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Testing Wave Measurement Systems

WAVES MEASUREMENT SYSTEMS TEST AND EVALUATION PROTOCOLS

IN SUPPORT OF NATIONAL OPERATIONAL WAVE OBSERVATION PLAN

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Wave Measurement Systems Test and Evaluation Protocols

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Wave Measurement Systems Test and Evaluation Protocols

1.0 Introduction

In 2009, the Alliance for Coastal Technologies (ACT) supported the U.S. Integrated Ocean Observing System (IOOS), NOAA National Data Buoy Center (NDBC) and U.S. Army Corps of Engineers (USACE) in developing community consensus on a plan for a comprehensive, high quality surface-wave monitoring network for the United States, entitled *A National Operational Wave Observation Plan***.** The national system of surface wave observations proposed by this plan will increase the wave observation spatial coverage along and across the US coasts and will serve as a stimulus for wave modeling activities in verification /validation improvements, data fusion and assimilation. This plan (IOOS, 2009) divides the US coastline into seven primary geographic regions and four along-coast observational sub-nets (Offshore, Outer-Shelf, Inner-Shelf, and Coastal Subnets). The plan focuses on real-time, in situ, directional wave sensors required to create a robust backbone across these four regions. It was further recognized by this Plan that as waves move from offshore to the beach the observational technology changes, as does the accuracy requirements of the sensors employed and the range of user applications.

The plan further recognizes that to serve the wide and ever growing range of IOOS users, a national wave observation network should accurately resolve the directional spectra of the incident surface gravity wave field. To achieve this goal requires that the observations satisfy a “First-5” standard. The plan states, “Technically, First-5 refers to 5 defining variables at a particular wave frequency (or wave period). The first variable is the wave energy, which is related to the wave height, and the other four are the coefficients of the Fourier series that define the directional distribution of that energy.” Since both the incident wave characteristics change with water depth as do the preferred methods of wave directional sensing, a clear Test and Evaluation protocol is required to ensure that operational wave sensing systems meet this stated goal. Technology Testing and Evaluation is called for in the IOOS National Operational Wave Observation Plan (2009) in section 3.3. Within this section of the report ACT is recognized as being well-positioned to support both the sensor requirements of IOOS as well as the technology testing and evaluation component of the plan. In this capacity, ACT hosted a Wave Sensor Technology Workshop at the University of South Florida in March 2007 (ACT, 2007). This workshop brought together wave sensor manufacturers and wave data users. From the workshop, the overwhelming community consensus was that:

- The success of a directional (First-5) wave measurement network is dependent in large part on reliable and effective instrumentation (e.g., sensors and platforms);
- A thorough and comprehensive understanding of the performance of existing technologies under real-world conditions is currently lacking, and
- An independent performance testing of wave instruments is required.

In FY 2010, ACT took a first step in implementing the Plan by developing the protocols for such a Technology Testing and Evaluation effort in anticipation that a comprehensive testing of "state of the art" wave sensors will be required in the near future. To achieve the goal of drafting and defining testing and evaluation protocols, ACT held a second focused workshop where protocols were further refined. The ACT Wave Test and Evaluation Protocol Workshop was held on 22-24 February, 2011 at the University of South Florida. Participants of this workshop included a number of ACT Partner Academic Institutions, ACT Quality Assurance Manager, the Wave Test and Evaluation Technical Advisory Committee and members of the leading government agencies; National Data Buoy Center (NDBC), National Weather Service (NWS), U.S. Army Corps of Engineers (USACE), the Joint Commission for Oceanography and Marine Meteorology (JCOMM), researchers, scientists and resource managers with expertise in wave measurements, as well as representatives from each of the participating wave sensor manufacturers.

The following protocols are based on recommendations and consensus achieved at this workshop and is written based on other successful ACT testing efforts. However, it is important to note that at the time of drafting this protocol, ACT has not been allocated the resources to implement a wave measurement systems evaluation, but this basic framework is intended to be applicable to be utilized by others interested in quantifying the performance of wave measurement systems.

2.0 Background on ACT Evaluations

Instrument performance verification is necessary to enable effective, existing technologies to be recognized and for promising new technologies to be made available in support of coastal science, resource management and the long-term development of IOOS. ACT has therefore been established to provide an unbiased, third party "test bed" for evaluating new and developing coastal sensors and sensor platforms for use in coastal, freshwater, and open ocean environments.

The following protocols describe how ACT would verify the environmental performance characteristics of commercial-ready, in situ, wave measurement systems through the evaluation of objective and quality assured data. The goal of this proposed evaluation program is to provide technology users with an independent and credible assessment of system performance in a variety of environments. Therefore, the data and information on performance characteristics will cover legitimate information that users need. ACT would not simply verify vendor claims, but instead will look to the broader community to define the data and operational parameters that are valuable in guiding instrument purchase and deployment decisions.

It is important to note that ACT does not certify technologies or guarantee that a technology will always, or under circumstances other than those used in testing, operate at the levels verified. ACT does not seek to determine regulatory compliance; does not rank technologies or compare their performance; does not label or list technologies as acceptable or unacceptable; and does not seek to determine "best available technology" in any form. ACT will avoid all potential pathways to picking "winners and losers". Therefore, although the following protocols will apply to all instruments evaluated, no direct comparisons will be made between instruments from different manufacturers and instrument-specific Verification Statements will be released to the public for each instrument type as a final report.

3.0 Roles and Responsibilities of Involved Organizations

The verification test would be coordinated and supervised by the ACT Chief Scientist and ACT Partner Institution personnel. Staff from the Partner Institutions participate in this test by installing, maintaining, and operating the respective technologies throughout the test; operating the reference equipment, downloading the data from the instrument package, and informing the ACT Chief Scientist staff of any problems encountered. Manufacturer representatives shall train ACT Partner staff in the use of their respective technologies and, at their discretion, observe the calibration, installation, maintenance, and operation of their respective technologies throughout the test. QA oversight is provided by the ACT Quality Manager. The Coastal Data Information Program at Scripps Institution of Oceanography (CDIP/SIO), NDBC, and JCOMM will collaborate in different aspects of the Test and Evaluation. In addition to aiding the development of these protocols, the ACT Wave Measurement System Technical Advisory Committee will be consulted during the evaluation in the event problems occur, will assist in the analyses of results, and will review the final Verification Statement prior to release. Specific responsibilities are detailed below.

3.1 ACT Chief Scientist

The ACT Chief Scientist has the overall responsibility for ensuring that the technical goals and schedule established for the verification test are met. The ACT Chief Scientist shall:

- Prepare the draft test/QA plan and verification statements;
- Revise the draft test/QA plan and verification statements in response to reviewers' comments;
- Coordinate distribution of the final test/QA plan and verification statements;
- Coordinate testing, measurement parameters, and schedules at each ACT Wave Test and Evaluation testing site;
- Ensure that all quality procedures specified in the test/QA plan are followed;
- Respond to any issues raised in assessment reports and audits, including instituting corrective action as necessary;
- Serve as the primary point of contact for manufacturers and ACT Partner Technical Coordinators;
- Ensure that confidentiality of proprietary manufacturer technology and information is maintained.

3.2 ACT Quality Manager

ACT Quality Manager for the verification test shall:

- Review the draft test/QA plan.
- Conduct a technical systems audit (TSA) once during the verification test.

- Audit at least 10% of the verification data.
- Prepare and distribute an assessment report for each audit.
- Verify implementation of any necessary corrective action.
- Notify the ACT Chief Scientist if a stop work order should be issued if audits indicate that data quality is being compromised or if proper safety practices are not followed.
- Provide a summary of the audit activities and results for the verification reports.
- Review the draft verification reports and statements.
- Have overall responsibility for ensuring that the test/QA plan and ACT quality procedures are followed.
- Ensure that confidentiality of proprietary manufacturer technology and information is maintained.

