval.

Smartstation capabilities include the ability to alter remotely, through the host computer and phone connections, any number of the field operating specifications. Some of the more relevant features are listed below.

1. Alter the data sampling frequency. Nominally, for most applications, the sampling frequency is 1 Hz. Under certain circumstances, and for trouble shooting purposes, the frequency may be changed from 0.125 Hz. to 10 Hz.

2. Change sample length. Under special conditions, such as during a tsunami alert or tsunami event, long or continuous data may be recorded.

3. Modify the number of data channels returned to the host computer. This feature is particularly useful in the event of a data channel failure. Erroneous data need not be brought back, thus reducing phone connect time.

4. Save all data to hard disk. This is the normal operating mode. In the event very high frequency, multi-channel data is recorded, a savings in system overhead will be achieved by writing data to the RAM disk only.

5. Data compaction option. To reduce data storage volume, subsequent flow over phone lines and reduce operating costs, only differences between successive data points are recorded and transmitted. The number of difference words between bracketing full words is nominally set to ten. Full word spacings may be changed under program control.

6. Chronological information is embedded into each channel's data stream. Standard intervals between successive time tags is five minutes. This interval is optionally changeable.

7. The system takes full advantage of existing, commercially available, modem data transfer integrity and compaction algorithms. Optionally the system can revert to an internal cyclic redundancy check.

8. Packet size transmission is under system control and can be altered from the standard 128 word size packet.

9. Special data runs can be requested from a field station. The request specifies the start and end times for the requested data as well as the data channels desired.

10. The field station can be remotely cold started. Upon restart, the system will boot from ROM, the hard drive or a floppy disk, in that order.

11. A commercial software package allows realtime remote control of the field station. The home keyboard controls the field station. The home screen mimics the field screen. This feature is specially useful during debugging sessions.

The host computer and Smartstation communicate via a header block. A default header is resident on the Smartstation and is returned to the host computer as a prefix to the data stream of every data collection episode. The header, which uniquely describes a station's attributes, contains all the relevant control, acquisition and other critical information about the incoming data set. In the event a change is requested from the field station, the appropriate station header is modified on the host computer and the new instructions are sent out during a normal polling call. The newly sent header becomes the field station default header. The new station configuration will take effect at the following data run. A new header can be sent out as part of a special data request.

Normally, a video display terminal is not part of the field smart station. In certain instances, where local data display is requested, an information screen depicting realtime measurements is displayed. Shown on the screen are the average wave period, the uncorrected (in the case of a pressure sensor) instantaneous wave height and the significant wave height. Data are sensed, according to the header block specifications, by a gauging suite and are telemetered to the shore based Smartstation. At the Smartstation, the data are received through a phase lock loop, electronically conditioned and optionally compacted, according to the header block instructions, and stored locally in RAM and on a hard disk. Storage is based on the "first in first out" principle, with the oldest word overwritten by the latest word as the storage buffer is filled.

In response to a phone query from the Central Station, the Smartstation uploads the latest data buffer. The Central Station data collection computer, a Sun Microsystem's work station, superficially examines the incoming data for obvious defects, such as incomplete transmissions and failed phone connections. A detected fault will trigger a retry call to the Smartstation.

Data Sampling

Stations are polled at a nominal interval of three hours. Event thresholds can be set on a per station basis. Threshold exceedence will cause data from a target station to be collected continuously. Tsunami alerts will cause manual activation of continuous sampling from designated tsunami stations.

Record length is a function of the study objectives. For the old type, memory-distributed system, record length can range from 1024 samples to 16384. For the new,
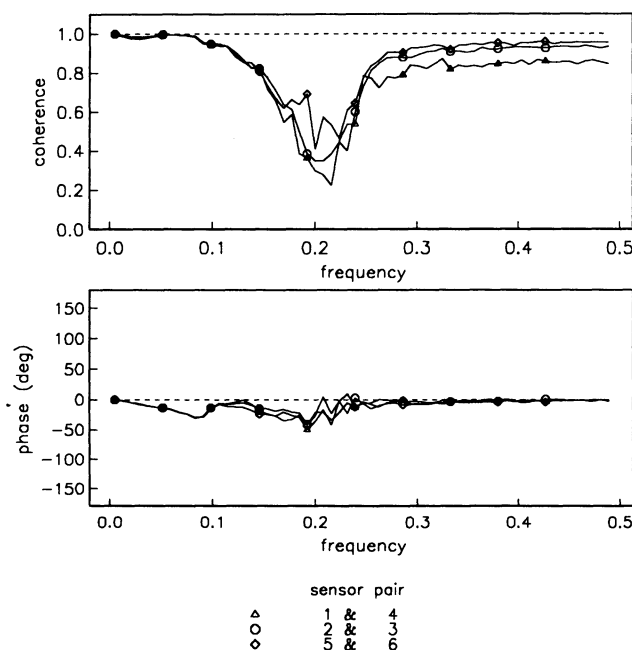
sensor pair
△   1 & 4
○   2 & 3
◇   5 & 6

