# The Next Generation Ocean Observing Buoy in Support of NASA's Earth Science Enterprise

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## Introduction

The Woods Hole Oceanographic Institution (WHOI) and Jackson and Tull (J&T) are developing an improved moored instrumented buoy system in support of NASA's Earth Science Enterprise. This new design utilizes WHOI's oceanographic experiences with buoys, moorings, and sensing systems, and J& T's expertise with aerospace telemetry and computer systems. The buoy system includes capability for a full suite of meteorological sensors, water temperature, conductivity (salinity), bio-optical sensors and radiometers at several depths and an acoustic Doppler current profiler (ADCP) for currents. 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 (LEO) communication satellites for two-way, high throughput command and data telemetry.

## Buoy Structure

These new NASA buoy systems are constructed from steel and aluminum with a foam flotation collar. Steel, used for low cost and simplicity of construction, was hot dip galvanized and painted for protection against corrosion. Some old steel guard buoys (submarine net floats with towers added) are still in use after 20 years, so life should not be a problem. Also, making the base from heavy steel bar stock eliminated the need to add zinc or lead weights for ballast as in aluminum buoys.

The buoy's tower is made of 6061-T6 aluminum for light weight, and electrically isolated from the steel base by plastic shoulder washers. Mounted on the tower are a radar reflector, Coast Guard approved flashing light, telemetry antennas, meteorology sensors, solar panels, and an ARGOS locator beacon antenna. 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 watertight electronics well is through a hatch in the top. The large diameter allows a person to lean into the well to work on batteries in the bottom

Mounting the electronics for easy servicing has always been a problem. In similar but smaller GLOBEC (GLOBal ocean ECosystems dynamics) buoys, the batteries and electronics are screwed to bars on the side of the electronics well. Bending over the smaller well and working on the components was difficult. In this new buoy, the electronics are mounted on racks that slide down four split guide tubes welded to the inside of the well. A hard rubber "spring" and pin at the top of each tube hold the racks in place. Lifting the electronics and batteries out of the buoy for servicing is still difficult.

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*The new buoy system undergoing tests off the WHOI dock. The foam flotation collar is the basic buoy hull. On top of the tower the satellite receiving antenna (on right) and transmitting antenna (on left) are mounted as far apart as possible.*

## Flotation Collar

A Surlyn foam flotation collar (Gilman Corporation) provides the buoyancy for the buoy. In GLOBEC (our first experience with this technology) the buoys were made with about 2000 pounds

Paper appeared in *Sea Technology,* **40**, pp. 37-43 (May 1999).

of reserve buoyancy with full payload. The initial design goal was to enable the buoys to float the anchor and not be dragged down and risk sinking. We had one guard buoy with a smaller foam collar moored by chain that did sink. We recovered it when dragging for other equipment. The foam was compressed, but has slowly expanded to nearly original size since recovery. The foam flotation could not survive being pulled very far under water by fishing activity. The present foam flotation will prevent the buoy from being pulled under to the point that it looses buoyancy and sinks. For heavier payloads, a larger diameter foam collar can easily replace the existing one to provide increased buoyancy.

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 hemisphere. Therefore, the waves can apply little tilting moment to the buoy, and with the elastic tether provide a more stable platform for scientific observations.

The Surlyn foam is formed with a yellow pigment indicating 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 only slightly, and 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 readily as steel guard buoys. 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.

**Solar Power System**

The buoy data and telemetry systems and sensors are powered by solar power. Four Solarex 64 Watt solar panels charge two Concord Battery Corporation 105 ampere hour deep-cycle sealed gel cell batteries through Specialty Concepts Inc. shunt switching regulators. The batteries are connected to the data system and sensors through a diode network to prevent a failure in 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 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 and Massachusetts Bay. GLOBEC science buoys use four 20 Watt Solarex or Siemen panels to charge three Powersonic 40 ampere hour gel cell batteries. GLOBEC guard buoys use two 10 Watt Solarex panels to charge a single 40 ampere hour gel cell 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 put in service, and they appear to be working just as well as when new.

