NEXT GENERATION OCEAN OBSERVING BUOY IN SUPPORT OF NASA'S EARTH SCIENCE ENTERPRISE

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1. Introduction

The Woods Hole Oceanographic Institution (WHOI) and Jackson and Tull have been developing and testing an improved moored, instrumented buoy system in support of NASA's Earth Science Enterprise (formerly Mission to Planet Earth Program.) This new design (see Fig. 1) builds on WHOI's oceanographic experiences with buoys, moorings, and sensing systems, and Jackson and Tull's expertise with aerospace telemetry and computer systems. The present buoy system includes capability for a full suite of meteorological sensors: wind speed and direction resolved to vector averaged winds, atmospheric temperature, relative humidity and pressure, long and short wave radiation, photosynthetically active radiation (PAR), and incoming spectral irradiance. The mooring cable anchors the buoy and holds sensors at various depths for water temperature and conductivity (salinity) and an acoustic Doppler current profiler (ADCP) for horizontal current profiles. Several bio-optical packages, (each with a chlorophyll-a fluorometer, a beam transmissometer or optical backscattering sensor, a scalar PAR sensor, and upwelling spectral radiance and downwelling spectral irradiance sensors, are spaced at several depths. The buoy is moored with a compliant elastic tether to reduce hardware wear and improve data quality. The system is capable of deployment on continental shelf regions worldwide for ocean science studies, including ocean color satellite ground truth validation. It uses the new generation of low Earth orbiting communication satellites for two-way, high throughput command and data telemetry transmissions.

II. Buoy

A. STRUCTURE: Many earlier buoys were made from surplus steel submarine net floats with towers and bases added. A number of these are still in use. GLOBEC (NSF and NOAA funded Global Ocean Ecosystems Dynamics program) constructed two new buoys for use on moored systems with telemetry on Georges Bank. These look similar (but smaller) to the buoy shown in Fig. 1. They were constructed

Fig. 1. The new buoy system undergoing full system tests off the WHOI dock. The large foam flotation collar is seen as the basic buoy hull. The tower holds the four large solar panels. Above the solar panels the tower holds the radar reflector, the guard light and an ARGOS locator beacon antenna. On top of the tower the satellite receiving antenna (highest on right) and transmitting antenna (spirals on left) are mounted as far apart as possible.

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from 5400 series aluminum, which has proven successful through four seasons on Georges Bank. The 5400 series aluminum was used because of some problems with the 6061 series aluminum corroding in the ocean environment. For this program, it was decided to construct the main buoy hull from steel for low cost and simplicity of construction and then hot dip galvanize and paint it for protection against corrosion. Some of the steel guard buoy still in use are over 20 years old, so life shouldn't be a problem with steel. Also, making the frame from steel allowed the use of heavy bar stock in the buoy's feet so that additional zinc or lead weights were not required for ballast.

The buoy's tower is made from 5400 series aluminum for light weight. Mounted on the tower are a passive radar reflector and Coast Guard approved flashing light, telemetry antennas, meteorology sensors and the solar panels. One solar panel can be swung up to gain access to the instrumentation well in the center of the buoy. The well is 24" in diameter and about 45" deep to provide space for the batteries, solar panel regulators, power distribution system, the data processing and storage system, telemetry system, and backup ARGOS buoy locator.

Access to the buoy's electronics well is through a hatch in the top. The hatch opens completely to allow access to the well. The diameter does allow a person to lean into the well to work on batteries.

Mounting the electronics for easy servicing has always been a problem. In GLOBEC, the batteries and electronics are screwed into bars on the side of the electronics well. Bending over the well and working on the components is difficult. In the NASA buoy, the electronics are mounted on racks that slide down inside four ¾ tubes welded to the inside of the buoy well. These racks are held in place by a hard rubber "spring" and pin at the top of each tube. This prevents any up-down movement. However, as there is some sideways movement in the racks, we are trying a clamp mechanism with rubber washers that are squeezed against the side to prevent movement. Still lifting the electronics and batteries out of the buoy is difficult.

B. FLOTATION COLLAR: A Surlyn foam flotation collar from the Gilman Corporation provides the buoyancy for the buoy. In GLOBEC (our first experience with this technology) the buoys were made with greater than 2000 pounds of reserve buoyancy with full payload. The initial design was to enable the buoys to float the anchor and not be dragged down and risk sinking. We did have one guard buoy with smaller foam collar that was moored by chain which did sink. We were dragging for a bottom package, caught the chain and were able to recover it. The foam was compressed when recovered, but has slowly expanded to nearly original size. This mooring was not designed to survive being pulled under by fishing activity, and didn't. The larger foam flotation currently being used will prevent the buoy from being pulled under to the point that it looses buoyancy and sinks.