Figure 11. Cross spectra from the data shown in Figure 10.

The phase and coherence relationships among the three redundant short lags in the array are illustrated in Figure 11. As expected, the coherence falls off as the wavelength approaches the sensor spacing. The increasing coherence at very high frequencies (very low energy levels) is due to spectral leakage from the peak of the wave spectrum. This is an artifact of the simple data analysis procedure that was used, and can eliminated by tapering the time series.

To illustrate how complex the typical deep water wave field is off of California, a slope array is formed from four of the platform sensors, and the first two directional moments of the spectrum are calculated following the method of Herbers and Guza (1989). A frequency directional spectrum is then derived from these moments using a maximum entropy estimator (Lygre and Krogstad, 1986). This spectrum is illustrated in Figure 12. The spectrum is truncated at 0.12hz because of the relatively large sensor spacing. Bias errors in the directional moment estimates become significant for wavelengths less than about five times the sensor spacing (Herbers and Guza, 1989). The two wave trains that produce the bimodality in the Figure 10 spectrum are clearly shown in this plot.

An example of rather typical spectra plots from the Harvest sensors are shown in Figure 10. The bimodal spectral shape results from a combination of southern swell and a sea-swell train from the northwest. Notice that the sensors track closely in the energetic band and that the noise level at high frequencies is low (the spectra have not been corrected for depth).
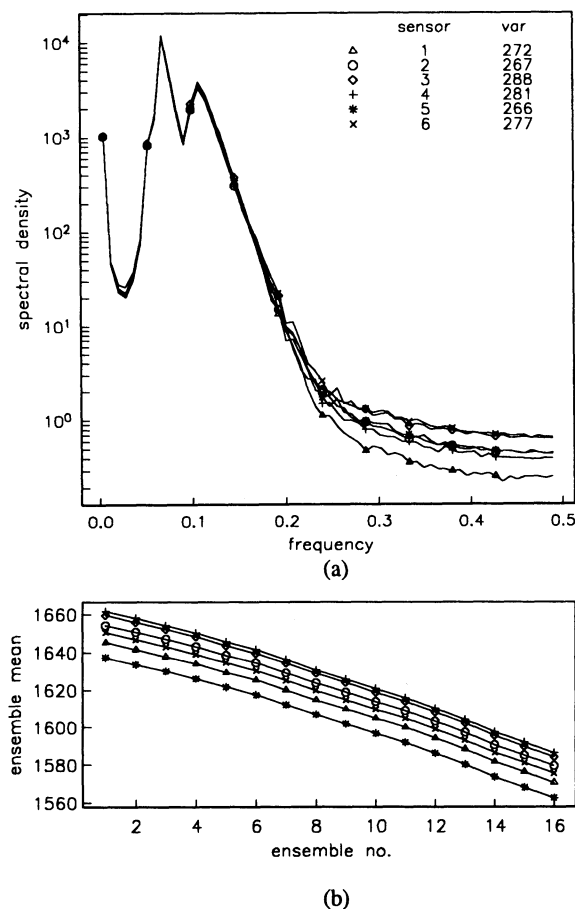

Figure 10. (a) Auto spectra from the Harvest Platform sensors at 2:04 AM, 24 May, 1993. The significant wave height is 1.3m. There are 120 degrees of freedom.
(b) Means of 512 observation ensembles.

smart stations, maximum record length depends on disk size. For both style stations, instruments intended to define energy or direction of wind-generated waves are sampled at 0.5 or 1.0 Hz. with sample lengths up to 16384. Instruments defining either wind velocity or waves of significantly longer periods sample at 0.125 Hz. and obtain 2048 samples. For ocean waves, this represents an 8 second average sea-level estimate, and covers a sample period of approximately 4.5 hours.

