Technical Bulletin
National Data Buoy Center

Volume 18, Number 1 June 1992

Environmental Measurements From Coast Guard Buoys — The End of an Experiment

Since the last century, mariners continually have received weather observations/warnings from Coast Guard lightships (in the past) and then Large Navigational Buoys (LNB's). These LNB's are located in the entrance to major and/or dangerous ship channels (Figure 1). The marine community has counted on weather observations and navigation information from these buoys. As a result, NOAA/NWS worked to continue these observations by installing automated measurement systems on the LNB's. These buoys, which are 12 meters in diameter (Figure 2), were an appropriate platform for the NDBC environmental package, since they were quite similar to existing NDBC buoys. There were problems, but these were quickly overcome.

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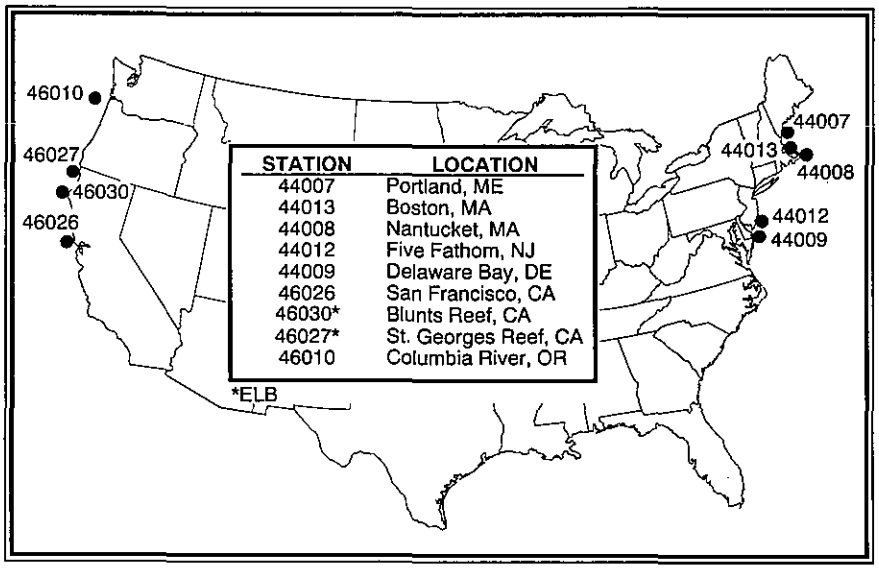

Figure 1. Locations of Large Navigational Buoys and Exposed Location Buoys

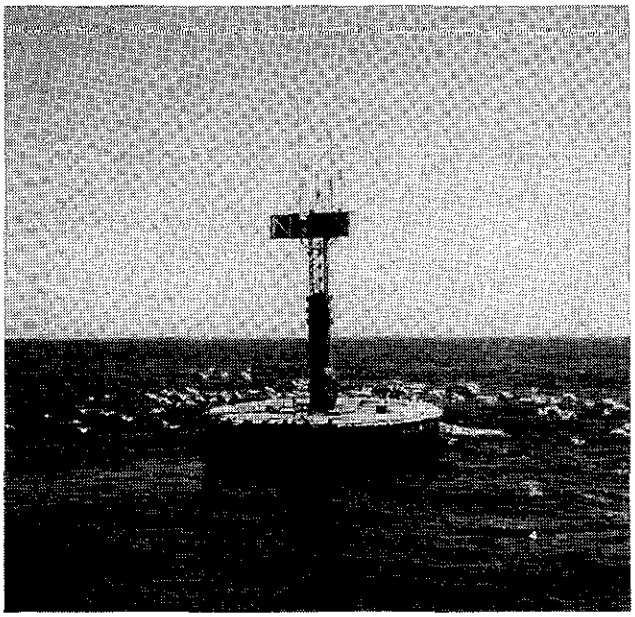

Figure 2. USCG Large Navigational Buoy (LNB) Nantucket, MA

Acoustic Doppler Current Profiler Systems Deployed on 10-Meter Discus Buoys

In the fall of 1991, the National Data Buoy Center (NDBC) installed an RD Instruments (RDI) Acoustic Doppler Current Profiler (ADCP) system on each of two NDBC 10-meter discus buoys. The buoys, sponsored by the Department of Interior, Minerals Management Service, were moored in the Southern California Bight in water depths of 175 and 400 meters. Near-real-time data from the ADCP's, as well as other oceanographic and meteorological measurements were transmitted hourly through the Geostationary Operational Environmental Satellite (GOES) system. The installation and handling of the ADCP transducer head assembly on the buoy, the interfacing of the ADCP system with the NDBC Value Engineered Environmental Payload (VEEP), and the shoreside processing of transmitted data provided interesting challenges to NDBC engineers.

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NDBC Data Observations Surpass 1.25 Million for 1991; Drifting Buoy Observations Top 100,000

The NDBC network of moored buoys and fixed stations delivered over 1.25 million hourly data messages in real time to the National Weather Service and other users during 1991. This is an increase of 7.6 percent over 1990 (Figure 3). Since each message typically contains information from several individual sensors, it is estimated that more than 4 million individual measurements were reported during the year.

The total message count was made up of 812,307 meteorological messages and 439,343 wave messages. In order to measure NDBC's success in delivering data in real time, a system performance percentage is computed that represents the number of usable synoptic observations reported, compared to the number of observations expected while the station was properly configured. The message count represents a delivery rate of 87.9 percent for meteorological data and 85.8 percent for waves (Figure 4). These are the lowest system performances in over a decade. The low percentages represent the impact of budget cuts imposed last summer that caused the cancellation or delay of service visits at the time of year when weather is most likely to permit repairs at sea.

NDBC's network of automated weather stations has grown steadily since the early 1970's. At the end of 1991, there were 61 moored buoys and 51 fixed Coastal-Marine Automated Network stations. Since 1978, the number of stations has more than quintupled, while the number of messages has increased 18-fold. During its existence, the mission of NDBC has evolved from primarily a test and development center into one that supports the critical National Weather Service mission of operational forecasting and warning.

Meanwhile, the size of the drifting buoy network in the oceans of the Southern Hemisphere sharply increased to approximately 35 systems in 1991. The number of observations from this network jumped by 43.8 percent to 100,900 data observations. The increase in drifting buoy activity was attributed to restoration of funding that was lost in 1990. This network of drifters was first established in late 1984 for the 10-year Tropical Ocean and Global Atmosphere Research (TOGA) Program. While TOGA drifting buoy data are used by operational weather centers, particularly in the Southern Hemisphere, the primary purpose of the program is long-term climatological research.

