S481

Buoy Systems for Acquiring Data in a Marine Environment

J. M. Hall, NOAA Data Buoy Office
E. G. Kerut, NOAA Data Buoy Office
J. Irico,* Sperry Support Services

Introduction

The mission of the NOAA Data Buoy Office (NDBO) is to develop and apply buoy systems for gathering and processing meteorological, oceanographic, and water-quality data to meet current and near-term user needs. Among existing and potential users are national and international weather services, the scientific research community, offshore industries, fisheries, environmental protection groups, and recreational interests. The Office is part of the National Oceanic and Atmospheric Admin. (NOAA) and is located in Bay St. Louis, Miss.

NDBO buoy systems involve a family of automatic and unmanned environmental buoys of differing capabilities, supported by communication/data processing facilities and servicing ships. Basically, this family can be divided into large moored buoys for use in the deep ocean, smaller moored buoys for application along the continental shelf, and small drifting buoys for use throughout the marine environment.

Our most developed area of technology applies to large discus buoys moored in the deep ocean for extended periods in frequently severe environments. Less developed areas of technology, now receiving increasing emphasis, are associated with the more limited smaller buoys for mooring on the continental shelf and for drifting applications. Supporting these technology areas is our ongoing program for developing or improving sensors for meteorological, oceanographic, wave, and water-quality measurement, with oceanographic-sensor development posing the greatest challenge.

*Presently head of J. Irico & Associates, New Orleans, La.

Deep-Ocean Moored-Buoy Systems

A large portion of the NDBO effort has been in the development of deep-ocean moored-buoy systems for acquiring meteorological and oceanographic data in a severe environment, primarily in support of the National Weather Service but designed also to support the scientific community and other interests. Starting with an experimental engineering program for testing and evaluating hardware, coupled with operational reporting to the National Weather Service and augmented by a payload simplification program, development has progressed to the next-generation prototype environmental buoy recently procured.

Experimental Engineering Program

A significant achievement in buoy development was realized in mid-1974 with the completion of our large-buoy experimental engineering program. This program was intended to improve the state-of-the-art hardware, to gain experience in its at-sea operation and maintenance, and to set the stage for prototype development.

A thick discus moored buoy, as shown in Fig. 1, was the result of this program. This buoy is 40 ft in diameter with a 100-ton displacement and a meteorological sensor suite located at 5 and 10 m above the water. It was designed to be moored to depths of 20,000 ft in a survival environment of a 6.2-knot current, a 155-knot wind, and a significant wave height of 45 ft. The mooring line was designed with an integral data line for accommodating inductively coupled oceanographic sensors at various levels in the upper 500 m.

Automatic, unmanned buoys are being used increasingly for acquiring meteorological, oceanographic, and water-quality data from the marine environment. This paper discusses large discus buoys moored in the deep ocean, small buoys used as drifters in open waters and polar ice regions, and moored buoys along the continental shelf.

Activation of all sensors to acquire and process environmental data is performed by a general-purpose digital computer that may be reprogrammed from the shore communication station at Miami, Fla. Environmental measurements are acquired automatically every 3 hours by buoy self-initiation and, after encoding, are transmitted to the shore communication station by high-frequency radio. There the data are processed further and are sent to designated users. Measurements can be obtained more frequently upon command from the shore station. Electrical power for buoy operations is supplied by diesel-driven motor generators.

Of the six buoys involved in this program, five were deployed in the Atlantic Ocean and the Gulfs of Mexico and Alaska for testing and evaluation combined with operational weather reporting to the National Weather Service. The sixth buoy was fitted with an advanced-type payload developed and built for the prototype environmental buoy discussed later.

The chief goal of this program was to evaluate existing and improved sensor systems for operational buoys. Sensor systems were largely unproved for extended periods of operation, and support-system hardware had to be very flexible to allow for remote testing and changes in testing routines. This flexibility was obtained only with system complexity and a sacrifice in reliability; while flexibility is important for testing and evaluation, it is not required for buoy payload systems tailored for specific mission requirements.

Measurements of wind speed and direction, air pressure and temperature, precipitation amount, dew point, and surface water temperature have been reported routinely to the National Weather Service for dissemination nationally and internationally. For certain buoys, wave height and period also have been included. Where possible, improvements have been made to enhance reliability when failures have occurred. Generally, the sensors making the meteorological measurements have performed satisfactorily for extended periods and are considered operational. However, the performance of the oceanographic sensors has not been satisfactory and further effort is required. These sensors were intended to measure current, conductivity, subsurface temperatures, and pressure.