3.3 ACT Technical Coordinators

ACT Technical Coordinators at each ACT Partner institution shall:

- Assist in developing the test/QA plan for the verification test.
- Install, maintain, and operate the wave measurement systems at the described test locations.
- Provide all test data to the ACT Chief Scientist and CDIP/SIO electronically, in mutually agreed upon format.
- Remove sensor systems and other related equipment from the test facility upon completing the verification test.
- Provide the ACT Chief Scientist and Quality Managers access to and /or copies of appropriate QA documentation of test equipment and procedures (e.g., SOPs, calibration data).
- Provide information regarding education and experience of each staff member involved in the verification.
- Assist in ACT's reporting of their respective test facility's QA/quality control results.
- Review portions of the draft verification statements to assure accurate descriptions of their respective test facility operations and to provide technical insight on verification results.

3.4 CDIP/SIO

CDIP/SIO shall:

- Develop a PC version of CDIPtool for ACT Wave Test and Evaluation.
- Receive "clean" spectral data from ACT Technical Coordinators or directly from instrumentation if possible for processing.
- Obtain First-5 variables for each frequency band from CDIPtool.
- Produce frequency/energy spectral comparisons with standard methods.

3.5 NDBC

NDBC shall:

- Maintain buoys for co-located experiments.
- Continue with initial co-location exercise in Monterey Canyon.

3.6 JCOMM

JCOMM shall:
- Assist in logistics at Ekofisk. The LASAR array on Ekofisk will provide the "ground truth" for testing the capabilities of the Datawell buoy as a reference method in the evaluation.

3.7 Manufacturers

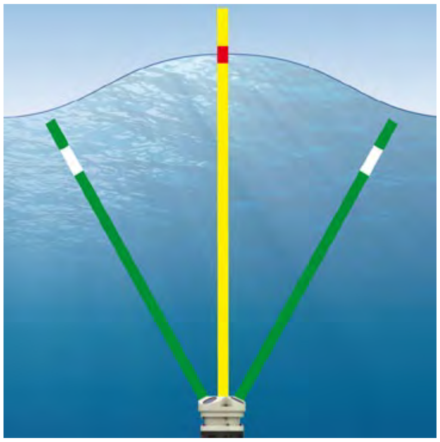
Manufacturers shall:
- Review the draft test/QA plan and provide comments and recommendations.
- Approve the revised test/QA plan.
- Work with ACT to commit to a specific schedule for the verification test.
- Provide duplicate commercial-ready sensor systems for testing.
- Provide on-site operator(s) to train ACT staff in the installation, operation, and maintenance of the sensor systems.
- Review and comment upon their respective draft verification statements.

4.0 Wave Measurement System Capabilities, Descriptions, and Claims

To date, the participating technologies range from the relatively simple pressure sensor to the more complicated remote sensing technologies. Regardless of technology, all instruments tested would be delivered by the manufacture as a stand-alone package, which includes data logging, data transformation/conversion equations, independent power, data transmission and any other features (such as bio-fouling prevention) typically provided to the customer. The following provides a brief summary of the specific technologies planning to participate in an evaluation to date. The sensors are grouped according to their typical deployment location (i.e. seabed, surface mooring, remotely sensed, etc.) because this, in large part, establishes the types of constraints imposed on the varying technologies.

4.1 Seabed Sensors:

Falmouth Scientific - The 3D Wave Meter provides wave direction, wave height, and other wave statistics by combining a high-accuracy acoustic current meter with a high-accuracy, state-of-the-art, micro-machined silicon pressure sensor (PUV method, pressure and U,V velocities). Wave direction is determined by an electromagnetic (flux gate) compass, and can sample at rates of 1 to 5 Hz. The Wave Meter can be deployed in a multiple-mode format to allow periodic burst sampling of wave data as well as long-term averaging. Internal processing of spectral data allows simplified telemetry of wave data for near real-time wave reporting.



Nortek - The Nortek AWAC (Acoustic Wave And Current) profiler is an acoustic instrument based on the Doppler shift of underwater sound waves. This instrument incorporates three distinct technologies to measure and calculate current and wave information: a pressure sensor, the acoustic transducers for current estimation, and an independent vertically oriented echo-sounder for Acoustic Surface Tracking (AST). The AWAC transmits at three different frequencies (1 MHz, 600 kHz, and 400 kHz) to accommodate different deployment depths, and estimates wave characteristics through a combination of the three sensor measurements. The AWAC allows users to select either the Maximum Likelihood method or an SUV-based approach for wave calculations (SUV refers to Surface tracking and U,V velocities). The output-message from both methods includes the First-5 Fourier coefficients. The AWAC is also available with an internal wave processing module that can output finished data products. This module was developed for applications where bandwidth and processing platforms are limited.

Teledyne RDI - The Waves ADCP (Acoustic Doppler Current Profiler) array resolves waves incident from multiple directions while accounting for distortion due to the near-surface current field. While deployed on the seabed, the ADCP Waves Array measures up to a total of 12 radial velocity measurements to quantify the near surface orbital fluctuations at up to 3 different depth levels as input for the directional array processing and also the primary non-directional spectra measurement. The system can operate at 300, 600, and 1200 kHz. This uses up to 20 independent velocity measurements from depth cells located as close to the surface as possible from the ADCP's 4 beams. By measuring near-surface wave orbital velocity variability across a spatial array, the ADCP Waves Array blends both phase and amplitude information to produce a time history of well-resolved frequency-direction spectra. The Waves ADP also provides surface tracking using redundant measurements of the non-directional spectra that are based upon the acoustic range to the surface from each of the beams. It is also capable of using PUV to resolve waves.

Valeport - The MIDAS DWR (Directional Wave Recorder) & WTR (Wave and Tide Recorder) use vertically oriented pressure sensors in combination with Valeport electromagnetic current sensors (ECS) to calculate directional spectra using the PUV method. The ECS measures electromagnetic current oscillations with direction referenced to an internal flux gate compass.

Reported Resolution/Accuracy/Range

	Wave elevation	Period	Direction	Max Depth of operation
	Resolution/Accuracy	(Range obs.)	Res./Accuracy	
Nortek	.01m / 0.1%	0.5-100s	0.1 ^{o} / 2 ^{o}	35m, 60m, 100m
FSI	.145x10^{-3} range/.01%	.4 s	.01 ^{o} / 2 ^{o}	23m
RDI	.025x10^{-3} range/0.25%	1.8/3.5/7s Min pd. for depth	0.5^o / 2^o	80m
Valeport	.01m / 0.1% high acc.	NA	0.1 ^{o} / 2^o	90m

4.2 Surface Moorings:

TRIAXYS - The TRIAXYS Directional Wave Buoy and TRIAXYS Directional Wave Sensor (DWS) measure and calculate waves based on 6 degree of freedom inertial sensing of the hull motion. The DWS is comprised of 3D accelerometers and 3D rate sensors. In addition, the DWS is equipped with a compass to determine wave directional spectra. These sensors ultimately calculate the total displacement along the three orthogonal-axes of the floating platform (x, y, z or North, East, Down). This total displacement is used to calculate both zero crossing wave statistics as well as spectral statistics and directional spectra. Output from the wave sensor includes approximately 20 statistical values, non-directional and directional spectra. The DWS also provides the first four Fourier directional coefficients from 0.030 Hz to 0.64 Hz in 0.005 Hz frequency spacing along with the corresponding energy spectrum for further or alternative processing of the wave spectra.