Eric A. Meindl, NDBC

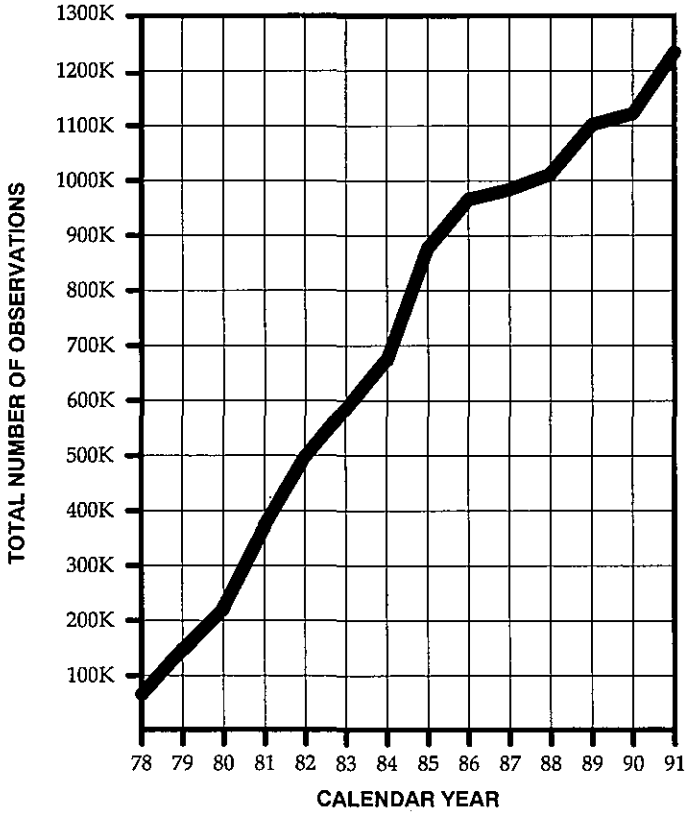

Figure 3. Total Number of Messages Per Year Delivered by NDBC Moored Buoys and C-MAN Stations

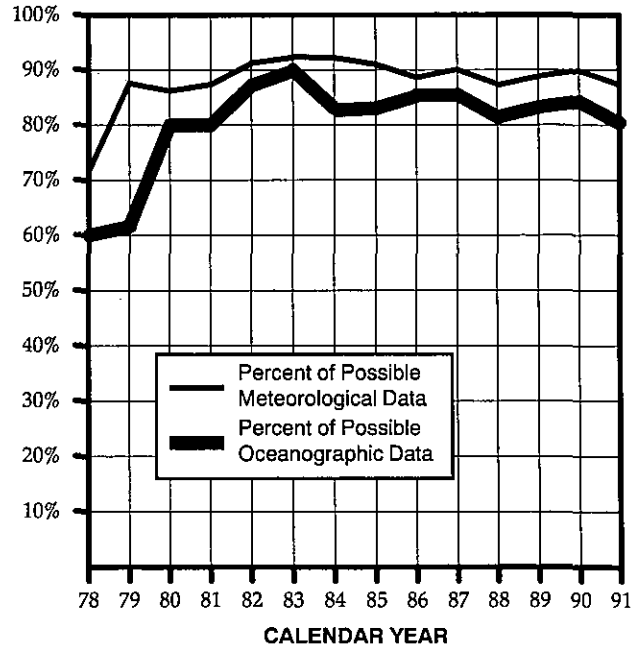

Figure 4. Station Performance for Meteorological and Oceanographic Data

Automated Equipment Management System

NDBC has experienced considerable growth in the number of environmental monitoring weather stations that it establishes and operates. Currently, there are 116 automated stations in the network, comprised of 63 moored buoys and 53 fixed stations. In addition, there are approximately 36 drifting buoys in operation. The demands on logistics and equipment resources to support this network have grown accordingly. These demands led NDBC to take action toward full automation of the logistic equipment management functions. Lead priorities of this effort were to track all expendable and nonexpendable items, maintain a complete history of certain nonexpendable items, update and track in near-real-time the weather station system configurations and status of operational equipment, and calculate performance data, such as mean time between failure (MTBF).

The Equipment Management System (EMS) was developed by NDBC's support contractor using the powerful features of CQCS, a Fourth Generation Language, which supports several off-the-shelf data bases, provides tremendous flexibility in designing data entry screens, and produces reports faster than conventional programming techniques by providing such features as automatic layout and formatting. The system was implemented on a network of Data General MV series super-minicomputers and IBM-compatible PC's. This multi-user system provides responsive, interactive resources directly to all required personnel. 'Update' access is provided only to designated users responsible for entering system information. 'Read only' access is provided to management and other users who need the necessary reports and analyses for equipment management. The software is modular in design, with each module being implemented as it is developed.

The first EMS module implemented was the Property Tracking and Evaluation Utility System (PROTEUS). PROTEUS provides Logistics with a tracking system for all property and a data base of information for other modules to be developed. There are over 9,000 expendable items, nonexpendable items, and Line Replacement Units (LRU's) that must be ordered, scheduled, quality controlled, tracked, and managed. LRU's are the nonexpendable items that are installed on weather stations.

The second EMS module implemented was the Integrated Reliability Information System (IRIS). NDBC has several different weather station system configurations deployed in the field. As new systems, sensors, and LRU's are acquired or developed, the complexity increases. The correct LRU's and equipment must be expeditiously identified and shipped promptly to the field service team. Exact configuration of each station must be tracked so that the correct processing parameters for each station can be set up within the data bases at NDBC and the National Weather Service (NWS) Telecommunications Gateway to process, quality control, and disseminate the real-time data to NWS forecast offices, and to ensure that archived data are of the highest quality. The IRIS module provides these essential requirements with near-real-time updates to maintain accurate configuration descriptions and management information. Replacement LRU's are tracked from purchase to warehouse, staging areas, and replacement on the stations. A complete history of each item is maintained, including all locations where the item has been installed, failure records, calibration history, and other information useful for proper management. Performance data, such as MTBF calculations are now available from these data bases. IRIS was the first module with wide impact and has quickly become an essential part of NDBC's technical and management activities.

