NDBC Wave Measurement Initiatives

Rodney Riley
National Oceanic and Atmospheric Administration
National Data Buoy Center
Stennis Space Center, USA

Richard Bouchard
National Oceanic and Atmospheric Administration
National Data Buoy Center
Stennis Space Center, USA

***Abstract*— The National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center (NDBC) provides wave spectral and bulk, sea state parameters from its fleet of Weather observation buoys. NDBC has focused on initiatives to (1) document and improve its wave measurements and (2) make these measurements more cost-effective. This paper describes these recent initiatives, as well as plans for the future.**

A significant accomplishment in NDBC's efforts to document and improve its wave measurements was the post-calibration of the heading component of NDBC's operational directional wave measurement system. Prior to deployment, functional tests are performed by NDBC on sensors to confirm each measurement is within a certain tolerance. NDBC has historically documented, through field tests, an accuracy of 10 degrees for its directional wave measurements, but has not documented any post-deployment calibrations. An effort was undertaken to test five buoys after their deployment life to determine the stability of their heading accuracy. These post-deployment tests showed maximum heading errors ranging from 6 to 8 degrees, which is within NDBC's published overall accuracy of 10 degrees.

NDBC also developed the capability to host two Digital Directional Wave Module (DDWM) systems on a single three-meter (3-m) buoy to evaluate improvements. This capability eliminated the cost of a second buoy and the spatial variability inherent in using two separate buoys for such evaluations. A recent modification to NDBC's DDWM is under evaluation against the present standard DDWM in the Gulf of Mexico at buoy 42003.

Additionally, NDBC partnered with the Army Corps of Engineers' Coastal Hydrology Lab (CHL) on a special project comparing legacy and present-day wave systems. This comparison will help gauge potential differences in wave height observations from the newer and older systems, with the results, as anticipated by the CHL, used to improve wave models, which draw on NDBC's 30-plus years of wave height observations. Thus, a six-meter (6-m) NOMAD (Navy Oceanographic Meteorological Automatic Device) buoy, which has a boat-shaped hull, was integrated with the wave observation systems and deployed off Monterey, California near a Datawell Waverider buoy.

Finally, NDBC is upgrading the DDWM, the workhorse of NDBC wave observations. This device contains a nine-axis motion sensor and processor, of which, both are commercially available, but nearing the end of their production life with newer, more power efficient and capable devices available. Thus, newer generation, motion sensors, as well as the possibility of moving the data processing to a modern, Linux-based, embedded platform, are under NDBC evaluation for their possibility of lowering both power demand and cost while maintaining compatibility with NDBC current, wave processing systems and quality standards. The Linux system will complete the processing significantly faster and likely use less power, overall. Increased computing capability will support future processing enhancements that older processing hardware cannot. Also, the new Linux system will be compatible with a desktop Linux version; thus, allowing for easier validation of any processing changes with the desktop version and previously recorded raw data. This new wave box will include NDBC Smart Module (SM) technology, for which the NDBC has a pending patent application, and allow for an upgrade to the electronics used for control and reporting, as well as maintain compatibility with the newest generation of NDBC Weather systems.

Keywords—Wave, DDWM, NDBC

I. INTRODUCTION

This paper describes NDBC's recent initiatives to improve quality and cost efficiency of its directional wave systems. The number of operational directional wave stations grew, from thirty-five at the end of 2005 to more than eighty by mid-2015, as engineering initiatives drove down the costs dramatically. Among the uses for NDBC wave measurements are the calibration of remote sensing techniques, the validation of numerical wave models, and the verification of National Weather Service marine forecasts and warnings.

II. POST CALIBRATION OF WAVE HEADING

A. Background

NDBC has conducted directional wave measurements from moored buoys for more than thirty years. Prior to deployment, these directional wave systems are rigorously tested and calibrated. Quality control procedures are applied to all data transmitted during deployment prior to public release of the data. NDBC documented in [1], and through subsequent field tests, an accuracy of 10 degrees for its directional wave measurements; however, prior to 2013 had not documented any post-deployment calibrations. Therefore, the NDBC began an initiative in 2013 to return some buoys from the field after their deployment life to conduct post deployment wave heading calibrations. The calibrations would document the stability of the accuracy of the directional wave measurements during their usual three to four-year deployment.

This is a DRAFT. As such it may not be cited in other works.
The citable Proceedings of the Conference will be published in
IEEE Xplore shortly after the conclusion of the conference.