The DWS is optimal for use in wave measurement from moored or free floating platforms, operating in wave heights of 0.1 meters to 20 meters in height, and wave periods from 1.5 seconds to 30 seconds. The system can be used in any body of water from 2 meters deep to over 5000 meters in depth with appropriate hull platforms and proper mooring designs.

Datawell - The Directional Waverider MkIII is an orbital following, stainless-steel buoy, moored with a 30 m long rubber cord. The vertical wave displacement is measured by an accelerometer mounted on a stabilized platform. Wave direction results from horizontal displacements, determined by two more accelerometers, pitch and roll sensors and a flux gate compass. The resulting system is robust, reliable, low-power (0.3 W), highly accurate, and is applicable in any depth (coastal and oceanic water). Output includes time series of the 3D displacements (@ 1.28 Hz), and heave and directional spectra (First-5) up to 0.58 Hz. Communication through HF link (up to 50 km), Argos, Iridium, Orbcomm or GSM. In addition to the MkIII, Datawell manufacturers a GPS based directional buoy, and a non-directional Waverider.

Reported Resolution/Accuracy/Range

	Wave elevation	Period	Direction	Depth
	Resolution/Accuracy			
Datawell	.01m / 0.5%	1.6-30s	0.4 ° / 2°	Surface
TriAXYS	.01m / 0.2%	0.1s/2%	3.0 ° / 3 °	Surface

4.3 Remotely Sensed:

CODAR - The SeaSonde technology is a high frequency coastal surface wave radar system that maps ocean currents and monitors wave fields in real time. Currents are calculated from the first-order Bragg backscatter of the HF radar waves returned from ocean-surface gravity-waves. Wave information is obtained from second-order sea-echo Doppler spectra representing the interaction of long and short ocean waves. The antenna is permanently mounted on shore or on an offshore structure and total on-site electronics require 350-500 watts of electrical power. Transmitting requires 80 watts at peak performance and 40 watts on average.

WERA – WERA Systems (WavE Radar) use short wave radio technology for long range, high resolution monitoring of ocean surface currents, waves, and wind direction. This shore based system uses back scattered signals (Bragg effect) from radio frequency emissions between 5 and 50 MHz. It uses a linear phased array receiver with 12-16 elements which can observe wave directional spectra including the First-5 Fourier coefficients over a limited region when there is appropriate overlap between two shore stations. This is typically done using an iterative method that inverts the observed Doppler sea echo. From a single station only, wave height and period can be directly observed.

Reported Resolution/Accuracy/Range

	Wave elevation	Upper limit	Period range/res,	Direction res.	Depth of observation
	Resolution/Accuracy	Freq. Dep.		Ant. Dep.	Freq. Dep.
CODAR	n-a / 7-15%		±0.6s	±5-12^{o}	d~> 2-10m
WERA	0.1m/10-15%		±0.6s	n-a	d~> 2-10m

When considering the First-5 and their accuracy, it must be kept in mind that there is a difference between the first coefficient (wave energy) and the other four (directional) coefficients. The wave energy spectrum is a clear concept, directly related to the variance of the sea surface fluctuations, easily translatable in terms of an effective wave height. The directional coefficients however, are merely the first four of an infinite series of coefficients (all of which are inaccessible to single instruments), and their interpretation as direction and directional spread inevitably requires theoretical modeling (e.g. a $\cos^2$s-model or a ME distribution). For example, when using a unimodal directional model for describing a multimodal wave system, directional estimators could be off the mark by as much as 90 degrees, although the sensor accuracy in simulations or under laboratory conditions may be 0.01 degree. Hence this ideal sensor accuracy in simulations or in the lab must be discerned from instrument accuracy at sea. In the latter case, the instrument response function, the statistical validity of the model and the sampling variability are at least as important as the fundamental sensor accuracy.

5.0 Objectives and Focus of Wave Measurement System Verification

It is stated in the IOOS National Wave Plan that "*Continuous testing and evaluation of operational and pre-operational measurement systems is an essential component of the National Operational Wave Observation Plan, equal in importance to the deployment of new assets.*" To have the ability to maintain a continuous testing and evaluation program, the protocols must be created as "living" documents, meaning they should be revisited at timely intervals and updated with lessons learned and new information. The results of continuous evaluations will not only be used to set accuracy requirements for new measurement devices and upgrades prior to implementation of the IOOS National Wave Plan, they will also allow users to determine the accuracy of historical data.

Permanent facilities should be created on the west coast (Monterey Bay, CA – deep water) and the east coast (Duck, NC – shallow water) for continued testing as new technologies develop and current technologies are upgraded. These facilities will also provide unique guidance for defining operational requirements for servicing and replacement of sensitive components of the various platforms. This information will be critical for allocating appropriate resources within the national network.

The development of these permanent facilities will provide opportunities to evaluate sensor performance in extreme conditions in the future. These extremes may include extreme winds, wave heights and/or currents, all of which may impact different aspects of sensors and associated mooring and communication systems. In these circumstances it will be important to evaluate the full frequency-height response because there could be disparate effects on short and long waves. These "extreme tests" will inform the NWS Weather Forecasting Office (WFO) as to the validity of hindcast data used in understanding forecast model extreme events.

6.0 Verification Design

Initial generic protocols were further refined through direct discussions during an ACT Wave Test and Evaluation Protocol Workshop held on 22-24 February, 2011 (described above). The protocols will follow a format that includes field tests to evaluate performance under a variety of environmental conditions. Laboratory tests will not be a component of this evaluation. Due to the large scope of the evaluation, it has been broken down to 5 Tasks and presented in order of feasibility and importance. Each of these components is described in detail in the sections that follow.

7.0 Test Verification Factors

Based on the extensive discussions held in the workshop, the test protocols will be primarily focused on the wave sensors performance in successfully recovering the "First-5" parameters. Performance will be determined by comparing each sensor's output with the reference method over a predetermined range of wave frequencies. The First-5 refers to the total wave energy (integrated over all frequencies), and the four directional parameters that define the low-order directional moments of underlying directional distribution of wave energy.
Here, ACT will adopt an approach developed by the CDIP/SIO that evaluates the differences between the first four directional parameters at specified frequency and energy bins (Figure 1). This practical approach to evaluating two sets of wave observations deviates from the traditional spectral representation of wave frequency-directional spectra as energy densities and instead interprets the spectrum as quasi-2D spectral wave components. It is motivated by the realization that directional wave instruments measure the frequency distribution of wave energy with greater resolution than the directional distribution. By defining the specific bins of frequency and energy to be compared, the ability of an instrument to measure the 4 directional parameters of each component relative to a second benchmark instrument can be directly evaluated.

ACT's purpose for adopting this methodology is to provide comprehensive information on the sensors and their relative differences with the standard. We define the observed wave components only by frequency and energy, and then look at the differences in the four directional distribution parameters. The goal is to deploy sensors in appropriate locations and for sufficient duration to fill out the frequency-energy matrix. This will provide an understanding of how each sensor behaves for a variety of frequency/energy combinations.

The frequency dependence of the directional errors is particularly important because large differences in particular frequency ranges may be obscured by integrating over all frequencies. An example of this is shown in Figure 1 where differences between the Datawell GPS and MKII wave measurement systems become much larger as frequencies increase above 0.35 Hz. While this may not be important for an experiment in a swell dominated regime, it will be significant in locations where the observed waves are fetch or duration limited. This methodology is consistent with other ongoing efforts (e.g. CDIP evaluation protocols) that will provide additional data for comparisons and will facilitate the involvement of databases obtained from other ongoing efforts.