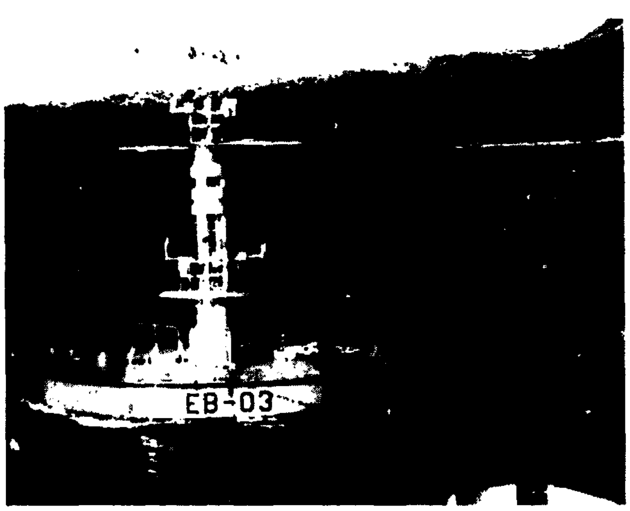

Fig. 1 — Deep-ocean moored buoy.

Although this early program is now completed, the five deployed buoys will be left on station for continued reporting to the National Weather Service and for additional testing until they fail to operate and are returned to base. At that time, they will be refitted with the simplified payload of prototype buoy design as funding permits.

In a parallel program, a boat-hull buoy with a deep vertical-plate keel was developed and tested at sea as part of our efforts to evaluate different hull shapes relative to performance and cost. While this buoy hull survived its trial period in the Gulf of Mexico, it did not compare with the discus hull in dynamic performance and as a working platform for at-sea maintenance. Moreover, after deployment in the more severe environment of the northwest Pacific Ocean, the buoy suffered a structural failure between the keel and the hull, rendering the buoy inoperable.

Payload Simplification Program

Concurrent with the engineering experimentation involving deep-ocean moored buoys, a program was initiated to simplify payload designs for operational missions. The objective was to test low-cost payloads, combining a low-powered, special-purpose, hardwired data processor with simplified sensor interfaces and battery power.

To achieve this objective and to minimize costs, small buoys were used in the program. Ten buoys were built for testing, primarily in the continental-shelf waters of the Gulf of Mexico. To provide for competition, three different designs were contracted — a horizontal-cylinder buoy, a vertical-cylinder buoy, and a spherical buoy, with displacements of 5,600, 3,300, and 1,600 lb, respectively. Although different in design, all buoys have a high-frequency communication system, simple sensor interfaces, a meteorological sensor suite located 2 m above the water, a low-power, special-purpose, hardwired computer, and batteries for a 3- to 6-month power supply. The buoys are capable of delivering environmental data every 6 hours in a self-initiated mode, and also can be interrogated from shore. Measurements of wind speed and direction, air pressure and temperature, and surface water temperature are common to all.

During testing in the Gulf of Mexico, the low-powered, solid-state electronics and the battery power supply performed quite well. This performance was further substantiated by extensive reliability testing of these subsystems in our laboratories. The conclusion reached was that the technology of simplified payloads was demonstrated sufficiently to warrant its application to deep-ocean platforms.

Mooring problems were experienced and were attributed to fishbite, chafing, and material fatigue that has been resolved. Additionally, the meteorological sensors were damaged by sea spray.

Prototype Environmental Buoy

In June 1974, NDBO awarded a contract for one prototype environmental buoy (Fig. 2) specifically tailored to meet the needs of the meteorological community. It was deployed in the Pacific Ocean for environmental monitoring and reporting to the National Weather Service. The design of the buoy is based primarily on our combined experience with the large- and small-buoy programs.

The principal characteristics of the prototype are high reliability, low life-cycle costs, sensor complement of modest accuracy, and provisions to facilitate efficient maintenance at sea. It is a 33-ft discus, capable of deployment and operation in a range of marine environments found in the coastal areas of the Atlantic and Pacific Oceans and the Gulfs of Alaska and Mexico. In fact, in-situ testing of the buoy took place in the rough waters of the Gulf of Alaska. Drawing upon our favorable experience with simplified payloads, a low-powered, special-purpose, nonprogrammable computer and battery power supply were chosen for the payload, with the battery packs sized for 3 years of routine buoy operations.