The latest EMS modules to be implemented were the Consumable Materials Utilization System (COMUS) and the Electronic Components Handling Operation (ECHO). Detailed data base records are required for all expendable items that are purchased, with automatic data base updates as items are issued or placed in storage. All items used on a given weather station, station location, quantity on hand, reorder levels, quantities on order, and similar information necessary for maintaining full control and accountability of the inventory is required. COMUS was implemented to meet these requirements as the multi-user inventory control system. At about the same time, ECHO was adapted, using the basic COMUS module, to meet the Engineering need for a special system to handle electronic components. Modules are also necessary to support shipping and receiving and work control to provide automated methods of tracking work requests, work request status, work hours, expendable and nonexpendable items charged to a request, and other similar management and tracking information. These modules are currently in work and are planned for implementation within 6 months. Configuration Management has also been identified as part of this automated system, providing the means for tracking and controlling all drawings and documents generated to design, configure, and maintain weather stations and support functions. Configuration Management will be addressed in the last planned module.

Insights are being gained as this automated system is used, and improvements continue to be made. Already the requirements cover more than equipment, and we are expanding to an automated resource management system. User groups are being formed to discuss the operational use of modules, and suggestions are made for procedures, improvements, and expansion to include new information and ideas. All these modules are interrelated and are designed to share information to provide an integrated approach to the management of equipment through automation. The system was developed to be responsive and flexible and is filling a very critical need here at NDBC.

Sallie P. Nolan, NDBC

Update On The Evaluation Of The Coastal Oceanographic Line-Of-Sight (COLOS) Buoy

In our last issue, CAPT W. E. Colburn described the design and initial testing of the 1.8-meter COLOS buoy. A comparison with a wavestaff on Chevron's Garden Banks platform showed excellent agreement in significant waves up to 3.3 meters.

Last summer, NOAA's National Undersea Research Program (NURP) asked NDBC to help develop a wave climatology to support the deployment of the Habitat Aquarius in the Florida Keys. On August 8, 1991, NDBC moored the COLOS buoy off Conch Key, Florida, in 52 meters of water at 24°56'13" N., 80°26'27" W. This location has a moderate current (not measured) as evidenced by the wake shown in Figure 5.

The deployment data quality evaluation was completed on September 16, 1991, and the data were then released to the NWS communications network. Archive data records of air temperature, surface water temperature, and wave data from station 42025 (COLOS buoy) started on September 12, 1991, and have been sent to NODC monthly. The Molasses Reef C-MAN station, located about 5 miles northeast of the buoy, provides hourly observations of wind speed, wind direction, barometric pressure, and air and water temperatures.

Figure 6 shows the data record when Tropical Storm Fabian brushed the area in October 1991. Figures 7 and 8 show the two highest wave heights measured to date (2.3 meters on December 20, 1991, and 2.2 meters on February 7, 1992). The wave heights correlated well with the wind records from Molasses Reef. Some shallow water wave attenuation occurred since the buoy was within 2 miles of the coral reef.

NDBC plans to inspect the mooring system this spring as part of our COLOS Buoy and Mooring Development programs. Present plans are to keep the buoy on station through fiscal year 1992. Extended wave measurements at Conch Reef will depend on future funding by NURP.

Raymond H. Canada, NDBC

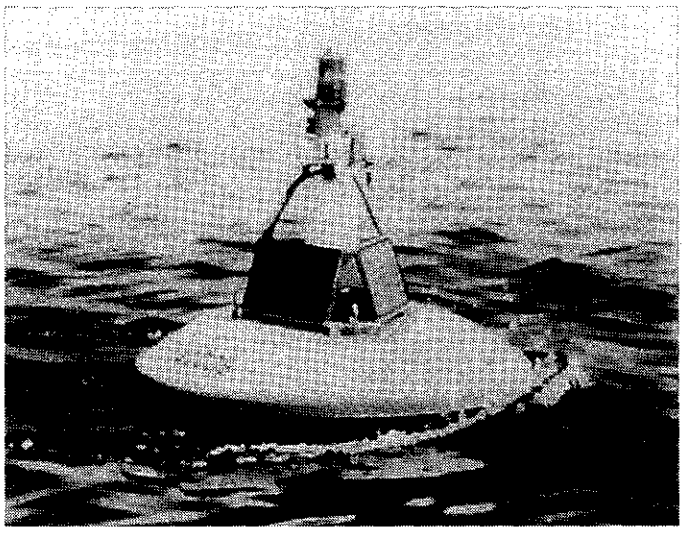

Figure 5. Coastal Oceanographic Line-of-Sight (COLOS) Buoy

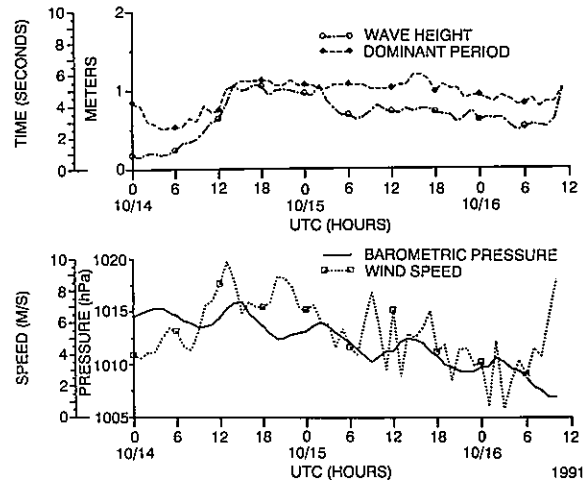

Figure 6. Time Series Plot of Tropical Storm Fabian, October 1991.