The solar panels on early steel buoys were mounted at about a 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. Requirements for additional power were met by adding solar panels higher on the tower, and they did not have observable fouling. Therefore, the GLOBEC solar panels were mounted as suggested for terrestrial applications of latitude plus 10°. In tests it appears that the reflection of light from the water makes this angle not as important as initially thought. The configuration in the new buoys has the panels angled out slightly from the tower with the panels being protected by the ring at the top of the tower and the Surlyn foam flotation collar at the bottom. We have not suffered a solar panel loss other than when it has been hit by a protruding part of the ship during recovery (two panels broken in 10 buoy deployment years).

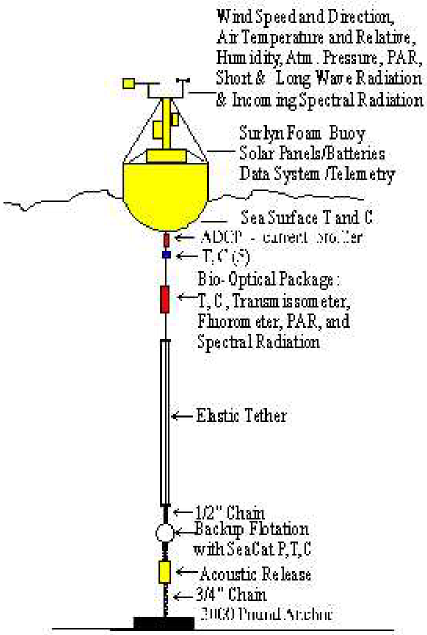
The power delivered by the solar panel array to the battery system and then to the buoy system is harder to calculate. The four panels around the buoy assure that at least one will be in direct sun and that at least one will be in the shade. In a test of the system in clear sky conditions in late morning 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 load current out is 3.7 amps, so we are not doing too badly. The two panels 90° from the sun supplied 1.0 amps each, and the one in the shade supplied 0.75 amps. Therefore, the “256 Watt” solar panel array was actually supplying about 80 Watts into the battery. That day, the solar panels delivered 42 ampere-hours (about 550 Watt hours) to the batteries. These numbers need to be scaled by the sun angle and daylight time. Also, in colder weather solar panels and batteries perform less efficiently.

A regulator is necessary to prevent overcharging of the gel cell batteries. If overcharged they release hydrogen gas, which can form an explosive environment in the buoy well. We also mount a catalytic cell to convert the hydrogen and any oxygen in the buoy into water that is absorbed by desiccants. There is a voltage drop across the blocking diodes on the batteries, so the power at the instrumentation runs about 1/3 volt below the battery voltage. We generally design power systems with a safety factor of two to account for temperature and battery inefficiencies, and the systems have supplied the necessary power.

The new system had an additional problem because the computer was continuously powered and additional circuits were on for diagnostic purposes, so that the solar system could only keep up during long summer months with little cloud cover. An internal power controlling clock which powers down the computer has allowed PC/104 systems to be successfully used in the past, and will be added to this system in the future.

**Mooring**

The mooring is a taut, compliant link between the buoy and anchor. In shallow water depths (40 to 100 m), this mooring must accommodate the greater than 6 m heave excursions of the buoy due to waves and tides, and the horizontal displacement due to currents. This is possible with compliant elastic mooring elements. Four to six one-inch diameter NATSYN rubber elastomeric elements (terminated and assembled by Buoy Technology, Inc.) form the tether. Each element is stretched about 100% with 100 lbs tension, resulting in a very soft spring response. The tether length is selected to provide sufficient stretch for the particular deployment conditions. Stretch often exceeds 100% in severe weather and high current events. The positive experience gained with the elastic tethers in GLOBEC was used to develop the elastic mooring for the NASA buoy.