The normal process for NDBC, after a three to four-year deployment, is to recover buoys and prepare them for shipment back to NDBC facilities without any modifications made to the internal section, the location for all the wave measurement equipment and batteries (see Fig. 1), of the buoy. However, the upper structure is disassembled and external cables are normally cut to facilitate shipping. In these cases, cables were not cut and special steps were taken so the buoy could be re-assembled into its as-deployed configuration, once returned to NDBC.

B. Wave Headings

A critical component of NDBC directional wave measurements is the determination for the heading of the buoy so that directional wave measurements can be rotated from the buoy frame of reference into the magnetic compass frame of reference and then into directions relative to True North. The heading is determined by measuring the earth's magnetic flux using three orthogonal magnetometers. The flux measurements are decomposed into bow and starboard magnetic field components and rectified by measurements of pitch and roll. Corrections are applied for residual and induced magnetic field influences from the buoy's hull and electronics. These influences, such as battery currents, may change over the deployment timeframe. This paper does not describe the wave computations, those details are given in [2]. The DDWM processing system is described by [3] and [4].

Before assembly, each wave measurement component is calibrated and tested to meet individual component tolerances. Once a buoy is fully assembled and powered, NDBC determines the constants to correct for the residual and induced magnetic fields using a modified method from [5]. The constants are then entered into the on-board wave processing system, and the buoy is checked at the eight cardinal and intercardinal headings against a reference gyrocompass mounted to the buoy for test purposes only. The largest difference between the gyrocompass and the calculated heading may not exceed 4 degrees.

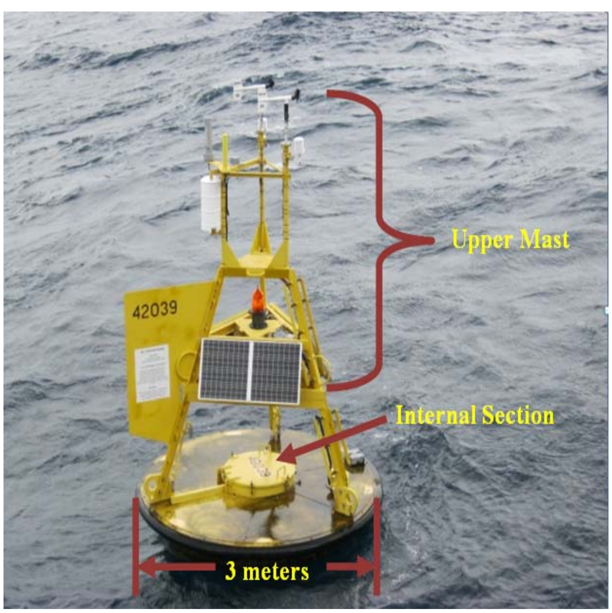


Fig. 1. NDBC Weather Buoy

C. Wave Heading Post Calibration

Upon return to NDBC, the directional wave measurements were subjected to the same heading verification technique they incurred before deployment using the original values for the residual and induced corrections.

Five buoys were tested. All were discus hulls of 3-meter diameter ("3D" in the hull number). Three were aluminum hull type ("D" in hull number) and two were foam hull type ("DV" in hull number). Tests were completed over a several month period; thus, environmental conditions were different both for each test and for tests conducted prior to deployment.

Table I summarizes the results and the associated parameters that might have an influence on the results. All the buoys were deployed with heading errors no greater than 4 degrees (Pre-Cal), established originally because it represented the resolution of the wave direction code values used in the World Meteorological Organization's (WMO) directional wave measurements found in [6]. The maximum of the eight post-deployment calibration heading errors for each buoy were on the order of 6 degrees with a maximum of 8.2 degrees, and within NDBC's stated accuracy of 10 degrees. There was no apparent trend or cause of the error in terms of age or temperature. Buoy 3DV11, which had the maximum error, was similar in environmental and age characteristics as 3D24, which had the least error.

Even though the sample size was too small to make a large-scale inference, the results and the absence of any large errors provide confidence that, even after two or more years in an extreme marine environment, the heading component of the directional wave measurements does not show significant degradation.

It should also be noted that the pre- and post-deployment calibrations are done with the buoy upright; thus, no effects of pitch and roll apply to the heading error. Errors in pitch and roll can affect the reported orientation of the buoy as well as the directional waves themselves, and are monitored in real-time for possible degradation. The focus of the post-deployment calibrations was to assess degradation due to changes in the induced and residual magnetism over time.