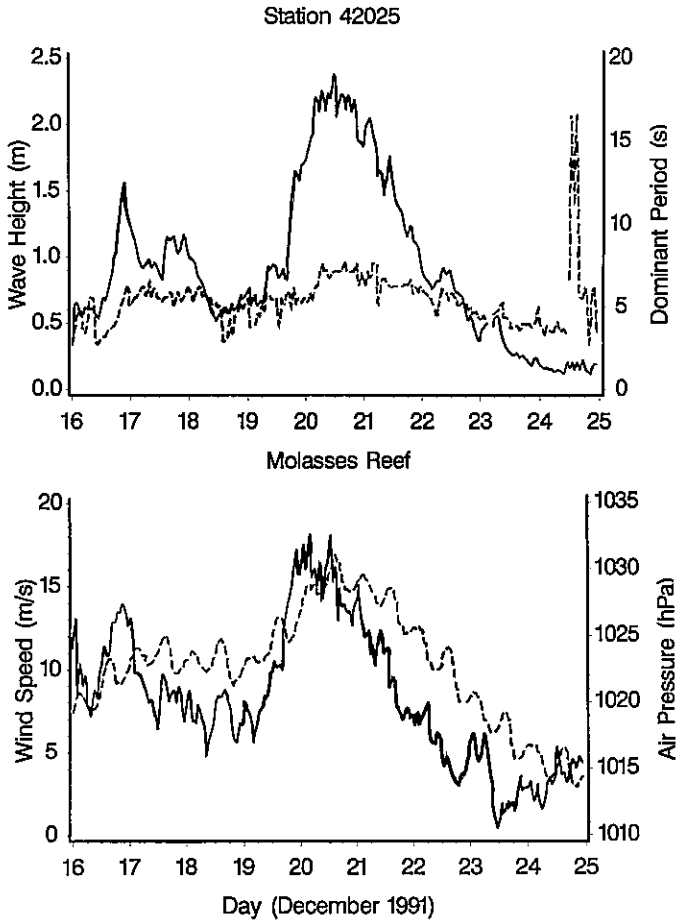

Figure 7. Time Series Plot of Wave Height, Wind Speed, and Dominant Wave Period from the COLOS Buoy, December 1991.

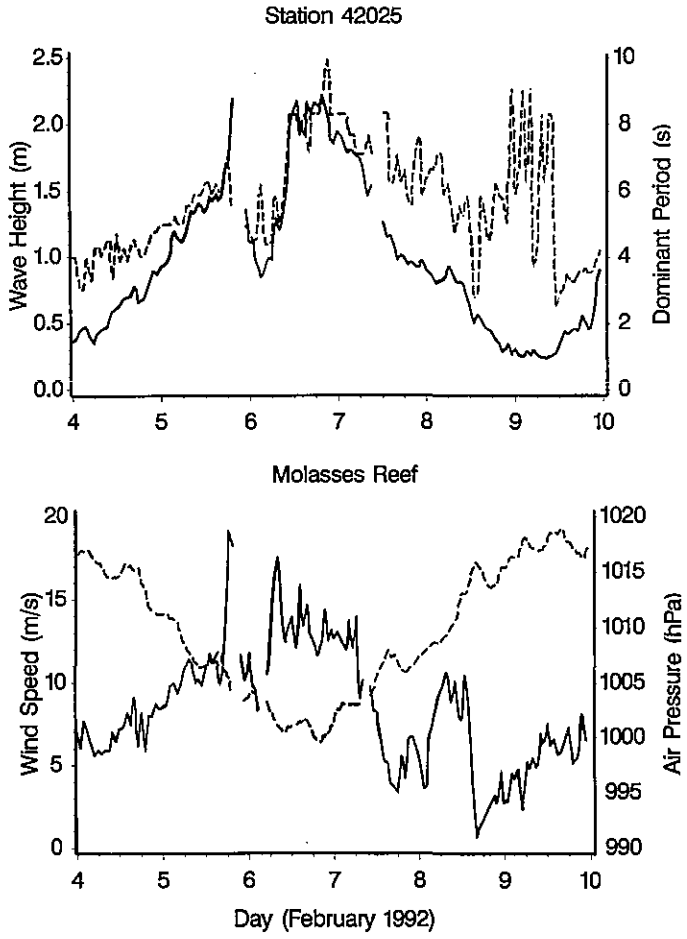

Figure 8. Time Series Plot of Wave Height, Wind Speed, and Dominant Wave Period from the COLOS Buoy, February 1992

ADCP Continued

The ADCP is a state-of-the-art instrument used to measure water current velocity profiles by transmitting short acoustic pulses into the water along the lines of position defined by four directional transducers that make up the transducer head assembly (Figure 9). Each transducer head is both a transmitter and a receiver. Backscatter of the acoustic pulses from plankton and other small particles in the water column is received by the transducers, and the ADCP then measures the Doppler shift between the transmitted and received frequencies. A water current velocity profile is then constructed from uniform segments of the water column being measured, called depth cells or bins. The water velocity measured in each depth cell is comparable to the velocity measured by a single current meter. Therefore, an ADCP velocity profile is comparable to measurements from a string of conventional current meters

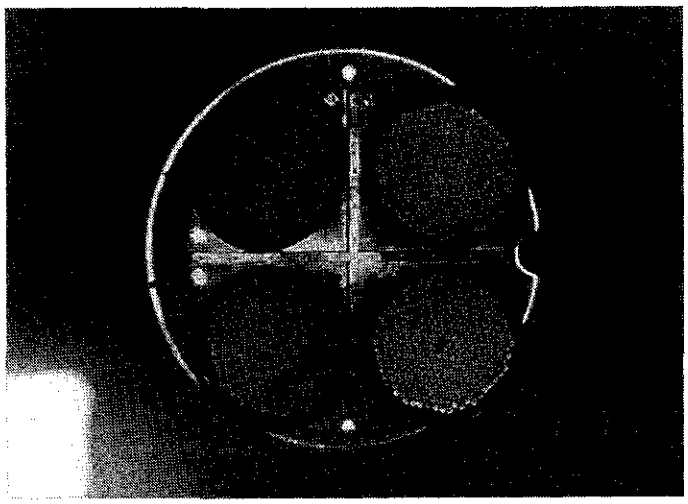

Figure 9. Acoustic Doppler Current Profiler Transducer Head

uniformly spaced on a mooring, except that the ADCP measures the average current velocity over the depth range of each depth cell instead of at a single point in the water column.

The ADCP may be configured to acquire current data through any part of, or the entire depth of, the water column, not exceeding 600 meters, by specifying the correct ADCP setup parameters. The setup parameters on the NDBC buoys were selected to accumulate data from 20 depth cells. The depth cells for the ADCP moored in 400 meters of water were set to 16 meters, while the depth cells for the ADCP moored in the more shallow water, 175 meters, were set to 8 meters. Both ADCP's were programmed to acquire data for 6 minutes each hour. The data sets, or ensembles, collected by the ADCP's are processed to provide average current velocities arranged in north, east, and vertical components for each of the 20 depth cells.