*Schematic configuration for a shallow water deployment of the system.*

A tether operates at significantly lower tensions levels than the all chain or cable mooring. The elastic tether eliminates the large shock loads of conventional moorings. The low tensions increase the life of these moorings due to reduced wear in the mooring hardware, which in return can reduce the weight of hardware required while increasing service life. Deployments have exceeded 12 months without failure. The constant tension on the bottom of the buoy reduces buoy motion for improved scientific observations.

A new feature of this mooring is electrically connecting a sensor package near the sea floor with the surface buoy. A coil-cord assembly (like a rugged telephone handset cable) is spiraled around one of the elastic elements. (The coil-cords were developed at WHOI for the SSAR drifting buoy program, part of the GAMOT project to measure global warming of the oceans. Coil-cord assemblies have survived 6 million stretch cycles in lab tests and long deployments inside rubber stretch hoses without failure.) They are constructed of a central braided strength member, heavily insulated #18 AWG conductors spiraled around the core, and a thick outer extruded rubber jacket. The 0.7 inch thick cable is spiraled around a steel mandrel, and autoclaved to vulcanize the initially uncured rubber jacket in its spiraled shape. The jacket provides torsional and flexural rigidity and retraction. Retraction is the ability of the coil-cords to contract to its original shape after removal of external tension. The wrapping direction of the coil-cord spiral is alternated in several segments along the elastic. We hope that further tests will show that the coil-cord assembly will survive without external hose protection over sufficiently long deployments, to power instruments from the surface, and return data to the surface platform for storage and telemetry.

## Connectors

All penetration of the electronics well is done through three feedthrough plates located on the well above the flotation collar. Each plate holds six connectors that range from coaxial connectors for the antennas to multiple pin underwater connectors for the sensors and power. GLOBEC used some traditional rubber stopper stuffing tubes to bring coaxial and shielded meteorological sensor cables into the electronics well. There were three occurrences of small (several drop) leaks which occurred during a 6 month deployment that left a salt 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 due to "hosing" down a nicked cable. Therefore, to provide a solid block to any water entering the well, only underwater connectors are currently being used.

The signal and power connectors are Brantner and Associates with 2 (for each solar panel) to 12 pins (for the meteorological signals from a separate electronics signal conditioning module on the tower). The signals from the sensors in the water are brought up alongside the mooring strength member to the buoy. They are protected from chaffing by standard garden hose and also some fire hose 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, connectors are capable of providing reliable electrical path, they are easily connected and disconnected and do not leak.

## Data System

The data system is built from PC/104-format components with a 100-MHz Intel 80486DX4 microprocessor, and runs the Linux operating system. Linux, a freely distributed, Unix-like operating system provides the multi-user, multi-programming process protection and network capabilities found in modern desktop workstations. Support for the AX.25 protocol, necessary for the packet-radio application, is built into the Linux system.

With a multi-tasking operating system, task scheduling such as turning sensors on and off is easily implemented, and the various instrument interfaces can be independently developed and executed. Sampling rates for individual sensors can be set separately. The system can also be configured via software to service sensors for multiple experiments on a single mooring and direct the data to the appropriate destination using standard networking tools.

The computer motherboard (WinSystems, Inc.) contains 16 MBytes of RAM, I/O interfaces, and a 16-bit PC/104 bus interface. Built for embedded systems, the computer operates from a single 5 volt power supply and does not require an attached keyboard or video monitor.

Analog data collection is performed using the PCM-A/D-12 (WinSystems), 12-bit A/D convertor with 16 single-ended input channels. Multiple serial interfaces are provided by a serial-port multiplexer (BayTech H series). Computer control of sensor and radio power is accomplished with the PC104-PDIS08 (WinSystems) 8-channel relay board. Satellite tracking is made possible with the SATPAK-104PLUS-L board (Zeli Systems) mated with a Trimble SK8 GPS receiver. An ethernet interface board completes the system, giving remote access to the data system when the buoy is not deployed.

