# NEXT GENERATION OCEAN OBSERVING SYSTEMS, PART 2: SENSORS, DATA SYSTEM, AND SAMPLING

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## 1.0 INTRODUCTION

Oceanography is an observational science driven and guided by data collected from ships, moorings and island based instruments, satellites and aircraft, Autonomous Underwater Vehicles, (AUVs) and freely drifting platforms, etc. The older technique of deploying instrumentation with internal recording then recovering the instrumentation to get the data a year or two later is no longer adequate for predictive efforts. New sensors and more rapid data distribution are required.

Besides the new technology developments in satellite and AUV remote sensing, and more traditional shipboard based observations, there is still a need for the continuous, long-term time-series observations at fixed positions made by moored platforms. The problem is sampling in horizontal space (Latitude and Longitude), depth and time. No single observing technology can make all the required observations. Just as we got a great improvement in data quantity and understanding of oceanographic processes when we advanced from individual bottles and reversing thermometers to electronic profilers, we are now getting increased understanding of the spatial variations at the sea surface from satellite imagery. However, the satellite observations need to be extended down into the oceans, and need to be more continuous in time, which can be supplied by moorings. It is the combination of all of these data that is required.

To provide the required data, (1) improved buoys and mooring technologies need to be developed, tested and utilized, (2) new sensors and data systems with intelligent sampling and processing capability need to be developed and incorporated into moorings, and (3) world-wide, two-way high-speed satellite telemetry systems need to be developed to return the data in near-real time. Besides providing data to the research, modeling and predicative efforts, the two-way link would allow control of the remote platforms from shore to optimize system capabilities.

## 2.0 SENSORS AND SENSING SYSTEMS

The sensors are the critical interface between the buoy system and the environment, and are probably the most important part of an ocean observing system. For our recent moored work, observations have been made of the meteorology forcing, the temperature and salinity variability at many depths, profiles of water velocity, and some bio-optical and radiance observations. The sensors utilized include those with just the basic sensing element that must be digitized by the buoy data system, as well as self-contained systems with batteries and internal data storage with external data output. For further information and pictures of the GLOBEC buoy configuration, mooring launch and recovery, and sensors, see http://kelvin.whoi.edu.

The meteorology observations are taken at about 3 meters elevation at the top of the buoy's tower as shown in Figure 1. This height could be modified somewhat for particular applications, but getting higher than about 4 meters requires larger buoys and new engineering studies. The sensors that have been successfully used include winds, air temperature and relative humidity, atmospheric pressure, long-and short-wave radiation and PAR (photosynthetically active radiation). The wind speed and direction are measured relative to the buoy, and then with separate compass measurements of buoy orientation, resolved into

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vector averaged wind components relative to magnetic north. The data system samples the winds at 1 Hz and also calculates scalar wind speed, minimum and maximum (gust) winds during the averaging interval that is typically one hour. This allows wind stress and forcing calculations to be made at the mooring site. The sensing elements are an R.M. Young wind monitor and KVH compass. An alternative, successfully used by WHOI in moored applications, is the IMET suite of smart sensors with built in microprocessor that holds the sensor's calibration history (Hosom, et al., 1995). The following meteorological sensors used in GLOBEC utilize the same sensing elements used by the IMET suite, but the buoy's data system for digitizing and processing.