Onboard processing of the ADCP data includes making necessary corrections for the ADCP's rotation (heading and tilt) and translation, since the ADCP measures ocean current relative to the position of the ADCP. The ADCP may be mounted in a downward-looking orientation on a platform such as a ship or a buoy, and moving relative to the earth, or it can be moored directly to the ocean bottom in an upward-looking orientation. For a bottom-moored ADCP, corrections for heading and for tilt are generally accomplished through the use of two sensors built into the ADCP - a flux-gate compass and a pendulum. These sensors are not normally used on ADCP's mounted to an unstable platform on the ocean surface, since both sensors are adversely affected by motion due to ocean waves and wind. Also, the flux-gate compass is difficult to use near ferrous materials, such as a steel ship or buoy hull, since the ferrous materials affect the accuracy of the compass. Remote gyrocompasses and vertical gyros are generally used to correct the data when the ADCP is mounted aboard a ship. Horizontal translation of a ship- or buoy-mounted ADCP is typically corrected using a navigational device such as a Global Positioning System, Loran system, or by a built-in function of the ADCP called bottom tracking.

The ADCP's on the NDBC buoys employ a flux-gate compass to provide ADCP heading. Magnetic correction is provided to reduce the deviation error introduced by the buoys' steel hulls. On the NDBC installations, no corrections were made for the pitch and roll of the buoy. Based on previous studies, pitch and roll introduce only small errors in

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NDBC's New Wave Processing Module

The National Data Buoy Center (NDBC), in the past 20 years, has developed payload and wave measurement systems to acquire and report wave data. Currently, every NDBC wave measuring system is dedicated to the payload system for which it was designed. Also, the payload software is tightly coupled with the onboard processing software so that upgrading the wave processing software means modifying the payload system software with attendant lengthy software testing. The Next Generation Payload system being developed by NDBC will incorporate distributed processing. This allows processing by independent processing modules and does not require extensive payload software modifications for changes in the processing software.

In keeping with this new payload distributed processing philosophy, a wave data acquisition and processing system, called the Wave Processing Module (WPM), was developed by NDBC using state-of-the-art technologies and experience accumulated over the years. The WPM is capable of acquiring either directional or nondirectional wave data through various sensors and transmitting the data to various host payload systems such as the Value Engineered Environmental Payload (VEEP) or the Next Generation Payload.

The WPM was designed to be compact, low cost, low power with high data processing speed and capability. Its flexibility and expandability will provide NDBC with an advanced wave system for many years to come. Other features of the WPM include the following:

- The WPM provides low turnover time periods for any future modification or trouble-shooting because NDBC has control of the software/hardware design, the WPM has an RS-232 interface to the host payload, and commercially available components are used.
- It is field serviceable with limited risk to other measurements onboard the buoy.
- As better technologies or processing techniques become available, the processing hardware and software can be replaced without modifying payload hardware and software.
- The current WPM design satisfies our cost target goals, thus allowing complete nondirectional wave systems to be acquired in production quantities at costs comparable to NDBC meteorological sensor suites (including pressure, wind, and temperature), and complete directional wave systems to be acquired at a very reasonable cost increment.

Conceptually, the WPM consists of four elements: processing hardware, interface hardware, processing software, and system software. The block diagram in Figure 10 illustrates these WPM elements and their interfaces to each other.

The processing hardware element consists of a single board computer platform for data processing, an A/D converter for digitizing the sensor signals, and storage memory to buffer the data.

The processing software element accesses the buffered time series sensor data, processes the acquired data, and encodes and formats the processed data for transmission.

The interface hardware connects the processing hardware to the sensors and the payload system. It provides the signal conditioning to transform sensor output signals to voltage levels compatible with the A/D converter on the processing hardware.

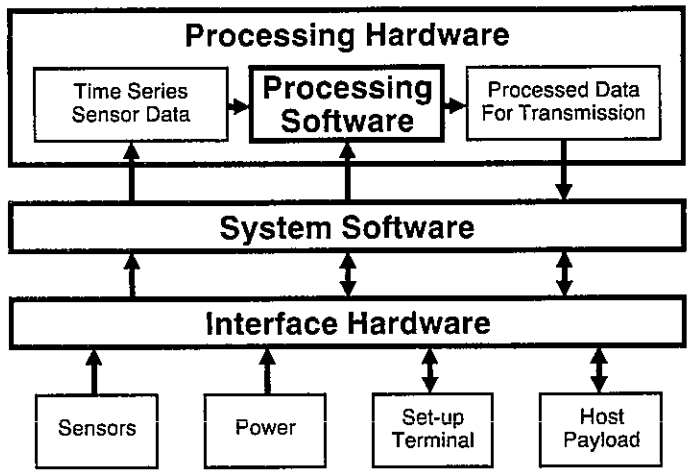

Figure 10. Block Diagram of Wave Processing Model Elements and Interfaces

The system software provides communication and control between the WPM, the host payload, and sensors. It also provides an interface between users and the WPM, allowing the users to set or modify operating parameters and system configurations through a PC computer setup terminal.

An advanced, low-power, off-the-shelf, single board computer is used as the processing hardware for the prototype WPM. The software installed in the WPM is a general wave processing software upgraded from the current NDBC wave processing programs and the past 20 years' experience. This software, named the Wave Record Analyzer (WRA), was developed by MEC Systems Corporation for NDBC. The WRA software, written in C language, was designed in a modular format to make future modifications and additions as easy as possible.

The first WPM prototype includes four analog input channels that are sufficient for implementing the Magnetometer-Only (MO) directional wave measurement technique. The MO system requires only three input channels (i.e., heave and two magnetometer outputs) and is used for the first WPM prototype in order to obtain early test data.

The WPM/MO prototype is presently used with the VEEP payload system. Since the industrial standard RS-232 communication interface is used, it can be connected to any other payload systems, such as the developing Next Generation Payload.

The prototype WPM/MO's were fully "bench" tested by using the NDBC digital directional wave simulator and Ocean Wave Instrumentation Facility (OWIF), which is a Ferris-wheel-type test device. The results confirmed that the overall WPM design and its implementation are correct.

After passing all the above tests, one prototype WPM was installed in a standard NDBC 3-meter buoy for its first field test. In addition to the WPM/MO system, an NDBC Hippy directional wave system was also installed on the buoy as a reference for evaluating the performance of the WPM/MO system.

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Coast Guard Buoys Continued

In 1976, NOAA tasked NDBC to develop an Aids-to-Navigation Buoy Environmental Sensing System (ANBESS) for use on LNB's and other U.S. Coast Guard navigation buoys. The Columbia River LNB was successfully instrumented in 1981. Other stations were instrumented over the next two fiscal years.