The Surlyn foam is formed with a standard yellow pigment to indicate a research buoy and not an aid to navigation. During the last four years the yellow color of buoys deployed on Georges Bank has faded slightly, but held up better than painted steel buoys. The foam has proven reliable and although it shows some signs of being hit, gouged and rough usage is not really damaged. It survives being hit better than a steel buoy that will chip and then rust. The foam buoy is also easier to handle as it can be "snugged" up to the ship on recovery without damage to the buoy or ship while recovery lines are attached. Surprisingly, the foam has also reduced buoy maintenance efforts because it does not bio-foul as severely as steel guard buoys deployed nearby. The buoys are easily cleaned by a pressure washer and then repainted below the water line with standard antifouling paint before deployment. We routinely have done no other maintenance. On the other hand, the steel buoys require scraping, priming, and regular painting each time they are deployed.

To minimize the tilting motion of the buoy in the wave field, the lower portion of the foam is cut with two chines so the bottom of the floatation collar approximates a sphere. Therefore, the waves can apply no tilting moment to the buoy, and, with the elastic tether elements in the mooring, provide a more stable platform for scientific observations, especially meteorology sensors.

C. SOLAR POWER SYSTEM The entire buoy data and telemetry system and sensors are powered by solar power. Four Solarex 64 Watt solar panels are mounted at the base of the buoy's tower (Fig. 1) and charge two Concord Battery Corporation 105 ampere hour deep-cycle sealed gel cell batteries through a Specialty Concepts Inc. shunt switching regulator. The batteries are connected to the data system and sensors through a blocking diode network to prevent one part of the system from discharging the other. Thus, there are two independent power systems with one battery and two solar panels each which supply power to the buoy system. This redundancy has not proven necessary in the past but adds a level of reliability.

Solar systems on earlier buoys (Irish et al., 1992) used four 10 Watt Solarex panels which charged two 40 ampere hour Powersonic gell cell batteries. This configuration worked well in the Gulf of Maine (Brown and Irish, 1992 & 1993) and Massachusetts Bay (Geyer, et al, 1992). For current GLOBEC buoys, four 20 Watt Solarex or Siemen panels have been successfully used to charge three Powersonic 40 ampere hour gel cell batteries. GLOBEC guard buoys use two 10 Watt panels charging a single 40 ampere hour battery. These systems have proven reliable, and unless an equipment failure has caused high current drain, have satisfactorily powered the experiments. We are still using some 10 Watt Solarex panels 15 years after they were initially put in service, and they appear to be working just as well as when new. The electrical connections to the panels are often inside junction boxes, which have routinely leaked, and are now potted after connections have been made.

The first solar panels on steel buoys were mounted at about 45° angle near the water. The idea was to have the waves wash over the solar panels and clean any fouling due to birds perching on the buoys. Later requirements for additional power was met by additional solar panels higher on the tower, and they did not have observable fouling, so that concept was abandoned. The GLOBEC solar panels were mounted as suggested for terrestrial applications of latitude plus 10°. However, in tests it appears that the reflection of light from the water makes this angle not as important as initially thought. The configuration shown in Fig. 1 has the panels angled out slightly from the tower. This is so that the panels are protected by the ring at the top of the tower and the Surlyn foam flotation collar at the bottom if a ship should run into the buoy. We have not suffered a solar panel loss other than when it has been hit by a protruding part of the ship during recovery (three panels broken in 10 buoy deployment years).

The power delivered by the solar panel array to the battery system and then to the buoy system is harder to calculate. The four panels around the buoy assure that at least one will be in direct sun (and also that at least one will be on the shady side). In a test of the system shown in Fig. 1 at 22° C, in clear sky conditions in late morning with the sun aligned with one solar panel, that panel delivered 3.5 amps into a gel cell battery. The manufacturer's specifications for these panels states that the maximum current out is 4.0 amps, so we are not doing too badly. The panels 90° from the sun supplied 1.0 amps each, and the one in the shade received 0.75 amps. Therefore, the "256 Watt" solar panel system was actually measured to be supplying only 75 Watts into the battery. In colder weather, these numbers will have to be degraded further for solar panel and battery inefficiency.