The matrix (Figure 1) displays the range of conditions where it may be possible to evaluate instrument performance. The dashed line indicates the JONSWAP spectrum (Hasselmann *et al.*, 1973) for an extreme wave with H_s of 20-m. The highest frequency included here (0.5 Hz) is the upper limit for the reference instrument (Datawell MKII) in typical deep water conditions. While this includes most of the energy in the surface wave field, significant remote sensing applications focus on waves with frequencies higher than this cut-off. These waves will not be included herein. For a particular experiment to have achieved a robust comparison of sensors there should be a sufficient number of samples at each frequency-energy bin to determine whether there is a significant difference between mean derived parameters. This will require long duration deployments to establish sufficient sampling over most of the intended range.

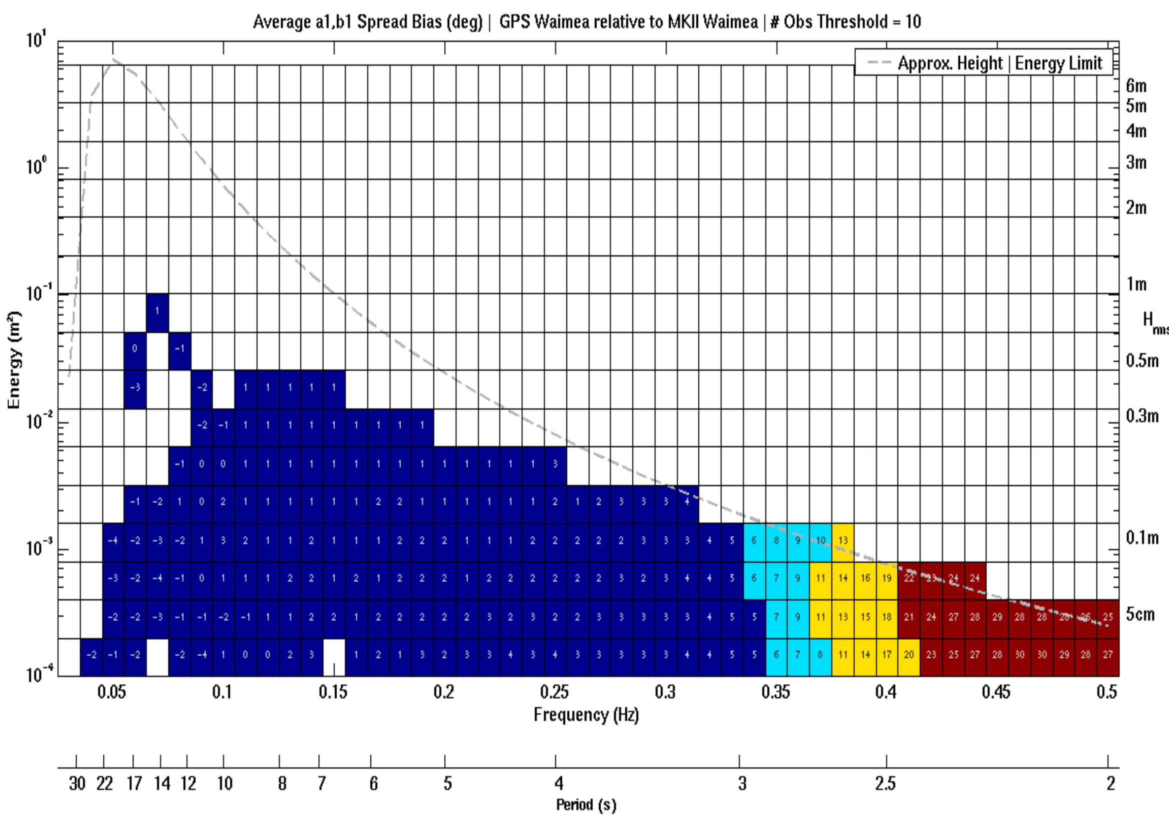


Figure 1. Sample frequency energy comparison plot of directional differences for GPS based and MKII wave observations at Waimea, HI. Dashed line represents the extreme JONSWAP spectrum for a wave with a 20 m H_s.

Some manufacturers expressed concern about their technologies' ability to resolve the First-5. In some cases this evaluation will serve as an exercise to determine whether in fact these sensors can resolve the desired parameters by establishing the following descriptors for comparisons with the reference instrument for each of the First-5 coefficients.

Unanimous agreement was obtained between both manufacturers and the user community to implement a practical, in-situ, field Test and Evaluation, no absolute standard exists for determination of the First-5 Fourier components of the incident wave field across all spatial domains. Hence, based upon this recognized reality, the Directional Waverider DWR- MkIII manufactured by Datawell Oceanographic Instruments will be used as the reference/standard for the deep and intermediate water wave evaluations. For more details on this selection, see Section 9: Reference Methods, of this report.

This Technology Evaluation will verify:

Accuracy: combination of bias and precision which reflects the closeness of the measured value to the true value. Accuracy will be determined in the field by a comparison of differences in the mean values reported by the test sensors versus values determined by the Datawell Waverider (see below) of the First-5.

Bias: consistent deviation of instrument measured values from the true values, here designated as the First-5 from the Datawell Waverider, caused by systematic errors in a procedure.

Precision: measure of the degree of agreement among replicate measurements of a sample, usually expressed as a standard deviation. Precision will be determined by a comparison of differences in standard deviation values produced by the test instrument versus values determined by the Datawell Waverider for a particular frequency/energy bin. We cannot control the number of replications because this is environment-dependent; however, a minimum number of replicates are required to determine whether there is a statistically significant difference between observed values.

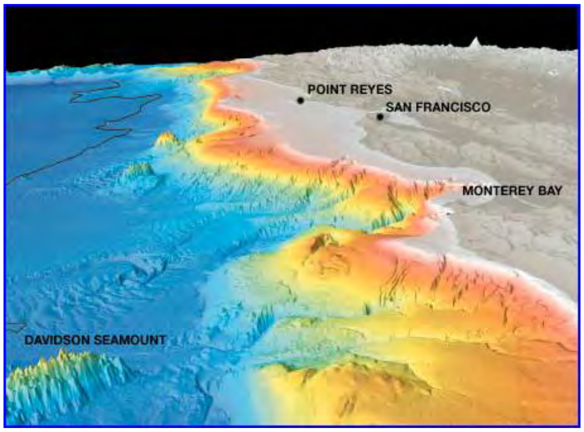
Drift: changes in the deviation of instruments measurements of the First-5 relative to the Datawell Waverider First-5 over the duration of the field test.

Reliability: measure of the ability to maintain integrity of the instrument and data collections over time, while adhering to manufacturer recommendations. Reliability will be determined by comparing the amount of the data recovered versus the amount of data expected.

8.0 Overall Test Configuration

Wave Sensor Test and Evaluation will involve a phased approach. This approach will allow the participants to focus on the evaluation for one environment while planning for testing in other environments, ultimately resulting in sensor testing in a matrix across a number of deployment environments. *These prioritized environments, in order of action/importance are: i) deep water on the West coast of the United States, ii) shallow water on the East coast of the United States,* *iii) enclosed large freshwater basin in the Great Lakes, and iv) shallow water with potential episodic events in the Gulf of Mexico.*

The deep water deployment in Monterey Bay will be the first Test and Evaluation task to be completed. Existing efforts are in place for a co-location exercise with Datawell, NDBC and MBARI. This JCOMM and NDBC sponsored project was planned for August 2011, pending funding availability, but its status is unknown at the time of this writing. While this is not an ACT sponsored test, it is suggested that the wave measurement evaluation build on this effort in the upcoming years by creating a permanent buoy farm at this location for deep water wave sensor testing. The continued deployment of the sensors making up the buoy farm will require continued operation and maintenance funding to keep the NDBC buoys deployed in this location. The sensors deployed for the initial NDBC/JCOMM co-location project will be retrieved in 2012.