Concurrently, NDBC developed systems to be installed on smaller navigation buoys. Successful deployments were done on an 8x26 (ft) buoy in the Gulf of Mexico and another in the Straits of Juan de Fuca; however, funding was not available for instrumenting channel buoys. The same systems were installed on 9x35 (ft) Exposed Location Buoys (ELB's) (Figure 11), with good data provided from stations 46030 (since October 1984) and 46027 (since October 1988) (Figure 1). However, these deployments were costly to maintain because instruments were damaged during most of the USCG's routine servicing operations due to the seakeeping qualities of the ELB hull (Figure 12). The USCG has tried to minimize the damage to the weather instruments by working the buoys in very calm seas. This increases operational costs to the USCG by reducing the number of days available for routine servicing of their navigational aids. Hence, the effort to instrument these buoys was abandoned in 1990 as not cost-effective for NOAA or the USCG. This will terminate all work on ANBESS development.

The Coast Guard is now committed to replacing seven of their LNB stations with ELB's over the next 2 years. Blunts Reef and St. George Reef, California, are now ELB's and are the stations that NDBC instrumented. The Nantucket, Massachusetts, and Columbia River, Oregon, stations will remain LNB's and will continue to support NDBC instrument packages. The current estimated replacement schedule of the other stations is:

Delaware Bay, Delaware — FY92 (fourth quarter)
Five Fathom, New Jersey — FY92 (fourth quarter)
Boston, Massachusetts — FY93 (fourth quarter)
Portland, Maine — FY93 (fourth quarter)
San Francisco, California — FY93 or FY94

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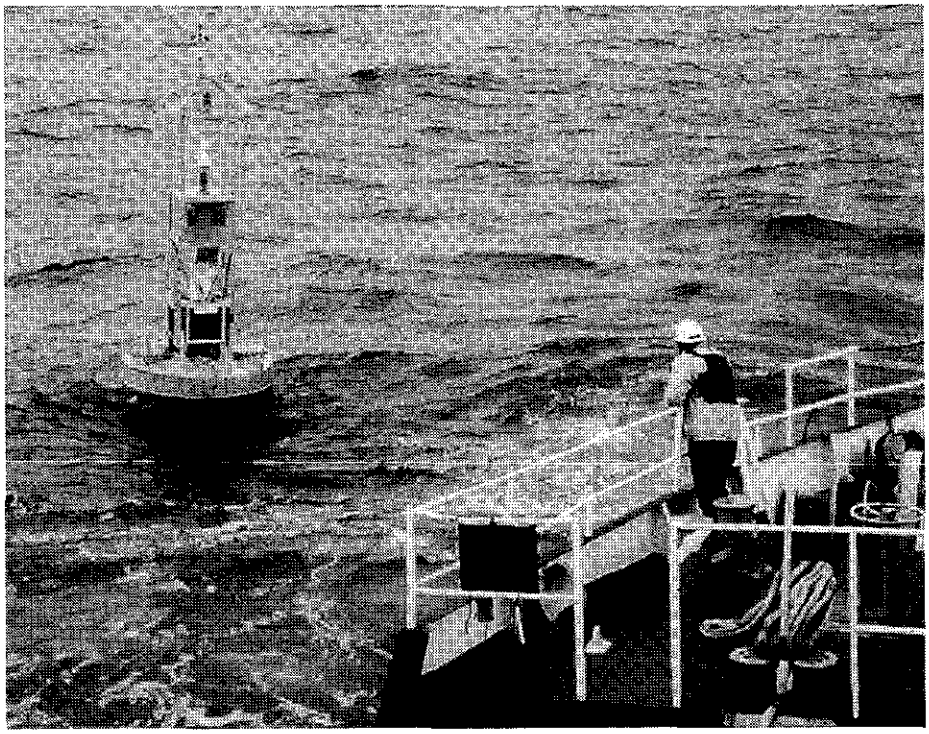

Figure 11. USCG 9x35 Exposed Location Buoy (ELB) with DACT System

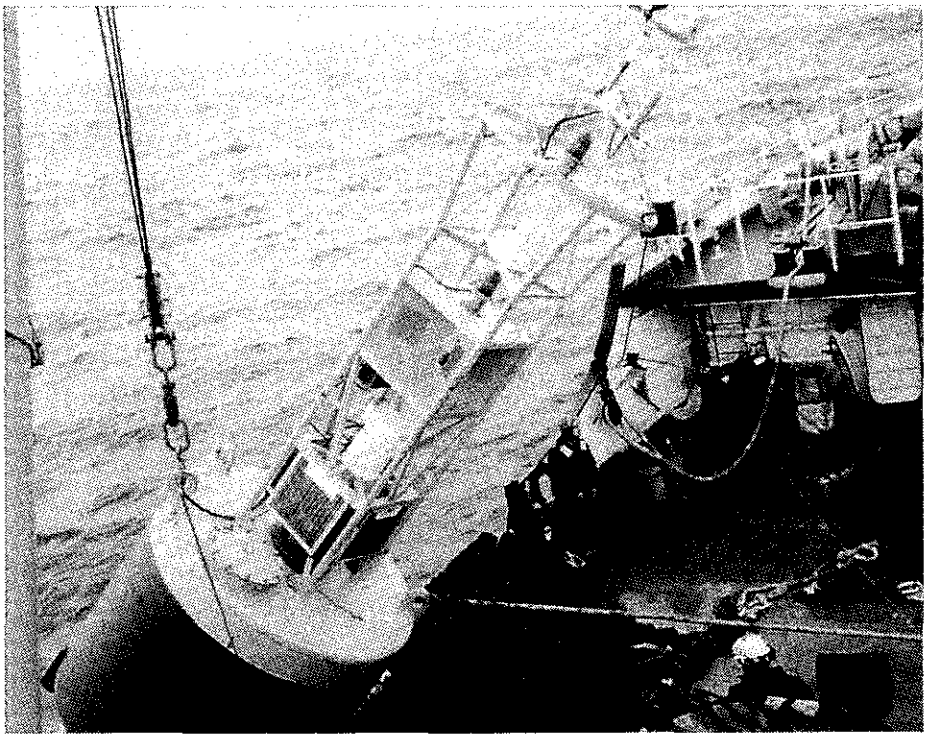

Figure 12. USCG 9x35 ELB with DACT System — Deployment

Coast Guard Buoys Continued

NDBC has prepared a proposal for replacing six of the seven lost data stations with dedicated NDBC buoys. Based on previous discussions with National Weather Service personnel, NDBC has recommended that the Five Fathom, New Jersey, station be abandoned because the Delaware Bay station should be able to serve both constituencies.