TABLE I. POST-DEPLOYMENT CALIBRATION (POST-CAL) RESULTS

Buoy Hull Number	*3D87*	*3DV13*	*3D33*	*3D24*	*3DV11*
In-service (years)	2.75	1.9	1.4	3.9	3.75
In-service Temperature (°C)	-5 to 32	2 to 30	7 to 31	7 to 22	4 to 32
Deployment Location (WMO Station Number)	44014	41012	41009	46011	42020
Pre-Cal Age (years)	2.8	3.2	1.9	4.0	4.2
Wave Instrument Age (years)	2.2	2.8	4.4	8.7	7.7
Battery Age (years)	3	4	2.2	5.25	4.5
Air Temperature at Pre-Cal (C)	18-22	16-24	16-27	28	17-32
Air Temperature at Post-Cal (C)	4-10	2-16	2-16	22	23-29
Maximum Post-Cal Heading Error (°)	6.7	-6	-6	5.0	8.2

III. DUAL WAVE TEST SYSTEMS

New or modified designs for NDBC wave systems must undergo testing at sea and are compared to the present, operational wave system. In the past, this has been conducted on separate hulls and moorings so as to not impact operational systems and, in some cases, a system using a Datawell Hippy-40 sensor was used on the same hull as the test system. Both of these methods worked well, but were relatively expensive. Most modern wave systems (including NDBC's) use Micro-Electro-Mechanical System (MEMS) sensor technology which greatly reduces physical size. In NDBC's case, telemetry has improved in terms of power demand by moving from traditional Geostationary Operational Environmental Satellite (GOES) systems to GOES high data rate systems and then eventually to Iridium satellite systems. Reduction in power and increased telemetry capabilities facilitate adding more systems to a buoy platform. Consequently, NDBC has developed a dual waves system that allows for an easy, efficient, and cost effective way to include a test wave system on any operational buoy, especially when those test cases include software modifications only. No special hull or mooring is required and only minimal, special production procedures or testing is needed. Thus, cost to an operationally-oriented organization like the NDBC is minimal but provides the benefit of an increased number of DDWM test cases which, in turn, improves statistical confidence in the test results.

NDBC's primary operational wave system is the DDWM (Fig 2). The new dual wave system (Fig. 3) is simply two DDWM units mounted back-to-back on a slide rack which is mounted in the existing buoy equipment rack of the 3-m Weather buoy (see Fig 4). The initial prototype, shown in Fig 3, was generated from the existing CAD design for a single DDWM and then printed on NDBC's 3D printer. The simple design and use of the 3D printer reduced the engineering and fabrication labor, providing further cost reductions for NDBC.

Fig. 2. Single DDWM on Single Slide Mount

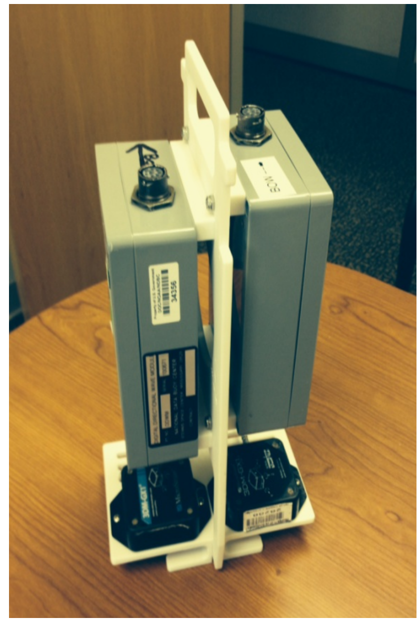


Fig. 3. Dual DDWM on Single Slide Mount

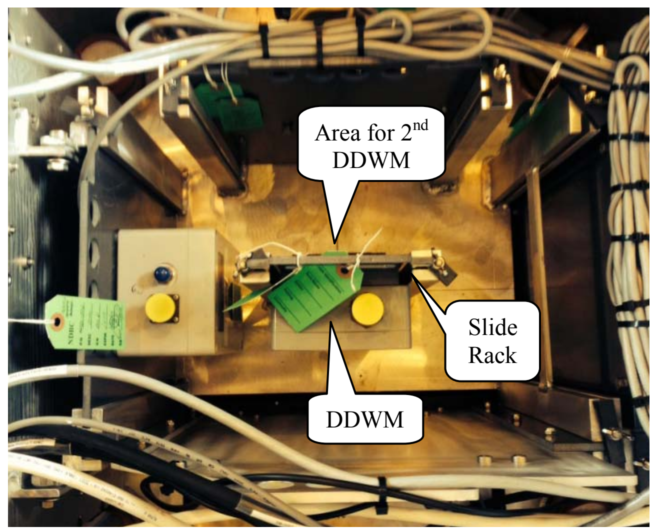


Fig. 4. 3-m Buoy Equipment Rack

IV. FLOSSIE

NDBC has compiled a long record of wave measurements from the 6-m buoy platform dating back to the 1980's. Through this time frame, wave measurement systems have changed. The Army Corps of Engineers' CHL uses NDBC data for correction and validation of its wave models. Small differences or offsets in wave records caused by the wave measurement system have the potential to cause significant errors in their models. There has been some evidence to suggest there are measurable differences between the systems as shown in [7].