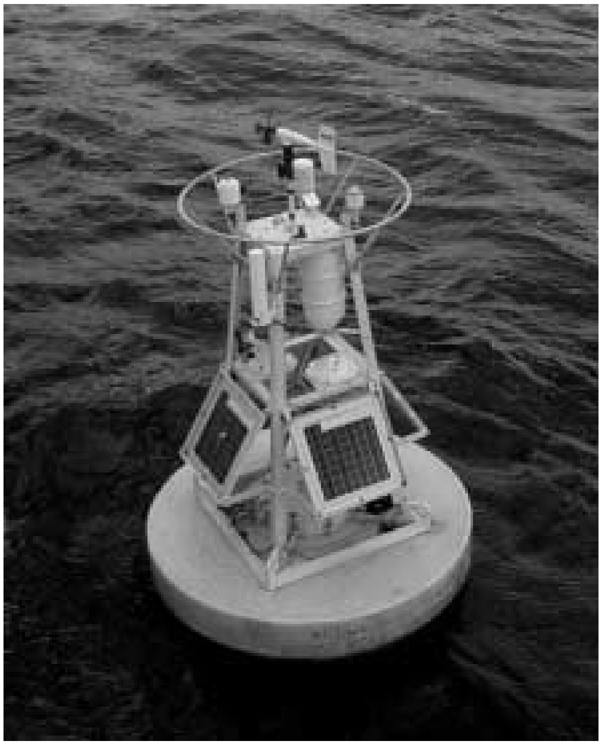

*Figure 1. The GLOBEC buoy with meteorology sensors visible on the top of the tower. The R.M. Young Anemometer is highest; dehind it is the Gill radiation shield holding the Rotronics air temperature and relative humidity sensor. On the left is the Eppley long-wave radiation; on the right is the Eppley short-wave radiation sensor. The small dark sensor on the front of the top plate of the tower is the LiCor cosine PAR sensor.*

The Rotronics atmospheric temperature and relative humidity sensor is mounted in a Gill radiation shield to protect it from solar radiation effects. The observations are used to estimate momentum and heat fluxes. To assist in the heat fluxes estimates, both long- and short-wave radiation measurements (Eppley sensors) are used. Because of the sensitivity of these sensors to the telemetry system (even the lower power ARGOS PTT), the data from these sensors are not collected during or right after a GOES or Low-Earth Orbiting satellite transmission. At these times the sensors record a spike toward lower radiation that is large and unrealistic. Moving the sensors around changes the magnitude of the interference but does not eliminate it.

An additional radiation measurement is made to connect with the biology components of GLOBEC. A LiCor cosine PAR (photosynthetically active radiation) sensor was also mounted on the tower. To connect with satellite ocean color downwelling spectral irradiance measurements could also be made.

The in-water observations include temperature and conductivity (salinity) and water velocity. Sea Bird Electronics temperature and conductivity sensors (Figure 2) are powered down the electromechanical mooring cable with FM signals telemetered up the cable, digitized, processed and stored within the buoy to measure temperature and conductivity. Sea Bird Seacat and Microcat instruments are used on the mooring. These sensors have internal batteries or are powered down the cable and internally record as well as telemeter the data to the buoy. From these basic temperature and conductivity observations, salinity, density, and other quantities are calculated using the 1980 Equation of State of Sea water.

The temperature and conductivity pairs are mounted at several depths along the mooring cable (see Figure 2 in the companion paper, part1). For continental shelf work, a vertical spacing of 5 meters has been used to resolve vertical water column structure and thermocline and pynocline depth. The temperature sensors have typically shown a drift due to component aging of several millidegrees Centigrade per year. The conductivity sensors are more susceptible to biofouling effects, and with poison tubes on the conductivity cells have functioned with low drift for one year in mild-fouling environments. Conductivity measurements are the limiting factor in long-term moored observations of water physical properties. Poison tubes to reduce biological fouling are beneficial and increase useful mooring length.