The NDBC proposal would continue instrumenting the Nantucket LNB (44008) and Columbia River LNB (46010). Normal LNB servicing schedules would allow NDBC to reintegrate the Columbia River LNB during the spring/summer of 1993 (FY93). In the meantime, a Congressional add-on in fiscal year 1992 has allowed NDBC to temporarily deploy a NOMAD buoy at station 46029 near the Columbia River LNB.

Station 44012 (Five Fathom LNB) would be abandoned in fiscal year 1993, when the USCG plans to deploy an ELB at station 44012. The remaining NDBC data packages on navigation buoys would be replaced with standard NDBC 3-meter discus buoys if funding is approved. The NDBC buoys would be moored in the vicinity of the channel entrances marked by the existing LNB/ELB data stations. This would permit the NWS forecast offices to continue marine services to its users and to maintain the climatological data base for those areas.

The National Weather Service, and especially NDBC, recognizes the importance of these stations to forecasters and mariners. Every effort is being made to ensure uninterrupted data collection continues.

Raymond H. Canada and J. Michael Hemsley, NDBC

Wave Processing Module Continued

After the WPM was integrated into the buoy and before the buoy was shipped for deployment, buoy spin tests and direction verification tests were performed that verified the system's correct operation.

The test buoy was deployed off the California coast (Station 46014) in late April 1992. The test results and the prototype WPM's performance will be reported in a later issue.

Currently, the development of a full version of WPM is under way. The full version will include 11 analog input channels. Thus, the WPM will be capable of processing data for the Hippy directional wave system (which requires five input channels) and all processing software. A complete onboard diagnostic and calibration capability will be included to simplify the onshore and at-sea testing and maintenance of the system. Self-diagnostic and calibration software is presently being developed by Neptune Sciences, Inc., for NDBC.

In addition, an easy-to-use interface will be developed to simplify the setting and control of configuration parameters.

Dr. Chung-Chu Teng, NDBC

The purpose of this Bulletin is to inform persons involved in automated acquisition or use of enviromental data, at sea and on land, as to the systems under development or in use, primarily by NOAA, that perform that function. Relevant articles are encouraged from non-NOAA sources. Subject matter should be current and in the general style illustrated by articles in this issue. Photographs must be 8- by 10-inch black and white prints. The right to edit all submissions is reserved. Articles ready for publication should be submitted to the:

National Data Buoy Center
Building 1100
Stennis Space Center, Mississsippi 39529-6000
Phone (601)688-2800

ADCP Continued

the horizontal current data. Buoy translational motion is corrected by using the ADCP bottom track data.

The ADCP data are transmitted hourly via the GOES satellite by an NDBC VEEP Payload. A special interface was developed that converts the data from the ADCP to a form that can be transmitted via the satellite since the RS-232 data from the ADCP are binary encoded and can contain some bit sequences that are prohibited in the GOES system. The interface assembly, installed between the ADCP and the VEEP, consists of a general purpose, single board computer, an associated RS-232 interface, and a power supply. The converted data transmitted through the GOES system are converted back to their original binary form at the NDBC facility.

To accommodate the ADCP transducer head assembly, a 36-inch (91.44 cm) diameter well was installed in the 10-meter buoy hull through the "equipment room" area of the buoy (Figure 13). The 500-pound (227-kg) bronze transducer head assembly was mounted on a steel plate that is steered and seated into its proper position in the bottom of the well using a vertical alignment guide and tapered dowels. A jib boom with a winch was installed on the buoy deck to remove the transducer head assembly from the well for routine cleaning and inspection, and for transducer replacement at sea. The ADCP electronics unit, an 8-inch (20.3-cm) diameter by 36-inch (91.4-cm) long pressure tube, was mounted inside the buoy equipment room. A water-blocked cable was used to connect the electronics unit to the transducer head assembly.

Prior to integrating the two buoys (on the west coast), a full scale mock-up of the ADCP transducer mounting and handling arrangement was first installed on a similar 10-meter buoy at NDBC during the design phase of the project. The initial design was tested and improvements were made before the design was finalized.

Initial testing of the flux-gate compass was performed with the compass installed in the ADCP transducer head as designed by the manufacturer to determine the magnitude of magnetic influence the steel buoy hull was having on the compass. A procedure was developed for correcting the compass for buoy hull-induced magnetic fields using a combination of internal ADCP software and externally applied magnets. While performing the compensation procedure, it was found that the magnetic influence from the buoy was too great for the compass error to be corrected while the compass was mounted in the transducer head. The compass was then removed from the ADCP, placed in a watertight enclosure, and mounted at the top of the buoy's aluminum superstructure, away from strong, non-uniform magnetic fields. The ADCP electronics were subsequently modified so that the compass could be mounted remotely from the transducer, and a modified compensation procedure was performed that indicated a satisfactory operation of the compass in this new location.

The two NDBC buoys, outfitted with the ADCP's, were deployed in early December 1991. Horizontal current data appear to be good. There is close agreement between the ADCP data from the uppermost bin (centered at 24 meters) and data from a nearby Vector Measuring Current Meter (VMCM), moored at the same depth, that was deployed by Scripps Institution of Oceanography. Additional current velocity profile comparisons will be made in the late spring of 1992 when recorded current data are recovered from additional VMCM's.