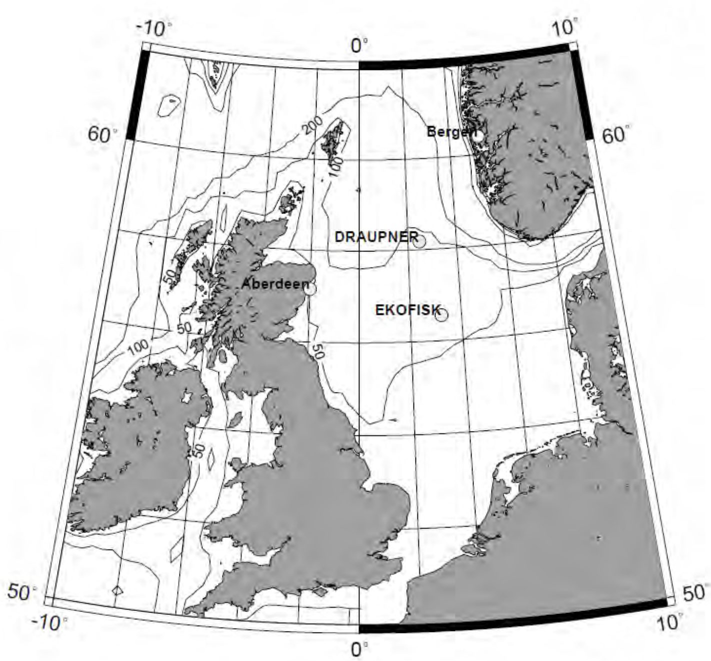
The shallow water deployment at the USACE Field Research Facility (FRF in Duck, NC), Great Lakes Deployment, and a Gulf of Mexico deployment would be the second, third and fourth priorities. The FRF will serve as the permanent shallow water evaluation location. Wave sensing instrumentation from participating manufacturers will be deployed for a full year at each Test and Evaluation location to ensure exposure to the full diversity of conditions for each environment.

9.0 Reference Methods (Task 1)

Unanimous agreement was obtained between both manufactures and the user community that to implement a practical, in-situ, field Test and Evaluation, no absolute standard exists for determination of the First-5 Fourier components of the incident wave field across all spatial domains. An exception to this observation may exist in one coastal (shallow water) and one intermediate/deep water location. In the coastal region, the USACE Field Research Facility (FRF) provides a unique measurement opportunity as well as long time series data of wind and waves. At the FRF, the Long Linear Array exists in 8 meters water depth which provides excellent directional resolution of the incident wave directional spectra. Similarly, in deep water, the Conoco Phillips off-shore platform Ekofisk, in the North Sea provides a stable platform in a water depth of 70 meters encompassing a Laser Array (LASAR), providing direct measures of wave height, period and direction through a wide range of frequencies. These two unique facilities will be utilized in providing direct comparison for the proposed "reference standard."

Hence, based upon this recognized reality, the Directional Waverider DWR- MkIII manufactured by Datawell Oceanographic Instruments will be used as the reference/standard for the deep and intermediate water wave evaluations. The DWR-MkIII has established a long and impressive history of side-by-side comparisons with other wave measurement systems and in particular with the Long Linear Array at FRF. Based on this history of comparison, the DWR-MkIII was selected as the "reference standard" for the purposes of these Technology Test and Evaluation protocols. The Waverider buoy uses Hippy heave-pitch-roll sensors to measure wave direction and energy and carry two horizontal accelerometers for measuring north/south and east/west displacements. This translational system uses pitch-roll to correct the buoy movement to a fixed x-y-z reference frame, giving it a better signal-to-noise ratio than buoys that use pitch-roll directly to estimate directional wave properties. The Waverider is the primary wave system operated by the Coastal Data Information Program, located at the Scripps Institution of Oceanography (CDIP/SIO). The Waverider has been shown to effectively measure waves with periods from 1/6 to 30 seconds with an error of no more than 3%. (see http://cdip.ucsd.edu/?nav=documents&sub=index&units=metric&tz=UTC&pub=public&map_stati=1,2,3&xitem=gauge#buoys)

As Task 1 of the Wave Test and Evaluation Plan, the Datawell Waverider Buoy will be verified for deep water at the Conoco Phillips off-shore platform Ekofisk in the North Sea in 70 meters water depth. The Ekofisk Laser Array (LASAR) has been in operation since February of 2003 and carries four vertically pointed lasers for wave measurement in a square configuration. The downward looking Optech lasers are positioned on bridges Flare North and Flare South, in the platform complex. The laser instruments determine the height of the sea surface at a fixed horizontal position by measuring the time from the emission of a light pulse to its detection after reflection at the air-water interface.



Location of EKOFISK in the North Sea (Norwegian Meteorological Institute).

As reported by Magnusson (2008) "…(Norwegian Meteorological Institute), Phillips Petroleum Norway, now ConocoPhillips, has recorded waves at or in the vicinity of the Ekofisk complex since 1980. Different sensors have been used, and mounting locations on the complex have changed through time. In the years 1991 to 1993, environmental data were available through modem. Since 1993 data have been transferred in real time through internet. The first winter season (1991-1992), wave data from two height measuring systems (an EMI radar and a Plessey radar) were largely affected by lee effects from the tank structure. Focus was thereafter placed on good quality wave measurements, because forecast skills are highly dependent on measuring feedback. A WAMOS (www.oceanwaves.de) was installed to measure directional wave spectra at 2/4-K, and two new sites were chosen for 2 down looking lasers (Optech lasers), one at flare South, with good exposure to waves from east-west direction, and one at flare North, with relatively good exposure to northerly directions, and also from the east and west sectors. This paper only deals with the wave measurements from the in-situ systems (wave profilers). The two Optech lasers have given relatively good measurements in the period 1995-2005, although with known problems of possible reflection of waves from the tank in northerly situations at the northern flare, and sea spray from the platform legs in the vicinity of both sensors when waves are large, as…" during a storm.

Further Magnusson (2008) goes on to state "Due to decommissioning of the platforms North of the tank, the sensor at flare North was replaced in 2005 with a new system of 4 lasers in an array on the bridge between 2/4-K and 2/4-B (Krogstad et al., these proceedings). The bridge is oriented East-West, with open sector towards North and South. Waves from the westerly sector may be subject to interference with the 2/4-B platform, which is about 80 meters away. The sensor at flare South was replaced with a MIROS down-looking radar altimeter, a Miros Range Finder (MRF)."

9.1 Co-locating Systems

The first and highest priority task of an ACT Test and Evaluation calls for the Datawell Waverider Buoy to be co-located with this array and evaluated against the LASAR.

Although the scientific community is aware of some of the issues with LASAR, the consensus is that a co-location exercise with a directional Waverider is necessary. At present, there is a non-directional Waverider at LASAR. However, ACT will purchase the directional Waverider and be responsible for buoy deployment at the Ekofisk site with Ekofisk oversight. Pre-deployment calibration of the Buoy will be performed by Datawell. This same directional Waverider will be used for all subsequent ACT co-location exercises; thus providing a reference standard for all future testing and evaluation.

For data review and delivery during the reference standard evaluation, the buoy will be capable of both iridium and high frequency (HF) radio communication. HF was considered necessary in case the buoy breaks loose from its mooring. The hand held GPS tracking unit, essential in recovery, communicates via HF. Iridium communication has proven to be very reliable offshore and out of range of the HF radio communication.