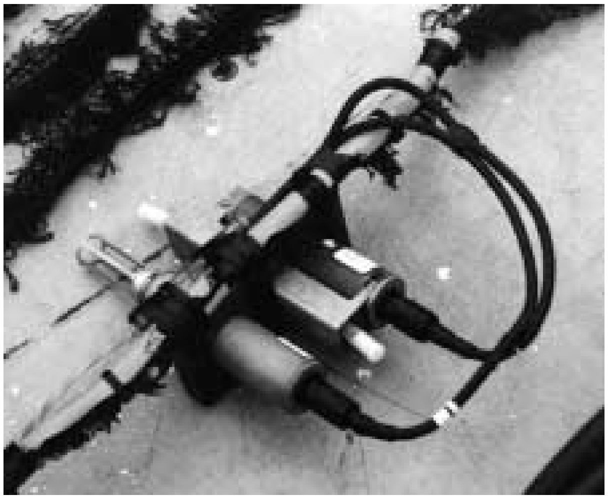

*Figure 2. Sea Bird temperature and conductivity sensor pairs are mounted on the Kevlar core electromechanical mooring cable. The "hair" seen on the cable is used to reduce cable strumming and provide a better base from which to make measurements. The sensors are mounted horizontal for greatest flushing. The electrical cables carry power and signals. The white poison tubes on the conductivity sensor are to reduce biofouing effects.*

An RD Instruments Workhorse acoustic Doppler current profiler (ADCP) provides profiles of ocean current from near the surface to near the bottom in continental shelf regions. These sensors can be fully self contained with batteries and internal recording, or can be powered from the buoy. Both configurations can telemeter data to the buoy for storage and telemetry to shore. A variety of acoustic frequencies and sampling configurations can be selected to optimize sampling for a particular application.

A bottom pressure instrument is mounted low on the mooring or deployed on a separate bottom mounted package. The pressure sensor measures the tides and weather forced sea level fluctuations. It can also burst sample for surface wind waves if the sensor is located in shallow enough water. The Paroscientific family of sensors has proven best either in Sea Bird or our own recording electronics. A new configuration under testing sends signals around the compliant elastic tethers to the buoy (Paul and Irish, 1998).

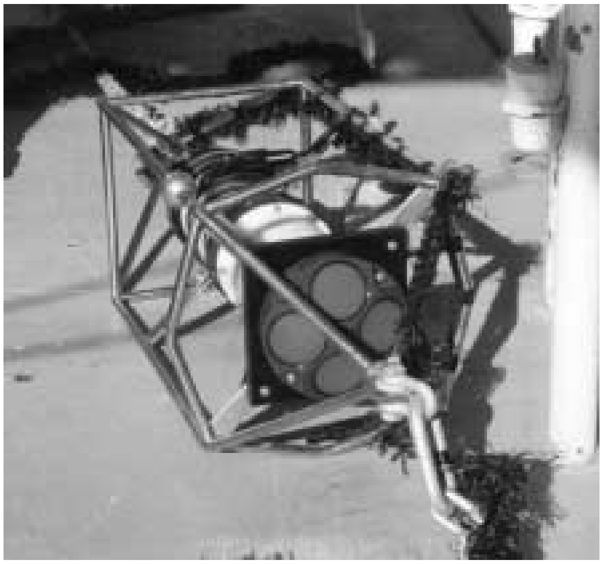

*Figure 3. An RD Instruments 300 kHz Workhorse ADCP in its in-line mooring frame. It can be mounted either at the top of the mooring looking downward or at bottom looking upward. (The electrical cable carrying power and signals to and from the temperature and conductivity sensors can be seen going around the ADCP sensor.) This ADCP system works well in depths to 100 meters with vertical resolution as fine as 1 meter.*

To couple with biological and global climate studies, several bio-optical packages (Figure 4) have been developed and deployed at various depth on the mooring (in GLOBEC at 10 and 40 meters). Each of these instruments has included its own data system with RS422 telemetry to the buoy. Sensors have included a LiCor 4 sterradian (scalar) PAR, a Sea Tech chlorophyll-a fluorometer, a Sea Tech beam transmissometer or Sea Point optical backscattering sensor, and Sea Bird temperature and conductivity. Additional upwelling and downwelling PAR sensors have also been successfully used.