Kathleen O'Neil, CSC

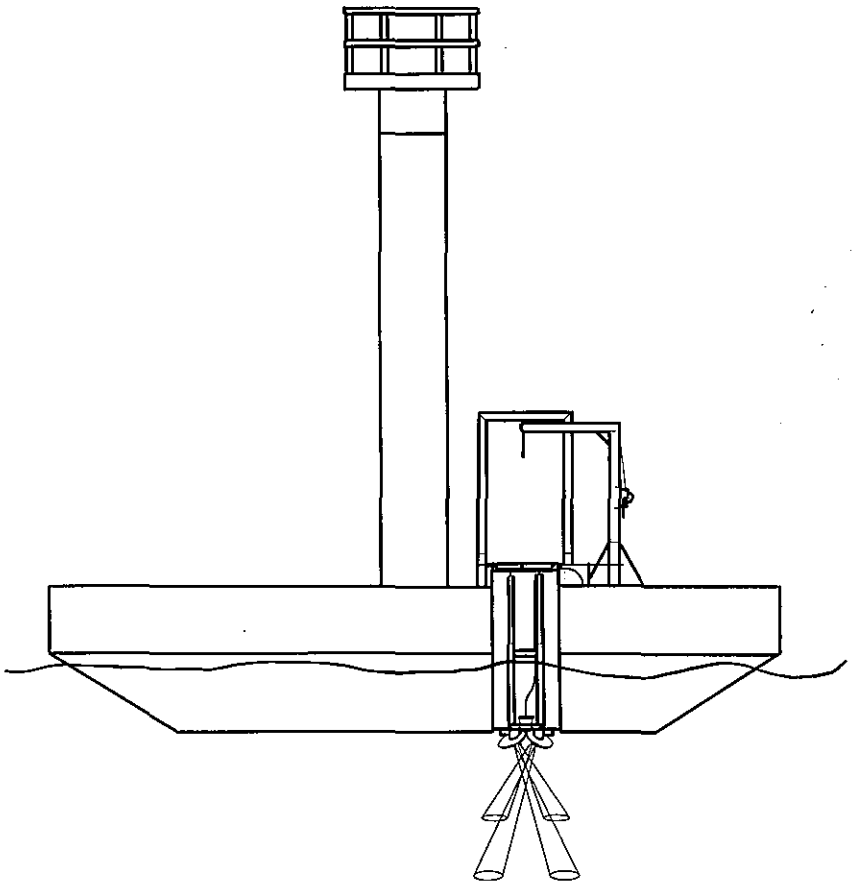

Figure 13. Diagram of 10-Meter Buoy Hull with ADCP Installed

"Smart Barometer" Buoys Deployed In the Gulf of Mexico

Barometers are the most costly meteorological instruments used by NDBC. The average cost of a barometer with the accuracy to meet NDBC requirements is in the $1500 to $2300 range. As part of an ongoing effort to reduce the cost for barometers and still maintain the high and long-term accuracy required, a new system package known as the "smart barometer" is being developed. A "smart barometer" system consists of one or more inexpensive, reliable pressure transducers, a microprocessor, and a temperature sensor.

The pressure transducers, devices that convert air pressure into electrical signals, were developed originally for the automotive industry for fuel and pollution control systems. They are inexpensive (less than $100) and reliable but are subject to errors in the output signal due to changes in ambient temperature. However, discrepancies between actual and measured pressure values caused by temperature variations are repeatable for a given set of pressure and temperature values.

The challenge, then, was to develop a set of mathematical equations describing this relationship that could correct the pressure reading to an accurate barometer value for any temperature the sensor may encounter. The equations would subsequently be programmed into a dedicated microprocessor where the precise temperature of the transducer is sampled along with the pressure, the result being a computed corrected pressure. This difficult task was accomplished by NDBC's own "Dr. Who," Dr. Ed Michelena.

For the first experiment, pressure transducers made by two different manufacturers were chosen for laboratory and field testing. The "smart barometer" development and testing was implemented in four phases.

The first phase consisted of calibrating each individual transducer over a range of pressures from 800 hPa to 1100 hPa, stepping the temperature in 5-degree increments from -40 °C to +40 °C. This data, unique to each of the test barometers, was to determine the relationship between actual pressure, temperature, and transducer output pressure. Dr. Michelena compiled the data from calibration of the transducers and developed sets of equations and coefficients to "linearize" each unit.

The second phase included installation of the calibrated barometers on two drifting buoys (ID numbers 7492 and 7494). Each buoy was outfitted with three "smart barometers" and an accurate reference barometer (Paroscientific Model). The experimental barometers were interfaced to an onboard microprocessor programmed with those sets of unique equations developed in the first phase. The Paroscientific barometer used the standard processing system for the drifting buoy payload.

In the third phase, the buoys were placed in a large environmental chamber and cycled through a temperature range of -50 °C to +70 °C over a 24-hour period to verify the functional operation of the complete system.

In the fourth phase, the buoys were deployed in a canal next to the NDBC facility for a period of 5 weeks. This test verified that the buoy payloads, including the transmitters, were functioning properly. The buoys transmitted the data to a NOAA polar-orbiting satellite, and the data were received at NDBC via Service Argos.

On January 19, 1992, the buoys were deployed into a gyre located in the midwestern Gulf of Mexico near 25° N., 93° W., by the USCGC *Decisive*. On February 5, 1992, a control module failed on buoy 7493, resulting in the loss of the Paroscientific reference barometer pressure reading. The three "smart barometers" continued to report pressure readings. Buoy 7494 had no similar problems.

NDBC, on a daily basis, monitored and analyzed the first 30 days of the deployment data to verify that the calibration procedures were correct. Table 1 shows the comparison between the reference barometer (P_s) and one test barometer (P_a) on each buoy. The comparison is based on the numeric difference between P_s and P_a. NDBC's quality control standard for barometric pressure is $[(\text{mean error})^2 + (\text{std dev})^2]^{1/2} \leq 1$ hPa. The data for buoy 7493 shows the data collected up to the time of the control module failure.

Table 2 shows that the test barometers in buoy 7494 have remained within the above quality control standard with the exception of P_a for the month of March. The value for this month was 1.03 hPa. Therefore, the process used to establish the relationship between pressure, temperature, and output voltage provides a sensor that can meet the quality control standard. Buoy 7494 had typically remained within 60 nautical miles of buoy 7493 through the month of April. The same pressure changes and approximately the same barometric pressures were observed.

The buoys separated from each other in early May and are no longer in the gyre. Plans were initiated to recover both buoys. Successful recovery would be very valuable and would allow postcalibration of all of the test barometers and verification that the pressure measurement correction curves remain valid.

The test results to date have fully justified NDBC's efforts. The future plan is to design and integrate a stand-alone barometric sensor package that can be used for all applications and that can provide a low-cost sensor meeting all of NDBC's high standards.

LCDR Neil Van de Voorde, USCG

Table 1. Comparison Between Paroscientific Reference Barometer P_s and Test Barometer P_a

	BUOY 7493	BUOY 7494
STANDARD DEVIATION (hPa)	0.26	0.26
MEAN ERROR (hPa)	0.02	0.02

Table 2. Comparison for Buoy 7494 Between Paroscientific Reference Barometer P_s and the Test Barometers P_a, P_b, P_c

MONTH	RANGE (hPa)	STD DEV (hPa)			MEAN ERROR (hPa)		
	P_s	P_a	P_b	P_c	P_a	P_b	P_c
FEB	1002-1024	0.41	0.65	0.58	-.35	0.11	0.74
MAR	1007-1024	0.48	0.55	1.01	-.57	0.54	0.18
APR	1003-1024	0.33	0.28	0.40	0.72	0.79	0.25

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