A consideration in using this type of system is the relatively large power comsumption of about 1.5 amps. Utilizing the full capability of the Linux system means leaving the system powered as much of the time as possible. Providing large amounts of RAM reduces process swapping substantially as the system hard disk is a significant power consumer. A power-controlling clock will be added in the future so that the system may be turned off under software control when circumstances require power conservation.

## Command and Telemetry System

The command and telemetry system is the major new development of this program. The system takes advantage of new Low Earth Orbiting (LEO) satellites to make an orders-of-magnitude increase in the amount of data sent by the remote platform, and to allow commands to be sent to the buoy.

Messages are sent between satellite and surface using packet (digital) radio. Uplink and downlink frequencies are different, allowing full-duplex operation with an effective baud rate of 9600. The link-layer protocol is AX.25; the application-layer is the PACSAT suite of protocols

PASCAT satellites operate in a store-and-forward mode, much like electronic bulletin boards. Data files with suitable headers can be uploaded to the satellite, stored for up to several days, and then downloaded by the groundstation, often during the same satellite pass. Similarly, the groundstation can upload files addressed to the buoy, which identifies the files, downloads, and then executes the commands they contain.

The radio, of our own design, is fully controlled by the data system computer. Software predicts satellite visibility based on GPS location and time, energizes the radio, initiates uploading, and tunes the radio receiver for Doppler shifts during a pass. A simultaneous process listens for information broadcast by the satellite and downloads files addressed to the buoy.

In general there are 4 to 5 orbital passes of a single satellite each day, but typically, only half are at an elevation and in a direction that can be efficiently used. Each pass lasts for 10 to 15 minutes. During a good pass our current system uploads about 50 kbytes of data for a throughput of about 100 kbytes/day per satellite. This number does not constrain our data-taking program since all data are separately archived on board before being subsampled or averaged for uplinking.

Although only one satellite has been used to date, the tracking software and radio design are capable of communicating with multiple satellites. We plan to do so in the future to increase the data throughput towards a target of at least 1 Mbyte/day of data.

## Sensors

The data system and sensor interface is versatile and able to accept analog inputs from 0 to 5 volts, and RS232 and RS485 serial data. For scientific studies, the system will have a full suite of sensors as described below.

Meteorology observations are made about 3 meters above the water surface. Wind speed and direction are resolved into vector averaged wind components relative to magnetic north, wind speed and gust. The buoy's data system samples the winds at 1 Hz, calculates vector averaged wind velocities, the minimum and maximum (gust) winds in the averaging interval. The atmospheric temperature and relative humidity are measured to allow momentum and heat fluxes to be estimated. To assist in the heat fluxes, both long and short wave radiation measurements are made. To connect with biology studies, incoming PAR (photosynthetically active radiation) measurement are made. Atmospheric pressure measurements are also made to complete the meteorological suite.

The in-water observations include temperature and conductivity (with calculated salinity and density) at several depths along the mooring cable. These sensors will be powered from the buoy's data system and return data to the buoy for processing, storage and telemetry to shore. An acoustic Doppler current profiler (ADCP) provides profiles of current from near the surface to near the bottom in continental shelf regions. A bottom pressure instrument, mounted low on the mooring, sends data around the compliant elastic tethers to the buoy.

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 fluorometer, a transmissometer or optical backscattering sensor, temperature and conductivity sensors. To connect with satellite ocean color ground truth studies, the package also carries 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 climate change studies.

**Acknowledgements**

The buoy development was supported by NASA/Goddard Space Flight Center under contract number NAS5-97057. We would like to thank Dr. Stanford Hooker of NASA/GSFC for his support and input. This development borrowed experience and sensors from the U.S. GLOBEC Long-Term Moored Program supported by NSF funding under research grants OCE-93-13670 and OCE-96-32348. We would like to thank Sean Kery for his initial design and help with the buoys, and Pat O'Malley and Jeff Lord for their assistance in getting the buoys assembled and tested.