Data Analysis

Each record is objectively and automatically edited before analysis. All incoming raw data is subjected to a battery of objective and rigorous verification and inspection algorithms. Data declared questionable by this inspection process disqualifies the parent data record from further participation in the verification and analysis process. CDIP's policy has been that, with the exception of a very limited number of spikes in the data, no attempt is made to 'repair' the data. Spikes caused by data transmission errors are interpolated by bracketing values. Spikes in excess of one percent of the number of data points cause the run to be rejected. Thresholds are set for maximum expected standard deviation, sequences of equal values, gross mean shifts and sequences without a crossing of the mean. Exceedence of the thresholds causes the run to be rejected. Records from instruments sensing long period waves are detrended to remove the tidal components. Directional arrays are subjected to time domain correlation checks.

Daily exception reports are generated by the system. These reports detail the various data failure modes. Individual data records so identified are visually examined by CDIP personnel. More as an effort to determine sensor status than an attempt to incorporate the data in the analysis stream. At the end of the month, an error summary report is automatically generated by the system software.
All records are analyzed by Fast Fourier Transformation. The Fourier coefficients from pressure sensors are depth corrected by linear theory. Coefficients are combined to produce an energy spectrum which is grouped into the period bands shown in the report.

During the first 14 years, the Coastal Data Information Program analyzed and reported directional data from nearshore slope arrays to produce estimates of Sxy, or the longshore radiation stress. The motivation for this was to enable a reasonably easy estimate of longshore transport (which is related to Sxy in certain models). This assumption is only valid where the contours between the gage and the shore are straight and parallel, a condition that is not met at every location. Further, this analysis depends upon a knowledge of the actual bathymetry near the site, which is subject to change over time. Finally, by providing only the radiation stress data, other valuable properties of the wave field directionality are lost to users of these data. After considerable review, CDIP has decided to alter the directional data analysis and reporting methods.

Beginning January 1992, CDIP adopted a new convention in reporting directional wave data products. This new standard analysis procedure for directional wave gauges produce a two-dimensional energy spectrum from the measured time series. Total energy, significant wave height, peak period and weighted direction are computed and reported.

Data Dissemination

Monthly and annual reports are generated on a routine basis. Project reports are generated upon request. The statistics included in the monthly reports are the following:

1.   Energy spectrum grouped into period bands.

2.   Vector plots of direction which indicate wave headings and relative energy densities. Angles reported in the directional data are true compass headings towards which the waves are travelling at the location of the measuring instrument.

3.   Persistence tables for maximum significant wave heights.

4.   Maximum daily significant wave heights.

In 1991 a statistical summary volume reporting all data collected in the 17 year period between 1975 and 1991 was published. 59 stations are characterized in an annual report format.

1.   Cumulative Height & Peak Probabilities Table.

2.   Height & Peak Period Occurrence Estimates as semilog Functions

3.   Seasonal Data. The significant wave heights for each observation at each station were evaluated during each quarter to display seasonal trends.

4.   Significant Heights of Sea & Swell. The spectra obtained from each observation were divided arbitrarily at a period of 10 seconds. All energy at periods greater than 10 seconds was labeled as "swell" and all energy less than 10 seconds was labeled "sea".

5.   Joint Distribution Table & Plot. Each data run was analyzed for significant wave height and period band containing maximum energy. Figures 2 and 3.illustrate the very large numbers of observations accumulated.

Instrumentation And Deployment Techniques

For nearshore instrumentation the CDIP typically relies on a telemetry cable for both powering the sensor package and recovering the data. While extremely reliable and robust, the requirement for a cable as the data path has presented some unique challenges in instrumentation deployment. For very nearshore applications and where coastal structures such as piers are opportune, gauges can be mounted against available pilings or other permanent structural members. Under these circumstances, installation is a relatively straight forward. Where offshore distance exclude permanent structures, the data cable must travel from the gauge on the ocean bottom, traverse the beach and terminate in a secure beach location. For low to moderate energy beaches, amphibious vehicles (LARC 4) have been used for the difficult task of laying the cable, from the gauge, through the surf zone and on to the beach. The LARC serves as the deployment vehicle in that it carries the sensor package and data cable to the deployment site. Once on site, the slope array is lowered to the bottom