Required parameters for measurement and ordered priority are wind speed and direction, air pressure and temperature, significant wave height and period, and surface and subsurface temperature (down to 300 m). Meteorological sensors are located at the 10-m level. Measured values are reported regularly to shore in a self-initiated mode every 3 hours. Stored hourly data can be acquired on demand upon interrogation from shore.

The wave-measurement system is the same as the initial version developed for the 40-ft discus buoy and will be updated as improvements become available and can be incorporated. Temperature measurements below the sea surface and through the mixed layer with a thermistor line may be troublesome initially. While thermistor technology is well established, there are potential problems in system application such as handling, deployment, retrieval, tangling, and leakage of the line.

Initial communication mode is high frequency, compatible with our existing shore stations, but with provision for conversion to ultrahigh frequency for communicating with NOAA's Synchronous Meteorological Satellite/Geostationary Operational Environmental Satellite.

In the spring of 1975, a contract option was exercised to procure another five prototype buoys; the first of these will be delivered shortly for deployment in the Pacific Ocean.

Wave-Sensor Developments

The initial wave-measurement system for the large engineering experimental buoys was designed to give significant wave height, significant wave period, and spectral width, and was installed on one buoy. The method of operation involved a voltage analog measurement by a strapped-down accelerometer near the vertical center line of the buoy, from which buoy velocity and displacement were derived by successive integration. The onboard general-purpose computer sampled the continuous analog values of acceleration, velocity, and displacement, converted them into digital form, and computed the wave height, period, and spectral width for relay to shore.

Recognizing that this system was limited in scope, a wave system of greater capability was designed and installed on two other large buoys. This system has the same hardware as the initial system but uses an improved onboard software program whose output, when operated upon by an onshore software program, produces high-resolution, one-dimensional wave spectra. Furthermore, the system can record and report to shore nonspectral data such as highest crest, lowest trough, mean zero crossing period, and number of samples per record. Results to date with this digital reporting system are very encouraging. Future prototype environmental buoys will be fitted with a system to provide wave spectra within the limitations of the existing interface design of the buoy data processor.

Oceanographic-Sensor Developments

NDBO efforts at measuring oceanographic parameters began when the specifications for the original large buoys were formulated in 1970. At that time, the objective was to have an all-purpose oceanographic system located on a single platform and capable of satisfying many users with large and diversified quantities of telemetered data. To accommodate this objective, a system was designed with water current, temperature, pressure, and conductivity sensors grouped in a spheroidal housing integral to the mooring line/data line and powered from the surface platform. The sensors are inductively coupled to the line and are located at various intervals along the 500-m mooring line/data line portion of the mooring. They acquire and transmit data to the buoy platform upon command from a sensor deck unit under control of the onboard data processor.

The result of this design was a highly complex sensor system whose performance has been rather discouraging. Damage has been incurred in the handling of the large sensor housings during deployment, and operational failures, including failures of the sensor housing

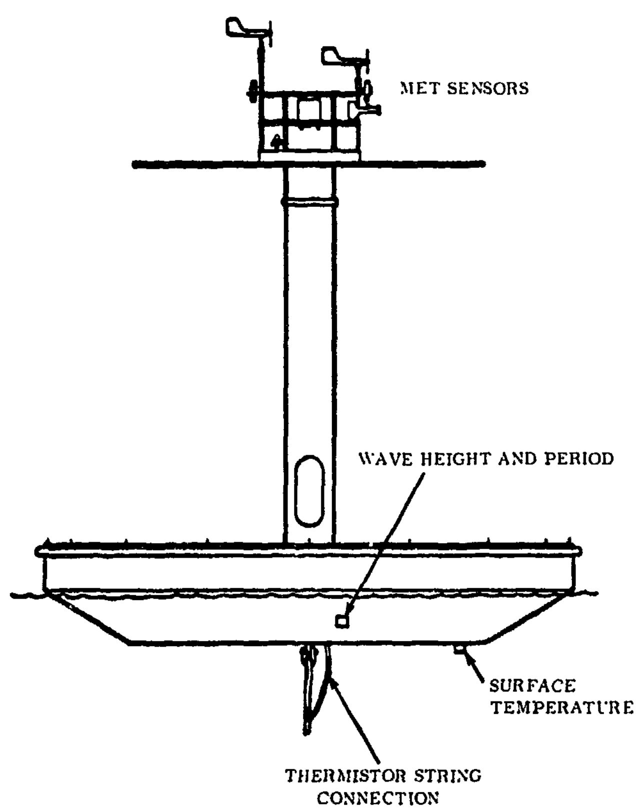

Fig. 2 — Deep-ocean moored prototype buoy.

electronics, have been experienced after deployment. Moreover, once deployed, failed sensor components are inaccessible for failure analysis until the mooring line is recovered.