A project was started to identify and quantify these potential differences. The project is named FLOSSIE for the Floating Laboratory for Ocean Sea State Intercomparison and Experimentation in honor of Florence van Straten, who coined the NOMAD name for the buoy while working for the U.S. Navy. "With pride or shame," she later wrote with characteristic, dry humor, "I must confess that I am responsible for the acronym: navy oceanographic meteorological automatic device." See [8].

The *intercomparison* is between the systems, the *experimentation* is to assess the feasibility of directional waves from 6-m NOMAD buoys, and the necessity is to correct for persistent tilt in a large hull. The project will make a one- to two-year comparison of wave measurements from a 6-m NOMAD with a nearby Datawell Waverider buoy (NDBC Station 46114). Both buoys will be deployed in Monterey Bay near NDBC station 46042. The 6-m NOMAD hull will make near simultaneous wave measurements using the older wave system (DACT-WA), an onboard reference wave system (DWPM-Hippy), and the latest wave system (DDWM) with transmitted data analyzed for differences.

At the time of this paper, the FLOSSIE buoy had just been deployed (Fig. 5). All systems are operational and comparing reasonably well with reference stations 46042 and 46114 (Waverider). Detailed data analysis will be conducted later once a longer data record is available.

V. Future Wave System

A. Background

The DDWM is NDBC's operational wave system. It uses a low power 32-bit processor (Persistor® CF2 board) and a MEMS technology motion sensor (Lord Corporation's, MicroStrain® 3DM-GX1). The processor acquires time series data from the motion sensor, which is then processed into directional wave spectra and transmitted to shore. Both of these devices are aging and may likely be discontinued. In fact, the 3DM-GX1 is already listed by the Lord Corporation as a legacy product.

In addition, NDBC has designed a smaller, lower power buoy system named Self-Contained Ocean Observation Payload (SCOOP). This new system has allowed for the DDWM to become a much larger piece of the power budget by minimizing the draw from data transmission and other functions. Therefore and due to the looming obsolescence and the need for even lower power demand to support use on the SCOOP system, the DDWM is undergoing a change. The NDBC is in the early stage of concept design and component evaluations for a new DDWM.

B. New Architecture

The big change with the use of a new motion sensor and processor is in the electronic architecture and, wince the processor would consume a relatively large amount of continuous power, it will be cycled on and off as needed for intensive processing. Cycling control for the processor and the motion sensor will be performed by the NDBC SM board. The SM will also interface the new wave system to existing NDBC payloads (central computing system), or third party devices, for data delivery and to power systems for its power source. This communication can be either wired or wireless. A concept of this new architecture is shown in Fig 6.

The process to acquire and report wave data will be the same as used for the existing DDWM, but will have more options and capabilities. Basically, the SM will either be polled by a payload to acquire data or will acquire data based on an internal clock and a stored configuration that defines its timing. The SM will then power the motion sensor and begin to receive and store the time series motion data. After a twenty-minute record is acquired, the SM will turn the motion sensor off and then turn the processor on (Gumstix board). The raw data file is then transferred to the processor where it is processed into a wave data message and returned to the SM. The SM will then turn power off to the Gumstix and report the wave message or wait until further command(s) are received to transmit the wave data message. The wave message format can be either the traditional type used for many years at the NDBC or a new XML format depending on the payload or desired configuration.

Moreover, the use of the SM and the Iridium communications in the SCOOP system will allow for shoreside control of various parameters while the system is deployed; thus, providing a new capability for the wave system as it can be "tweaked" from shore. The design and SM coding for this new wave application have not been implemented. Some questions exist concerning the SM's ability to read and store the relatively fast and large, raw-time series data record. Testing and evaluation have not yet been completed.