Deepwater Directional Measurements

The CDIP has measured waves for about ten years from the Harvest Platform - a deep water (approximately 225m depth) oil production platform belonging to Texaco. This site, off Point Conception, has particular value because it is open to direct wave approach from both southern swell and Aleutian storms. Recently, a six-element array was added to the platform to allow high-resolution directional data to be collected. The array configuration and the location of the platform are shown in Figure 9. Almost continuous observations are obtained from this station and relayed to shore through a microwave link.
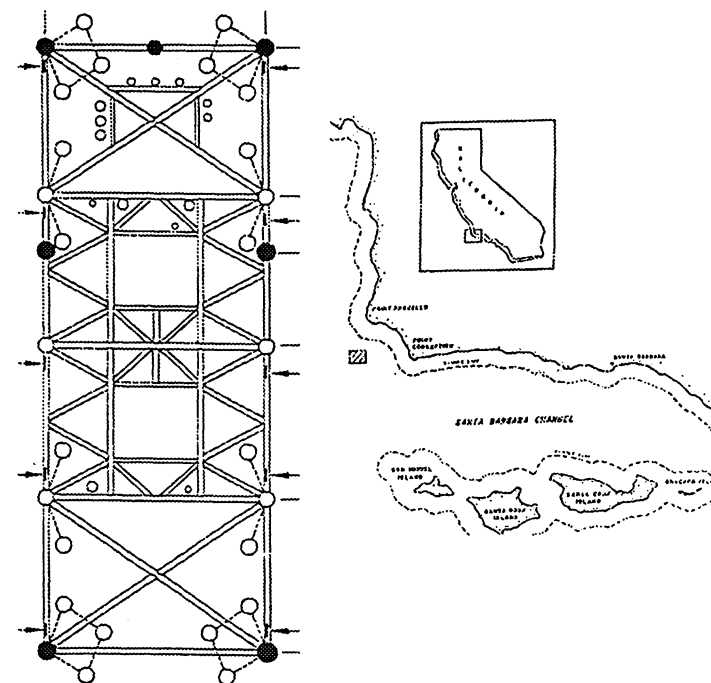

Figure 9. The directional array on the Harvest Platform. The sensors are indicated by the shaded circles in the left diagram, with the maximum distance between sensors of approximately 65 m. The map at the right shows the location of the platform along the California coast.
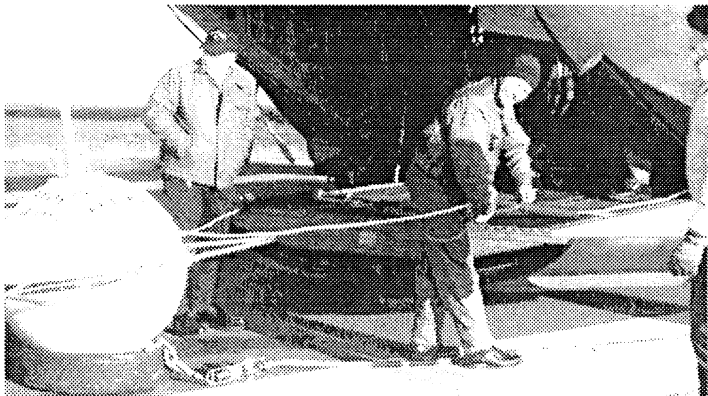
Figure 7. Loading a Waverider buoy prior to helicopter installation off the Washington coast.

In remote, or offshore locations where electricity is unavailable, CDIP has employed solar panels in conjunction with storage batteries to provide power to the sensors. This method works well where cloud cover and vandalism are not an issue. However, battery servicing increase labor costs. Cellular phone service can be used in lieu of regular phone lines. Both the above methods served the network's data collection effort in the Hawaiian islands, as shown in Figure 8.
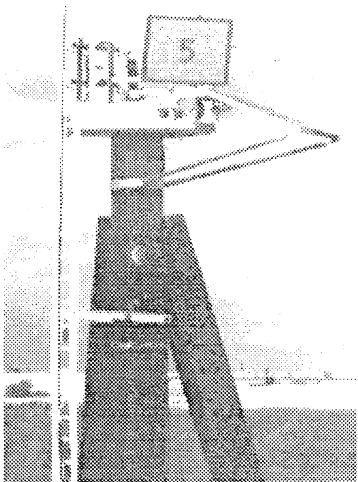

Figure 8. Solar panel powered installation using cellular phone link offshore of Barbers Point harbor in Hawaii.

and the LARC returns to the beach laying out data cable as it advances. A typical LARC deployment arrangement is shown in Figure 4.