When design began on the current measurement sensor, two promising techniques were investigated: the sonar doppler and electromagnetic techniques.

It has become evident that user needs can be satisfied with a much simpler system. Accordingly, we have reoriented our program toward a system that provides for the measurement of current and temperature, which are considered the parameters of primary interest, in a self-recording configuration. Expansion of the system for additional measurements and for near real-time data reporting can be undertaken as user needs are demonstrated.

Consistent with this reassessment, emphasis has shifted to self-recording current meters, with or without temperature measurement capability, using in-line and self-orienting sensors. Some success has been achieved, notably with a sensor of individual electromagnetic-probe design that orients itself with the current. However, this self-orienting sensor is not too responsive to fast changes in current direction. Moreover, it is susceptible to fouling that results in sluggish movement or mechanical binding.

Related Buoy Programs

NBDO also has taken action to assist the scientific community and others in deep-ocean endeavors.

In 1975 we assumed responsibility for deep-ocean moored-buoy support for the North Pacific Experiment. This is an emerging program that involves long-term environmental monitoring, large-scale air/sea interaction, and low-frequency weather changes. The two large discus buoys currently involved are for meteorological measurements, although one buoy is equipped with a developmental profiling oceanographic sensor to measure the temperature/pressure profile in the upper 300 m of the water column. This sensor is attached to a cable and is allowed to free-fall at a near constant rate while measuring 25 data samples per meter of drop. Data are communicated to the surface through a single conductor cable using sea water as the return path. A uniquely designed winch is used to deploy and retrieve the sensor. A complete drop and retrieval cycle requires about 6 minutes. The profiling sensor system is still being tested and evaluated.

Preliminary discussions have been conducted on the definition of a buoy system in support of ocean-mining impact studies. It is envisioned that such a buoy would use a proved discus hull combined with a subsurface float and would measure wind speed and direction, air pressure and temperature, wave height and period, current, and water temperature from the surface to the bottom.

Continental Shelf Moored-Buoy Systems

NDBO is accelerating its efforts in the development of buoy systems to provide environmental data from the waters of the continental shelf.

Meteorological Buoy Program

This program is dedicated to better understanding and

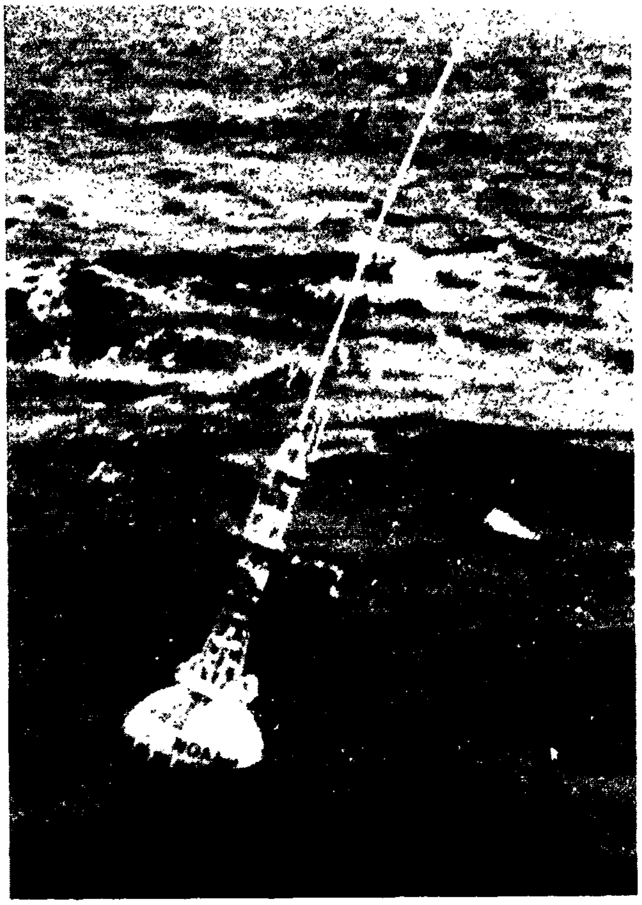

Fig. 3 — Continental-shelf moored spherical buoy.