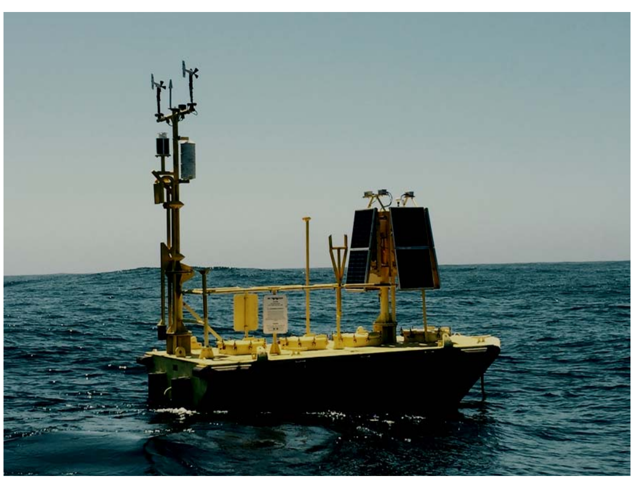


Fig. 5. FLOSSIE Buoy Deployed at Station 46FLO

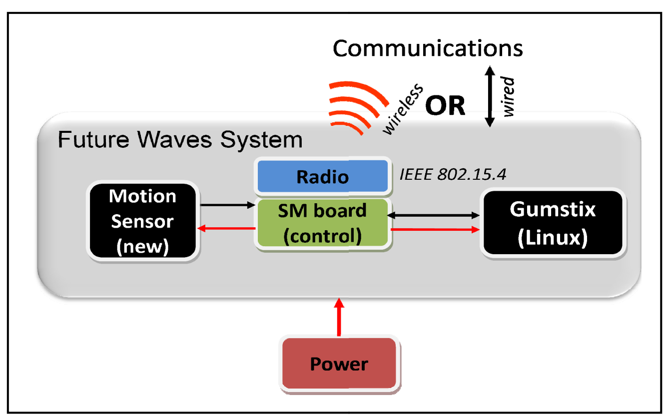


Fig. 6. New Wave System Block Diagram

C. New Processor

The processor will use a modern processing board from Gumstix, Inc. The DDWM code has been transitioned to a Linux system on the Gumstix board and, as a result, the waves processing time reduced substantially from about five minutes to half of a second. The Gumstix board does consume more continuous power, but the board will only be powered for a few seconds to boot up and then process the motion sensor data file for each observation period. This change may lower power (full tests remain), but will certainly provide the processing capability for future processing upgrades that might be more computationally intensive. Furthermore, the same embedded Linux code will be used in the new DDWM and shoreside processing systems to process DDWM, internally recorded motion sensor time series data. The new processing board and software will facilitate future code modifications and development as it provides ease in testing the code with existing, raw time series data. This is not easily done with the present DDWM system as two sets of code (embedded and desktop) would have to exist and be maintained.

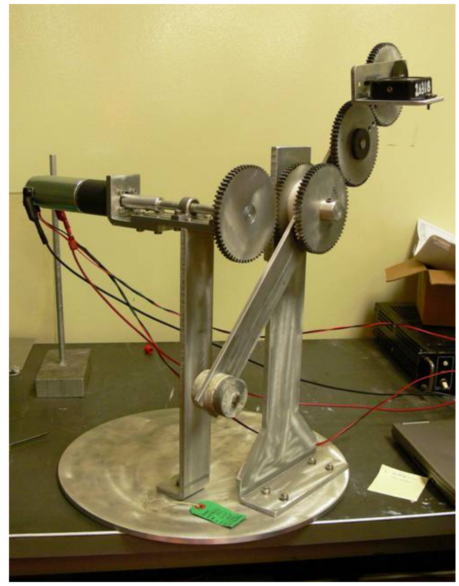
D. New Motion Sensor

The MicroStrain® 3DM-GX1 motion sensor is now a legacy sensor and production could be halted at the Lord Corporation's discretion. Thus, NDBC is taking this opportunity to explore lower power and lower cost, MEMS technology motion sensors. There are over a hundred of these types of devices on the market, but NDBC has narrowed the choices down to the three sensors shown in Table II.

To test and evaluate these three, new sensors, the NDBC placed each sensor on its Desk Top Wave Simulator (DTWS), or miniature wave wheel. See Fig 7. This device is used to functionally verify each deployed, motion sensor. The device moves the sensor through a circular motion and includes tilt up and down. The required twenty-minute data record with the DTWS in motion was acquired for each sensor and processed by the existing DDWM code to produce the wave parameters; primarily, wave height, period, and direction. All the sensors did not provide the correct, processed results and, in viewing the time series data from the tests, it was also noted that the amplitudes were incorrect and noise appeared to be excessive. Filtering attempts were made to smooth the signal, but results were still not acceptable. Testing and evaluation efforts are not complete with test methods, sensor configurations, etc., to be revisited to confirm repeatability of results. Besides, other motion sensors may be considered as newer products are introduced to the market.