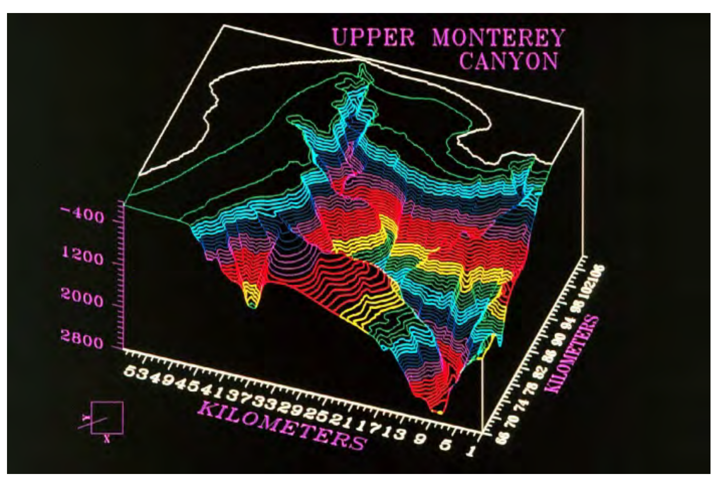
For a similar comparison in shallow water, the 15 sensor pressure array located at U.S .Army Corps of Engineering Field Research Facility (FRF) in Duck North Carolina will serve as the verification standard. As specified by the FRF, wind wave frequency-direction spectra are obtained from the nine-element linear array of bottom mounted pressure gauges located on the 8-m contour about 900 m offshore of the FRF. Directions depicted in frequency-direction spectra from the FRF 8-m array represent azimuths from which waves arrive in degrees counterclockwise from normal to the array, or from parallel to the FRF pier, or, approximately, from shore normal. Zero degrees represents waves propagating straight onshore, having wavenumber vectors aligned with the pier, and wave crests perpendicular to the pier. A direction of +45 degrees indicates waves coming from the northeastward side of the pier, and propagating along an azimuth 45 degrees to the left of the pier axis for an observer looking seaward. An angle of +90 degrees represents the (rather uncommon) condition of waves propagating straight down the coast from north to south. Negative angles represent waves from the southeastward side of the pier. Waves at -45 degrees propagate onshore and northward along an azimuth 45 degrees to the right of the pier axis for an observer looking seaward.

All results are based on 8192-sec (2 hr 16 min 32 sec) time series of data collected at 2 Hz or, rarely, 4 Hz. The basic analysis algorithm is the iterative maximum likelihood estimator derived as described by Pawka (1983), using his recommended convergence parameters and a maximum of 30 iterations. A description of the FRF linear array is given by Long and Oltman-Shay (1991), and details of data analysis are given by Long and Atmadja (1994).

10.0 Field Study Location and Deployment

10.1 West Coast, Deep Water Waves (Task 2)

In situ evaluations of wave measurement systems performance in deep water, moored, application will be conducted in Monterey Bay, CA. This location was chosen to capture the long period, energetic waves typical of the west coast environment. It was noted that the complicated bathymetry of the Monterey Canyon causes large, longshore, spatial variations in shallow water waves making this a poor choice for a co-located shallow water wave test and evaluation. The depth at the proposed deep water location (36.753N, 122.423W) in the Canyon is 2115 meters. As stated previously, NDBC and JCOMM are both deploying directional wave sensing buoys at this location for a co-located inter-comparison. NDBC 46042 (3-m discus buoy), MBM2 (NDBC 46093), and a Scripps Datawell Waverider (NDBC 46236) are currently positioned in the Canyon.



ACT would take advantage of these existing tests and operations by using the NDBC/JCOMM deployed Datawell Waverider for its standard and deploying the participating manufacturers' instrumentation near, on, or around the NDMB buoy 46042. The test instruments will be pre-calibrated by the methods designated by the manufacturer for operational deployment. Superstructure and bridle must be configured as it is to be deployed operationally. The mooring should follow manufacturer's recommendations for deep water mooring.

Ancillary data are provided by NWS WFO Monterey operationally running the SWAN Model, and by CDIP providing additional wave model output (see: http://cdip.ucsd.edu/themes/user_groups/mariners). Wind speed, direction, atmospheric pressure, air temperature, relative humidity and sea surface temperature are all available at this test site. Additionally, there are 8 coastal -HF Radars, (2 long and 6 medium range) providing surrounding data. It was also noted that NOAA has stationed its LIDAR aircraft at Monterey and can also collaborate with satellite observations. This location was viewed as an ideal, multi-party collaboration. Special thanks to JCOMM and NDBC for making this comparison possible.

10.2 East Coast, Shallow Water Waves (Task 3)

In situ evaluations of measurement systems performance in shallow water will be conducted at the FRF. Located on the Atlantic Ocean and Currituck Sound, the FRF supports coastal missions of the U.S. Army Corps of Engineers. The FRF, an IOOS Observatory, has a 15 sensor, cross shore, pressure array located at 8 meters water depth for high resolution, shallow water directional spectra wave measurement. The pressure array extends 250 meters in the longshore direction and 100 meters in the cross shore direction. There is also a nearshore acoustic array in 3.5 -11 meter depth, two Directional Datawell Waveriders, one in 17.4 meter depth and another in 26 meter depth, and a NDBC Buoy (44014) in 48 meter depth. The 8 meter pressure array transmits data that are sampled at 2Hz for 2 hours, 16 minutes every 3 hours. NWS WFO Morehead City/Newport, NC is running SWAN for this region and are also providing meteorological data. The Delft 3D Model is also available for this location. Satellite observations can also be obtained.

This site will be used to evaluate acoustic and pressure sensor measurement systems as well as buoys. The ADCP's (such as RDI and Nortek) will be deployed 30 meters apart, to avoid cross talk, in 8 meters depth. The FSI and Valeport can be deployed directly within the pressure array with no concern of interference. A TRIAXYS will be added to the NDBC 1 meter buoy and the Waverider will be deployed in the surf zone. If test buoys have an integrated meteorological package they will be deployed further off shore and co-located with the 17.4 meter depth Waverider. All systems will be deployed in the longshore direction. A Datawell may be deployed in 8m array as well. All the instruments will be cabled for real time data transmission to insure the systems are working for the entire deployment. Instrument maintenance will be per manufacturer recommendations. All raw data from instruments will be recorded and processed as in full operational deployment. ACT staff will be on site to set up and deploy instrumentation with support from USACE.

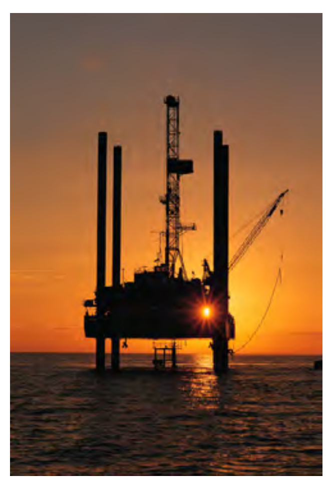
The shallow water test at the FRF site will also heavily benefit the local NWS WFO and their efforts to implement and improve their near shore wave modeling efforts. Data from this co-location exercise will be made available to the WFO in near real-time for this purpose.

10.3 Great Lakes, Deep Water and Shallow Water Waves (Task 4)

There are two potential sites for a co-located evaluation in the Great Lakes. The first is a deep water site (160 m) adjacent to NDBC 45007 in southern Lake Michigan. The deep water site will be the top priority for the Great Lakes evaluation. A secondary, shallow water site was identified (20 m water depth) immediately offshore of the NOAA / GLERL (Great Lakes Environmental Research Laboratory), Field Station in Muskegon, MI. This region has cabled capability for instrument communication and data collection. Ideally, the evaluation would begin in March and end in November due to the constraint of winter weather (ice) conditions. However, near shore wave measurements and wave instrument performance during the winter months are critical to the NWS WFO operations. One component of this test would be to keep bottom-mounted wave sensors in the water during the winter months to evaluate performance in this harsh environment.