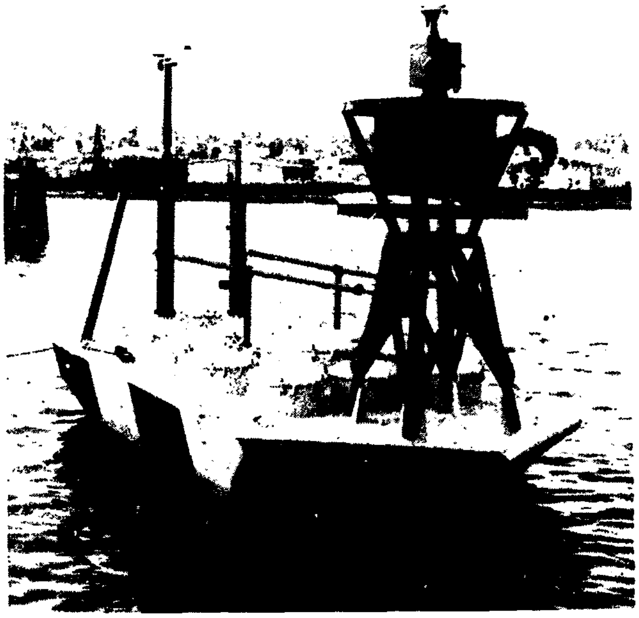

Fig. 4 — Continental-shelf moored buoy.

predicting the meteorological forcing functions that affect the ocean dynamics over the continental shelf. Environmental data acquired support scientific researchers and operational weather users such as offshore industries, fisheries, and pleasure-boat operators.

An effort completed last year was in support of a shelf dynamics study conducted by the U. of Miami. It involved the deployment and operation of three existing small spherical buoys (Fig. 3) for 6 months off the west coast of Florida. Measurements of wind speed and direction, air pressure and temperature, and surface water temperature were acquired every 6 hours and were reported both to the National Weather Service and the University.

Another meteorological buoy was deployed on behalf of the Environmental Research Laboratory of NOAA, which is conducting environmental studies for the Bureau of Land Management. This buoy, as shown in Fig. 4, combines a hull obtained from a previous Navy program with a simplified payload from one of our small vertical-cylinder buoys. It was moored off Prince William Sound, Gulf of Alaska, for an initial period of 6 months to acquire and report wind speed and direction, air pressure and temperature, and surface water temperature every 3 hours to both the National Weather Service and the Environmental Research Laboratory.

In preparation for further investigations along the continental shelf, a program is in progress to provide a buoy of increased hull size and measurement capability. The hull selected is a 16-ft discus, acquired from another government program, that will be integrated with an existing small-buoy payload and a wave-spectrum analyzer system. Two buoys were assembled and deployed in mid-1975 along the Atlantic continental shelf.

Oceanographic Buoy Program

There exists a need for obtaining quantity and quality data on the marine environment in support of the design of offshore structures such as oil platforms, nuclear power plants, and superports, as well as in support of fishery operations. In an effort to satisfy this need, NDBO recently initiated activities for the design of a first-generation oceanographic prototype buoy system patterned after the cluster concept of a surface parent buoy augmented by one or more satellite-instrumented subsurface floats.

The parent buoy will be a discus hull with an improved version of a small-buoy simplified payload. In addition to the usual meteorological measurements, the improved payload will provide appropriate interfaces for a wave-spectrum system, and for subsurface water current and temperature sensors located on the parent buoy and subsurface floats. It is expected that an acoustical signal device will be used to monitor the operation of the oceanographic sensors. The wave-spectrum system will be similar to the high-resolution system operating on two of our large buoys, but will be refined and reduced to a hardwired form.

Activities in this area will take advantage of the state-of-the-art sensors and the work we are doing in developing self-orienting and in-line sensors and profiling systems. One such profiler, known as the Cyclesonde, provides for the sensor to ride up and down a taut cable, while simultaneously measuring and recording current and temperature data.