TABLE II. CANDIDATE MEMS MOTION SENSORS

Manufacturer	***Part #***
VectorNav	VN-100
Ryan mechatronics	CHIMU
Lord MicroStrain®	3DM-GX4-25



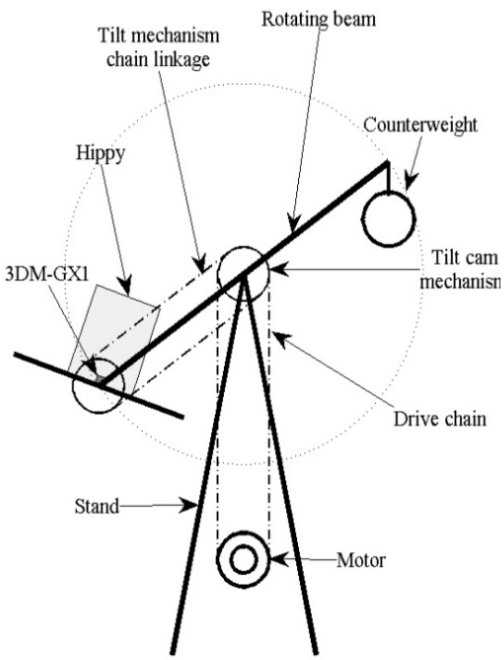


Fig. 7. TOP - DTWS picture, BOTTOM - DTWS Diagram

E. Present Status

The project is presently in the concept stage with some preliminary work complete with code development and sensor evaluation. Initial testing of motion sensors was not successful. Re-conduct of the motion sensor test and evaluation is planned with the Gumstix code development, either in parallel or independent of the evaluation, to proceed. Packaging and other mechanical design considerations remain.

VI. CONCLUSION

The NDBC has been engaged in improving its directional wave quality and cost efficiency. Four initiatives were highlighted that work toward this goal: (1) Post-deployment calibrations showed no significant drift in the heading component of directional waves, (2) A dual DDWM that provides a cost effective way to test new or modified wave systems was presented, (3) The FLOSSIE project, aiming to address potential differences in wave heights from newer and legacy wave systems that support Army Corps of Engineers wave modeling, was initiated, and (4) The NDBC started an effort to upgrade the DDWM performance in power consumption and cost while maintaining quality standards.

ACKNOWLEDGMENT

Funding for the fabrication, integration, testing and deployment of the FLOSSIE project was provided by the Army Corps of Engineers. The NDBC provided a 6-m hull, onboard systems, most wave equipment, and engineering resources.

REFERENCES

[1] Gilhousen, DB (1990), "NDBC Directional Wave Measurements," Proc. Marine Instrumentation '90, San Diego, CA, 110-117.

[2] NDBC (1996). "NDBC Technical Document 96-01, Nondirectional and Directional Wave Data Analysis Procedure," 13-15.

[3] Riley, R, C-C Teng, R Bouchard, R Dinoso, and T Mettlach (2011). "Enhancements to NDBC's Digital Directional Wave Module," Proc. OCEANS '11, IEEE, 1-10.

[4] Teng, C-C, R Bouchard, R Riley, T Mettlach, R Dinoso, and J Chaffin (2009). "NDBC's Digital Directional Wave Module," Proc. OCEANS 2009, IEEE, 1-8.

[5] Remond, FX and C-C. Teng (1990). "Automatic Determination of Buoy Hull Magnetic Constants," Proc. Marine Instrumentation ;90, San Diego, CA, 151-157.

[6] World Meteorological Organization (1995). "FM65-XI WAVEOB," WMO No. 306, Manual on Codes, Part A, I.1, 129-132.

[7] J. Gemmrich, B. Thomas, and R. Bouchard. "Observational changes and trends in northeast Pacific wave records." Geophysical Research Letters 38. L22601, 2011, doi:10.1029/2011GL049518.

[8] Department of Defense, "A Pioneer in Naval Meteorology: CDR Florence van Straten", Armed with Science, The Official Department of Defense Science Blog, http://science.dodlive.mil/2010/03/30/a-pioneer-in-naval-meteorology-cdr-florence-van-straten.