Efforts will be made to determine the interest of the Canadian Government in investing their buoys for a Lake Superior deployment. If they have no interest in comparison, ACT will deploy the sensors in southern Lake Michigan. The Datawell Waverider will be co-located with the NDBC buoy 45007, S2, and Triaxys.

10.4 Gulf of Mexico, Episodic Events (Task 5)



The Gulf of Mexico site was chosen to provide an evaluation of instrument performance in shallow water, off Tampa Bay, during extreme events. The USF/COMPS network operates and maintains a coastal and offshore monitoring network that measures currents, in-water parameters, and a full suite of meteorological variables. A co-location exercise off Tampa Bay would be ideal due to the amount of available ancillary data. Overall, meteorology is not significant for general wave climatology, however tropical storm systems can spin up waves at least 6 meters high. It will also be valuable to consider a deep water co-location evaluation using oil platforms as deployment sites. Most platforms are equipped with oceanographic sensors and capabilities for additional deployments. This would require collaboration and logistical support from platform operators. ACT identifies this as a low priority. If the funding climate dictates, the

East Coast deployment site is also capable of capturing episodic events in the form of tropical cyclones or severe winter storms.

An additional component of an Eastern Gulf of Mexico evaluation would include co-locating wave sensing technologies with the CODAR and WERA footprint. There is an operational WERA system located on the West coast of Florida between Coquina Beach and Venice. There are also three CODAR sites in this region at Redington Shores, Venice, and Naples. The evaluation of the radar technology may include the First-5 in limited situations. There is interest in comparing wave statistics from the Waverider to those generated by the radar, particularly for large amplitude, episodic events.

10.5 Test Instrument Calibration and Deployment

At all test and evaluation deployment sites described above, both the reference and the test systems should be co-located to the extent feasible. It should be assured that there is substantial distance between the test site and hydrographic features that may cause spatial variation in the wave field. The system separation distances will be dictated by the water depth and mooring lengths. The instrumentation should be as close as possible without interference from one another and each test system should be deployed equal distance from the reference buoy.

10.6 Ancillary Measurements

ACT will provide measurements of local meteorological data as well as and in-water ancillary data (water velocity and temperature). Both deep and shallow water sites have existing infrastructure and monitoring for these variables. However, ACT will guarantee their availability and performance to participating manufacturers and the NWS WFO.

10.7 Reference Instrument Calibration and Deployment

10.7.1 Datawell Waverider

The calibration of the Waverider is essentially the comparison of measurements performed in the ferris wheel (the rig) to the known dimensions and orientation of the rig, at three different frequencies (corresponding to 20, 12.5 and 6.25 s). The rig's orientation is regularly established by a reference compass. In addition, the cross-sensitivity of the accelerometers is checked, as well as the (sea surface) temperature sensor. (For details on the calibration process, see http://download.datawell.nl/documentation/datawell_publication_hydrographicinstrumentation-calibrationwavebuoys_oct1993_2004-06-30.pdf)

Instrument Standard is a Datawell Mark III Series Directional Waverider. For details concerning the Datawell Mark III deployment and operations, please consult the Datawell DWR-MKIII manual accessible on the website at: http://datawell.nl. The pre-deployment buoy configuration and preparation should be verified according to the Datawell DWR manual. Between each deployment, accelerometer and compass checks are performed. Datawell suggests that every 3-6 years, the buoy is returned for calibration. Calibration ferris wheels are presently located in The Netherlands at the Datawell facility or at CDIP at the Scripps Institution of

Oceanography in La Jolla, CA. Additional ferris wheels could be manufactured as geographic coverage necessitates.

When deploying the Datawell, no additional superstructure or sub-structure mounts must be attached. The accuracy of the wave measurements is dependent upon the frequency response of the buoy. The mooring system consists of a 30 meter bungee and terminations supplied by Datawell, polypropylene line for the appropriate depth (2*depth, or 1.5*depth in deep water with little current) and large anchor chain links for the 1200-pound anchor. Datawell approved mooring line must be used. Deployment protocol as specified by Datawell is explicitly described in the manual. The Mark III deployment is very straightforward, and depending on sea conditions and distance offshore, can be performed from small vessels. Additional information can be found at: http://cdip.ucsd.edu/?nav=documents&sub=index&pub=public&map_ stati=1,2,3&xitem=gauge#buoys. It is suggested that the buoy be capable of both iridium and HF. As mentioned, HF is necessary in case the buoy breaks loose. The hand held GPS tracking unit is essential in recovery (which communicates via HF). Iridium communication has proven to be very reliable and solid.

10.7.2 FRF Pressure Array

The FRF long linear pressure array is perhaps the only location for which real and accepted “sea truth” exist for incident directional wave spectra. The fundamental work on this nearshore directional wave sensing system was performed by Long and Oltman-Shay (1991). The array consists of 15 bottom-mounted pressure sensors centered on the 8-m contour about 900 m offshore. Under most conditions this location is beyond the active surf zone. Records of 136 min duration are collected at 3 hourly intervals at a sampling rate of 2 Hz. Time series are windowed and Fourier transformed to compute cross-spectra between all unique pairs of gages. Cross-spectra of pressure are surface corrected to sea-surface displacement cross-spectra using linear wave theory, and then ensemble and band averaged for a final resolution bandwidth of 0.01 Hz (approx. 160 DOF). Directional spectral estimates are made using the Iterative Maximum Likelihood Estimator on both the full 15-gage array (360 degree processing) and on just the 9 gages of the longshore linear array (180 degree processing). The latter calculation is necessary because refractive blurring occurs in the 360-degree analysis (Long, 1994). This high-resolution directional array produces estimates of incident directional wave spectra to approximately 2 degrees under nominal east coast wave conditions (Long & Oltman-Shay, 1991). Hence, it represents an ideal shallow water test and evaluation location.

11.0 Data Management

The purpose of the CDIP wave instrument intercomparison tool (CDIPtool) is to allow wave data collectors and instrument developers to easily compare wave spectral data from different sources, and view the differences between spectral data sets in a standardized form. It compares wave spectra data sets that have been calculated by the user or by using the processing software provided by an instrument manufacturer. The sampling rates are sensor/manufacturer issues and not related to the CDIPtool.

As for the spectral layout/frequency bands, CDIPtool takes all spectra and redistributes them into equal-width 0.01Hz bands.

In addition, the tool is only useful when used with weeks or months of wave spectra from two different sources, not just a single record. The CDIPtool will be ideal to compare ACT's proposed longer term co-location exercises.

The intercomparison spectral data are permanently archived at the CDIP facility. All results are in the public domain.

12.0 Quality Assurance/Quality Control

Credible, high-quality performance information is one of the tenets of independent testing and verification of wave measurement systems. In order to provide verifiable and defensible data on the performance of wave instrumentation, the testing organization must control its technical and human factors that affect quality. Therefore, the highest appropriate level of quality assurance (QA) and quality control (QC) procedures should be applied throughout the test. Quality assurance is the system of review procedures that verify that test activities are likely to meet specific data quality objectives. Quality control activities provide routine and consistent checks to ensure data integrity, correctness, and completeness; identify and address errors and omissions; and document and archive all test operations.

Only data collected under a well-defined, documented quality system should be considered for verification of wave instrumentation performance. The quality system provides the framework for planning, implementing, documenting, and assessing work performed by the organizations carrying out the verification testing and for carrying out QA/QC activities. The goal of the quality system is to ensure that decisions on technology performance are supported by data of the type needed and accepted quality standards and practices. Because QA/QC related to real-time, in situ, surface wave data is covered by existing standards such as Quality Control of Real Time Data (QARTOD), the Coastal Data Information Program (CDIP), and the National Data Buoy Center (NDBC), this guidance addresses quality systems at the organization level and focus on the verification process.