Water-Quality Buoy Program

The purpose of this program is to provide buoy systems for such uses as pollution monitoring and dispersion studies in estuarine/coastal waters, as well as monitoring of ocean dumping areas. The goal of our initial effort is to demonstrate the technology to permit tailoring water-quality buoys for specific operational applications. This initial effort involves the development of a water-quality indicator system to measure dissolved oxygen, chlorophyll, pH factor, turbidity, water temperature, and conductivity.

Two systems have been fabricated and delivered. The first system was deployed 35 miles southeast of Cape May, N.J., in the summer of 1975. Data analysis is still incomplete, but it appears that sensor operations were fairly successful. A second system will be installed on a piling in Lake Pontchartrain, La., this spring in a cooperative project with the U.S. Corps of Engineers.

Drifting-Buoy Systems

NDBO is developing a variety of drifting buoys for meteorological and oceanographic experiments of limited duration where extended areal coverage is desired and low cost is very significant. A drifter is defined as any instrumented buoy dependent on a position-fixing capability to identify its location, and often is irretrievable through planned expendability or loss.

Open-Water Drifter — Lagrangian

An expendable buoy has been developed to achieve a Lagrangian-type tracking of water parcels for determining current flow, while simultaneously measuring a few meteorological parameters. Tracking is accomplished with a drogue that couples the surface buoy to a particular depth in the mixed layer.

A moderate-environment version of the buoy without its drogue is shown in Fig. 5. It is designed as a low-cost system, with an approximate price of $4,500 each in quantity production. The hull is a spar section with a foam-filled fiberglass flotation section, and has a displacement of 250 lb. The drogue is a window-shade type consisting of a rectangular piece of fabric positioned lengthwise between top and bottom horizontal spars. It has a bridle at the top for attaching to the hull and one at the bottom for attaching to an underwater temperature sensor line that can extend through the thermocline. A surface water temperature sensor is mounted on the hull. Meteorological sensors for wind speed, air temperature, and air pressure are located less than 2 m above the design water line. Communication and position fixing are dependent upon a buoy transmit terminal (BTT) sending data to a random-access measurement system (RAMS) aboard a polar-orbiting satellite. Successful system end-to-end testing with the satellite has been demonstrated.

A severe-environment version of the buoy also has been developed, and a number of drifting experiments have been successfully performed.

About 60 buoys of both the moderate- and severe-environment configuration were built to support pilot experiments for the First GARP Global Experiment, the International Southern Ocean Study, the North Pacific

Experiment, and other experiments. Extensive engineering testing of both types of buoys has taken place in the Gulf of Maine. A pilot engineering experiment in the southern oceans started in Jan. 1976.

Open-Water Drifter — Air/Sea Interaction

Another expendable prototype buoy is being developed for understanding and monitoring air/sea interaction phenomena, initially in support of heat budget experiments being conducted under the North Pacific Experiment. This buoy is shown in Fig. 6. It is a relatively inexpensive drifter about 66 ft long, displacing 1,200 lb. The oval-shaped hull is 4 ft in diameter and 5 ft high, made of fiberglass, and filled with polyurethane foam. Housed in the hull are the electronics. Extending above and below the hull are open towers of equal length. The upper tower supports the meteorological sensor suite and a wind orienting vane, while the bottom tower supports the batteries and ballast to provide necessary stability.

The buoy is designed to measure incoming radiation, relative humidity, wind speed and direction, air temperature, and air pressure at 10 m above the water line, as well as water temperature at and below the surface to 200 m. As with the Lagrangian drifter, the buoy will make use of a BTT unit operating in conjunction with a RAMS-equipped polar-orbiting satellite for communication and position fixing.

Ice-Drifting Buoys

We also have a program to develop and build buoys to monitor environmental quantities in the deep polar regions, for initial application to the Arctic ice-dynamics joint experiment. This is an international scientific experiment dedicated to furthering the understanding of the sea-ice-atmosphere thermal-mechanical system and its effects upon the environment.

During Phase 1 of the development, seven expendable buoys, weighing 337 lb each, were implanted in Arctic ice floes to provide environmental data on air pressure, temperature, and ice movements. Fig. 7 shows one of the buoys being implanted. During the melt season, the buoys were free-floating, but were still captive in the ice floes. Data telemetry and buoy location were obtained with the interrogation recording and locating system aboard the NIMBUS-4 polar-orbiting satellite, now in decay orbit. Disassembled buoys were transported by a ski-equipped airplane to their deployment sites, where they were assembled and deployed.

Fig. 5 — Lagrangian drifting buoy.