A regulator is necessary to prevent overcharging of the gel cell batteries. If they are overcharged they can release hydrogen gas, which can form an explosive environment in the buoy well. We have also mounted a catalytic cell to convert the hydrogen and any oxygen in the buoy into water that is absorbed by standard silica desiccants. In the system, typical voltage drop across the Specialty Concepts, Inc. regulator is 0.5 volts. The voltage drop across the blocking diodes on the batteries is about 0.3 v, so the power at the instrumentation runs about 1/3 v below the battery voltage, depending on system drain. We have generally designed power systems with a factor of two safety to account for temperature and battery inefficiencies, and the systems have supplied the necessary power. The main problem on Georges Bank is getting through the cold, short, overcast days in January and February. Most of the rest of the year, the system generates surplus power which is dumped by the regulators.

III. Mooring

The mooring system utilizes compliant elastic elements to reduce wear on mooring components, and thereby prolong mooring life, and to provide a constant tension on the bottom of the buoy to reduce buoy motion for improved scientific observations. A typical configuration used for instrument testing is shown below in Fig. 2, and is similar to systems used in the Gulf of Maine, Massachusetts Bay (Irish et al., 1997), and in GLOBEC (Irish and Kery, 1996 and Irish, 1997). The main difference of the new mooring for the NASA ocean observing buoy is that sensors will be located below the elastic tether that need to be connected to the buoy's data system. This is accomplished with a coil-cord assembly that carries power down and signal up around one of the elastic elements. (see Paul and Irish paper elsewhere in proceedings).

IV. Connectors

All penetration of the electronics well is done through three plates located on the well above the flotation collar. Each of these plates holds six connectors. They range from coaxial connectors for the antennas, to multiple pin underwater connectors for the sensor and power. In GLOBEC we used the more traditional rubber stopper stuffing tube to bring coaxial and shielded meteorological sensor signals into the electronics well. There were several occurrences of small (several drop) leaks which occurred during a 6 month deployment and left a salt

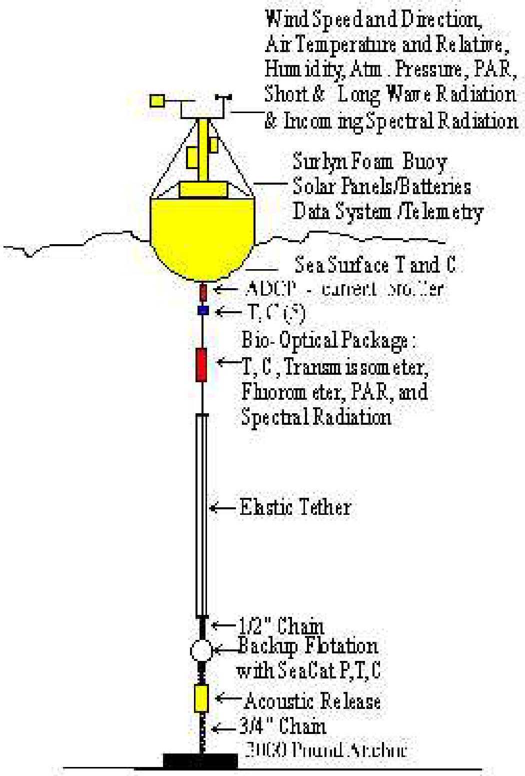

Fig. 2. A schematic of the mooring configuration for shallow water testing of the system during summer 1998 at the WHOI Buoy Farm.

trail on the inside of the electronics well. Because of dry nitrogen and desiccants, there was only damage in one case where a small amount of salt water got onto the sensor connections on the digitizer interface. Therefore, to provide a solid block to water entering the well, only connectors are currently in use.

The signal and power connectors were standard Brantner and Associates K size. They range in capacity from 2 pin (for each solar panel) to 12 pin (for meteorological signals from a separate electronics module on the tower). This module holds the atmospheric pressure sensor, wind speed interface, air temperature and PAR conditioning, and the compass. The compass needs to be mounted away from the steel buoy hull to minimize interference.

The signals from the sensors in the water are brought up alongside the strength cable to the buoy. They are protected from chaffing by standard garden hose and also some firehose where the cables are attached to chain elements and go around sensor mounting cages. The cables then go through a hole in the Surlyn foam and plug into bulkhead connectors in the buoy well. We have adopted the philosophy of using full underwater design even above water since the buoy may be pulled under or have waves wash over it. Therefore, the connectors are capable of providing reliable connections which are easily connected and disconnected and no not leak.

V. Data and Telemetry System

The data and telemetry system for the buoy is being developed by Jackson and Tull and is discussed separately (see Shaumeyer and Gaither papers elsewhere in proceedings). The data system is a PC/104 embedded computer composed of a series of stacked PC/104 modules. The system is running a 486/33 processor with 8MB of RAM and a LINUX operating system. This allows multiple tasks to be running simultaneously: collecting data from the various sensors, operating the satellite radio, and performing various other functions. The system has a several serial input ports which are used to collect data from the sensors in the water (see below). This allows both RS232 and RS485 sensors to be interfaced and data logged. The system is set up so that data from each sensor is appended to a file with the time that the data is received. This time stamp is from the CPU's clock which is regularly updated by time from the GPS receiver. The GPS also provides position information, allowing the buoy to accurately compute satellite pass times and for assuring that the buoy can be tracked if it should break loose. The major negative to this type of data/control system is the high power (about 2.5 amps) when running.