SIGNIFICANT WAVE HEIGHT (CM)

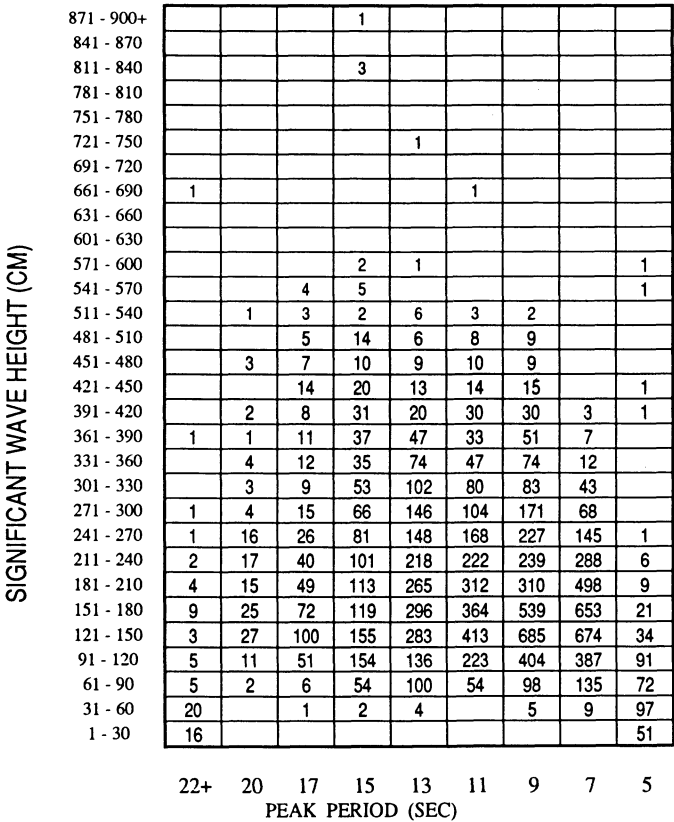| Height	22+	20	17	15	13	11	9	7	5
871 - 900+			1						
841 - 870									
811 - 840			3						
781 - 810									
751 - 780									
721 - 750			1						
691 - 720									
661 - 690	1					1			
631 - 660									
601 - 630									
571 - 600			2	1					1
541 - 570		4	5						1
511 - 540	1	3	2	6	3	2			
481 - 510		5	14	6	8	9			
451 - 480	3	7	10	9	10	9			
421 - 450		14	20	13	14	15			1
391 - 420	2	8	31	20	30	30	3		1
361 - 390	1	1	11	37	47	33	51	7	
331 - 360		4	12	35	74	47	74	12	
301 - 330		3	9	53	102	80	83	43	
271 - 300	1	4	15	66	146	104	171	68	
241 - 270	1	16	26	81	148	168	227	145	1
211 - 240	2	17	40	101	218	222	239	288	6
181 - 210	4	15	49	113	265	312	310	498	9
151 - 180	9	25	72	119	296	364	539	653	21
121 - 150	3	27	100	155	283	413	685	674	34
91 - 120	5	11	51	154	136	223	404	387	91
61 - 90	5	2	6	54	100	54	98	135	72
31 - 60	20		1	2	4		5	9	97
1 - 30	16								51

PEAK PERIOD (SEC)