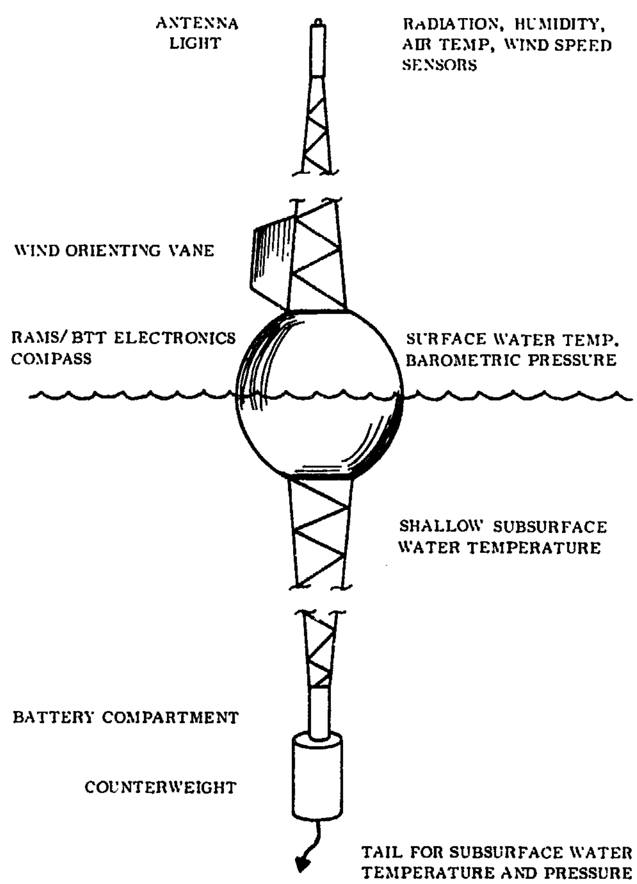

Fig. 6 — Air/sea interaction drifting buoy.

Fig. 7 — Ice buoy.

The buoy array spanned 470 miles and demonstrated the feasibility of deploying larger numbers of data buoys throughout the Arctic regions by airplane. Temperatures to −50 °C, winds to 50 knots, and heavy icing conditions did not noticeably affect system operations. Failures that were encountered were attributed to a malfunction of the water seal between hull sections and to damage caused by polar bears.

Another ice-buoy system was completed for support of the Arctic experiment in 1975. Eight of these buoys are now operational. This system consists of nonexpendable-type buoys arrayed around a manned central control station in the Arctic ice pack. The Navy navigation satellite system is used for position fixing, while communication is by a high-frequency radio link to a shore station. A degree of flexibility for other measurements is provided to widen the area of potential applications where requirements exist for high position-fixing accuracies, high date rates, and satellite-independent communications.

Present planning calls for a separate, expendable, air-droppable ice-buoy system to provide basic environmental data coverage in the Arctic and Antarctic during the First GARP Global Experiment. This buoy system will be equipped with pressure and temperature sensors and will use a BTT/RAMS or a similar system for communication and position fixing. Prototype systems are being tested as part of an ongoing Arctic ice-dynamics joint experiment.

Summary

Environmental data buoys are becoming an increasingly versatile and reliable means for acquiring data in the marine environment. Beginning with deep-ocean applications, the horizon for buoy missions has been extended throughout the ocean regimes, including the polar regions.

Large buoys are deployed in the deep ocean, routinely reporting meteorological and wave data to our National Weather Service in near real-time for national and international dissemination. Concurrently, a prototype environmental buoy featuring high reliability and low cost is being developed as the forerunner of our next generation of deep-ocean moored buoys.

Buoys are also deployed on the continental shelf, with more to come; one of these additional buoys will be our first venture with an oceanographic buoy system. Pacing the success of this buoy is the development of oceanographic-sensor subsystems with long-term stability and ease of servicing, a task that will benefit from our oceanographic-sensor experience.

In planning ahead, we foresee an increasing need for oceanographic reporting to support ocean-related industries, and we intend to meet this need with appropriate development programs. **JPT**

Original manuscript received in Society of Petroleum Engineers office Jan. 22, 1975. Paper accepted for publication Nov. 10, 1975. Revised manuscript received Jan. 26, 1976. Paper (SPE 5481, OTC 2296) was first presented at the Seventh Annual Offshore Technology Conference, held in Houston, May 5-8, 1975.