The telemetry system is the major development in this program. We are exploring the family of low earth orbiting satellites to learn the advantages and problems in utilizing this technology for two-way data telemetry from remote platforms to shore. The radio system in the buoy (see Gaither paper elsewhere in proceedings for details) is controlled by the data system which runs an orbital prediction program which tells the radio when the satellite should be within sight and turns on the system. Then the data system formats the data and relays it in packets to the satellite. The satellite then downlinks the data the next time it passes within site of a designated base station. The data is then sorted, normalized, and provided for evaluation, and input to scientific research efforts.

VI. Sensors

The data system and sensor interface is versitile and able to accept inputs from standard analog and serial output sensors. For the test we are borrowing sensors from the GLOBEC program which is in the off year of the field effort. For the next set of deployments the system will have an updated set of sensors as described below. The meteorology observations will be taken at about 3 meters elevation and will include wind speed and wind direction measured relative to the buoy and then by compass relative to magnetic north. The buoy's data system will sample the winds every 10 seconds, and calculate vector averaged wind velocities, the minimum and maximum (gust) winds in the averaging interval. The atmospheric temperature and relative humidity will also be measured to allow momentum and heat fluxes to be estimated. To assist in the heat fluxes, both long and short wave radiation measurements will be made. To connect with the biology components, an incoming PAR (photosynthetically active radiation) measurement will be made. Finally, to connect with satellite ground truth studies, downwelling spectral irradiance measurements will be made.

The water observations will include temperature and conductivity (and calculated salinity and density) at several depths along the mooring cable. These sensors will be powered from the buoy data system and return data to the buoy for storage and telemetry to shore. Also on the mooring an acoustic Doppler current profiler (ADCP) will provide profiles of current from near the surface to near the bottom in continental shelf regions. A bottom pressure instrument will be mounted low on the mooring, and send signals around the compliant elastic tethers to the buoy. This is a new technology being tested as part of this program development (see Paul and Irish paper elsewhere in proceedings).

To couple with biological and global climate studies, several bio-optical packages will normally be spaced along the mooring. Each of these will include its own data system with telemetry to the buoy data system and 4π sterradian (scalar) PAR, chlorophyll-a flurometry, a transmissometer or optical backscattering sensor, temperature and conductivity. The package will also carry upwelling and downwelling spectral radiometers to collect radiation in 7 bands (presently set to the SeaWiFS wavelengths). The combined data will allow basic physical and biological studies to be conducted and supply profiles of upwelling radiance to estimate water leaving radiances for satellite color studies as part of global warming studies.

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VIII. References:

Brown, W.S. and J.D. Irish, "The Annual Evolution of Geostrophic Flow in the Gulf of Maine: 1986-87," *Jour. Phys. Ocean.*, 22(5), 445-473, 1992,

Brown, W.S. and J.D. Irish, "The Annual Variation of Water Mass Structure in the Gulf of Maine: 1986-87," *J. Mar. Res.*, 51,53-107, 1993.

Geyer, W.R., G.B. Gardner, W.S. Brown, J.D. Irish, B. Butman, T. Loder and R.P. Signell, "Physical Oceanographic Investigations of Massachusetts and Cape Cod Bays," Massachusetts Bays Program, Tech. Rept. MPB-92-03, 497 pp, October 1992.

Irish, J.D., "Real-Time Telemetry in the Gulf of Maine," Proc. of the Gulf of Maine Scientific Workshop 8-10 January 1991 in Woods Hole MA, ed. J. Wiggin & C.N.K. Mooers, 251, 1992.

Irish, J.D., K.E. Morey and N.R. Pettigrew, "Solar-Powered, Temperature/Conductivity/Doppler Profiler Moorings for Coastal Waters with ARGOS Positioning and GOES Telemetry," *Proc. of Oceans '92*, 730-735, 1992.

Irish, J.D., and S. Kery, "Elastic Tether Technology for Shallow Water Moorings in Harsh Environments: Results from Georges Bank," *Proc. Oceans 96*, 635-639, 1996.

Irish, J.D. "Elastic Tether Mooring Technology: Experiences in the Gulf of Maine and on Georges Bank," *Sea Technology*, 38(10), 61- 69, 1997.