There are several quality system standards and models that may be considered for wave instrumentation verification, and there is considerable commonality among them, regardless of application. The quality systems for two technology verification organizations, the U.S.E.P.A's Environmental Technology Verification Program (ETV) and NOAA's Alliance for Coastal Technologies (ACT), are based on the national consensus standard ANSI/ASQ E4-1994. The American National Standard, *Specifications and Guidelines for Quality Systems for Environmental Data Collection and Environmental Technology Programs* (ANSI/ASQ E4-1994) (ANSI/ASQ, 1995), was developed to promote consistency among the many quality systems requirements for environmental programs throughout the Federal government and the environmental industry. The standard provides a basis for planning, implementing, documenting, and assessing an effective quality system and describes the elements that, at minimum, should be in place to ensure that a functional quality system exists for organizations that perform environmental data operations or design.

Implementing a quality system requires resources, expertise and time. Therefore, the development and implementation of a quality system should be based on the scope and nature of program and the intended use of its products or services. A "one size fits all" approach is not appropriate, and the use of a component or tool should reflect the specific needs of stakeholders. For example, the quality expectations of a research program are different from that of a technology verification program because the intended use of the products differs.

Practical considerations in developing any quality system include some of the following:

- The level of QA/QC appropriate for testing;
- Resources allocated to QA/QC for different phases of verification;
- Frequency of QA/QC checks and reviews of field tests and data quality;
- Time allocated to conduct the checks;
- Requirements for archiving information;
- Procedures to ensure confidentiality of proprietary information, when required, and
- Whether sufficient expertise is available to conduct the checks and reviews.

The main components of a quality system at the organizational level include may include: 1) quality system documentation; 2) system assessments; and 3) training. The individual test-level components cover 1) planning, 2) implementation, and 3) assessment, corresponding to the different phases of the T&E life cycle. Successful implementation of each component at the program and test levels is important to an effective quality system. Tools are available to assist in the implementation of each of these components.

The organization/program components of a quality system for wave instrumentation T&E should address the policies and responsibilities that apply to activities that are common to all verifications:

1. Quality System Documentation - A Quality Management Plan (QMP) is a document that describes the waves T&E quality system. It identifies the organizational structure, policy and procedures, functional responsibilities of management and staff, lines of authority, and its processes for planning, implementing, documenting, and assessing all activities conducted under the quality system.

2. System Assessments – Quality System Assessments and Audits are tools that are used to verify that applicable elements of the quality system are appropriate and have been developed, documented, and effectively implemented. The focus of these assessments is on the quality system process.

3. Training – Training should be provided to ensure that all personnel for T&E activities have the skills and knowledge to complete their tasks in accordance with the quality system's requirements.

Quality system components for individual tests include activities and tools which are applied to ensure that test objectives are achieved:

1. Planning - Systematic planning methods should be used to develop performance criteria for the test data, i.e., the type, quantity, and quality of data needed to meet test objectives. A Test Plan or Protocols should be prepared to describe the steps to satisfy these criteria and to determine the level of oversight and quality control activities needed to ensure the criteria are satisfied. The Test Plan is therefore used to guide personnel in performing appropriate procedures, using specified equipment, and performing specified operational and maintenance checks.

2. Implementation - Data should be collected according to the methods and procedures documented in the approved Quality Assurance Project Plan and other test design documentation, such as standard operating procedures. Technical system audits may be conducted during data collection to assess whether or not data are being collected as stated in the Test Plan. Deviations from planned procedures should occur only with agreement of all parties involved in the test and should always be documented before being implemented.

3. Assessment - The test data are verified to ensure that the measured values are free of errors due to procedural or technical problems and then are analyzed and validated to determine if they meet the performance criteria documented in the Test Plan.

Successful implementation of a Quality System for waves instrumentation T&E contributes to:

- Increased data integrity, i.e., technology performance data of known and documented quality based on sound scientific principles.
- Improved oversight for evaluation purposes.
- Improved decisions on technology use.

12.1 Audits

Independent of each Partner test facility QA activities, the ACT Chief Scientist will be responsible for ensuring that the following audits are conducted as part of this verification test at a minimum of three ACT Partner test sites. Audits shall be performed by Quality Assurance personnel, who shall be independent of direct responsibility for performance of the verification test.

Performance Evaluation Audits – A performance evaluation audit will be conducted to assess the quality of the reference measurements made in this verification test. Each type of reference measurement will be compared with a National Institute of Standards and Technology (NIST)-traceable standard that is independent of those used during the testing. This audit will be performed once during the verification test.

Technical Systems Audits (TSA) – ACT's Quality Assurance personnel will perform a TSA at least once during this verification test. The purpose of this audit is to ensure that the verification test is being performed in accordance with the test/QA plan, published reference methods, and any SOPs used by the Partner test facility. In this audit, the ACT Quality Assurance personnel may review the reference methods used, compare actual test procedures to those specified or referenced in the test/QA plan, and review data acquisition and handling procedures. A TSA report will be prepared, including a statement of findings and the actions taken to address any adverse findings.

Data Quality Audits – ACT's Quality Assurance personnel will audit at least 10% of the verification data acquired in the verification test to determine if data have been collected in accordance to the test/QA plan with respect to compliance, correctness, consistency, and completeness. The ACT Quality Assurance personnel will trace the data from initial acquisition to final reporting.

12.2 Reporting

QA/QC Audit Reports

Assessment Reports – Each assessment and audit will be documented, and assessment reports will include the following:

- Identification of any adverse findings or potential problems,
- Response to adverse findings or potential problems,
- Possible recommendations for resolving problems,
- Citation of any noteworthy practices that may be of use to others, and
- Confirmation that solutions have been implemented and are effective.

Data Reports

Data will be uploaded from instruments as manufacturers' instructions indicate. Because of the long test duration, instruments may need to be serviced every 3-4 months to address biofouling issues or to retrieve data to avoid memory concerns leading to data loss. The surface buoy data from the Datawell Waverider and the NDBC buoys from the West Coast deployment will be transmitted via iridium in near real time every 30 minutes and sent to CDIP. The data are then disseminated to NDBC for distribution. CDIP currently has the ability to provide full spectral data for all of the NDBC wave data and will do so for all co-location exercises described here. Similar analyses will be performed on the data from the surface buoys for the East Coast deployment. Parameters from the accepted standard will be compared directly to the test instruments for the year long deployment; heave, period, direction, the First-5 Fourier coefficients.

ACT staff will work closely with the Technical Advisory Board and participating manufacturers to ensure consistency with comparisons to the Datawell Waverider.

Final Verification Reports

ACT Verification Reports are normally released within 3-4 months after final instrument retrieval. ACT is aware that in this case the data quantity will be an issue in determining our time-line due to the deployment length. Our ability to retrieve and analyze the data in near real-time and CDIP's involvement will alleviate some of the data management burden and will expedite our reporting process.

12.3 Environmental, Health, and Safety plan

Environmental, Health, and Safety plans for all participating entities will be consulted and adopted as needed for all laboratory and marine operations. For all marine operations, ACT staff will work closely with the local NWS WFO to determine "spot" forecasts in the area of marine operations to ensure safe and successful deployments. For all operations at the USACE FRF, all equipment, procedures, manning levels, and submittals shall comply with Section 30 of the Corps Health and Safety Requirements Manual EM 385-1-1 (Nov 03 or most current version). The current version is available at: http://www.usace.army.mil/SafetyandOccupationalHealth/SafetyandHealthRequirementsManual.aspx.

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Copies may be obtained from:
ACT Headquarters
c/o University of Maryland Center of Environmental Science
Chesapeake Biological Laboratory
Post Office Box 38
Solomons, Maryland 20688-0038
Email: info@act-us.info