Figure 2. Joint distribution table of significant wave height and peak period for the Harvest Platform site off Point Conception, CA. The data span from January 1987 to December 1991 for a total of 11,910 observations.
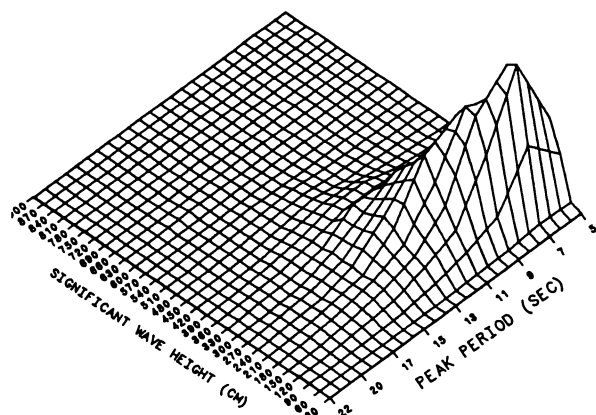
Figure 3. Joint distribution table of significant wave height and peak period for the Coquille River, Oregon buoy. The data span from November 1981 to December 1991 for a total of 13,673 observations.
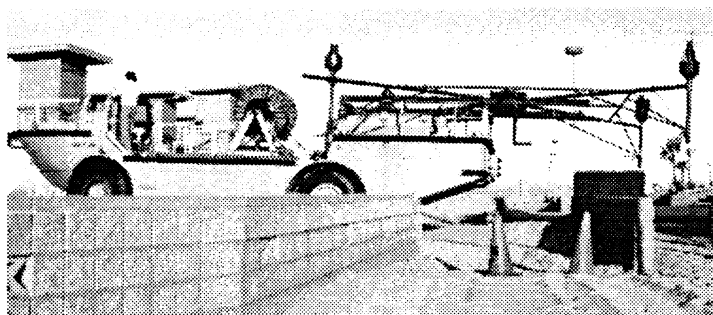

Figure 4. A slope array mounted on a LARC amphibious truck prior to an installation in Southern California.

For high energy beaches or for wide surf zones a LARC is ineffective. For these applications the CDIP has adopted airborne deployments as the method of choice. Using a heavy lift helicopter, the slope array is carried as an external load while the data cable is carried inside the aircraft, as shown in Figures 5 and 6.
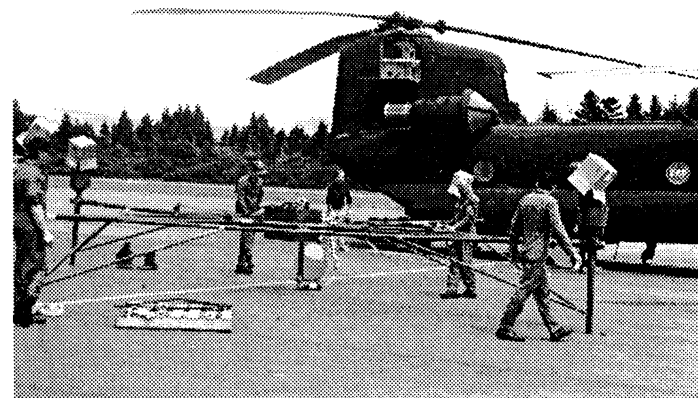
Figure 5. Preparations for installing a slope array by helicopter off the Oregon coast.
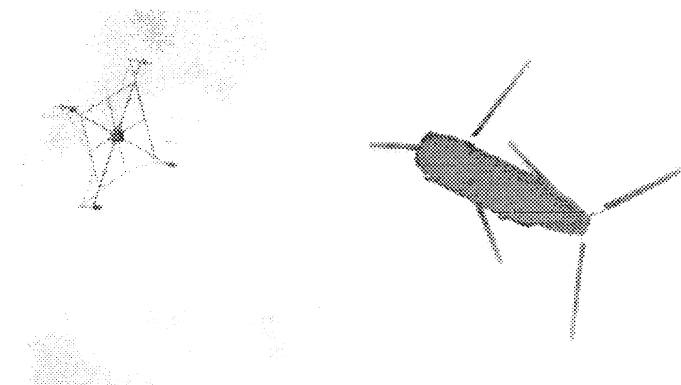

Figure 6. Helicopter installation of a slope array.

Over the target location, identified by a marker buoy, the helicopter lowers the slope array to the bottom, disconnects from the slope array and proceeds towards the beach, laying out cable on its way to the shore station. Over the shore station the data cable is severed with a fast acting pneumatic hydraulic cable cutter and is dropped from the helicopter. This method has proven very successful . The CDIP has also used helicopters in the deployment of offshore buoys. This technique is particularly useful during stormy days where bar closures exclude the use of boats as deployment vehicles. Loading of the buoy on the helicopter is shown in Figure 7.