To demonstrate potential for satellite ocean color ground truth studies, the packages have also carried Satlantic upwelling and downwelling spectral radiometers to collect radiation in the 7 SeaWiFS bands. The combined data sets will allow basic physical and biological studies to be conducted and could supply profiles of upwelling radiance to estimate water leaving radiances for satellite color studies as part of global climate change studies.

*Figure 4. Paul Fucile with a bio-optical package in its mooring frame. The "light bulb" on top is a scalar PAR sensor, the horizontal sensor below the transmissometer, the large horizontal tube in the middle the data system and battery case, the chlorophyll-a fluorometer is on the left bottom, and the Sea Bird temperature and conductivity sensors can be seen lowest in the frame.*

The major limitations to these measurements are the biofouling of the optical sensors. On Georges Bank a typical summer observation at 10 meters depth will last for about 90 days before biofouling effects become significant. In the winter, good observations can extend beyond 120 days. In addition, radiation sensors need good calibrations at more regular intervals than more standard sensors such as temperature and pressure. These sensors are not very well suited for long term moored applications where servicing is done at yearly intervals.

## 3.0 DATA SYSTEMS AND SAMPLING

Data system technology that is applicable to moored instrumentation is also growing rapidly. Notebook computer developments have given us the processing and hard disk storage space found in desktop computers, and provided computation power that is capable of being deployed in oceanographic applications and powered for long time from batteries. On buoys with solar power, these systems provide capabilities not previously available. Higher speed, more accurate A/D conversion, *in situ* digital signal processing (DSP), large, robust data storage capabilities (hard disks) at low cost, and more complex sampling programs and data compression. With two-way telemetry the option now exists to control sampling programs and update software for more optimum performance of the remote platform (Shaumeyer et al., 1998).

The data system and sensor interface is versatile and able to accept inputs from standard analog and serial output sensors. Some of our older systems still use a Synergetics data system with separate modules for control, sensor interface, GOES and ARGOS telemetry, and backup data storage. Newer systems are being built from PC/104-format components. Processor boards with 33 to 100-MHz with Intel 80386 and 486 microprocessors have been successfully used in various oceanographic instrument systems. Standard notebook hard drives are readily available in sizes greater than 10 GB to allow a large quantity of data to be stored on board the buoy, and couple nicely with increased data needs and high-speed LEO telemetry systems.

The operating system in the PC/104 systems has been standard MS-Dos and we have also tried Linux. The DOS system allows applications to be developed on desktop computers with inexpensive assemblers and languages. Linux, a freely distributed Unix-like operating system, provides multi-user, multi-programming process protection and network capabilities found in modern workstations. Also, support for the AX.25 protocol, a necessary part of the packet-radio application for Low Earth Orbiting satellite telemetry, is built into the Linux system.

The older systems, often restricted to integer arithmetic, generally do not allow more complicated processing. However, with global data requirements, normalizing the data on the remote platform and keeping track of sensor history and calibration on the remote platform requires more computational power provided by the PC-104 systems. 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. Also, satellite tracking, required for use of a single LEO satellite, is made possible by adding a standard SATPAK board and GPS receiver. An ethernet interface board gives remote access to the data system when the buoy is not deployed. Such versatility and the ability to increase system capability with readily available components increase the power and potential of the PC/104 approach.

However, a consideration in using the PC/104 systems is the relatively large power consumption of about 0.5 to 1.5 amps at 12 volts with fully configured systems with hard drives . 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. In remotely powered DOS systems, a power-controlling clock has been used so that the system may be turned off under software control when circumstances require power conservation. Then the power drops to about 60 microamperes to keep the clock powered. Then the system is wakened at a preset time (downloaded to the clock before the system goes to sleep) to continue processing, storage, telemetry, etc. These systems offer great potential for the future, but the high power considerations may mean that a distributed processing approach, such as using the IMET suite of sensors, is more realistic. The sensor then samples as commanded by the main system, and the data is then downloaded to the system for processing, storage and telemetry.

## 4.0 CONCLUSION

Present sensors and data system capabilities in modern moored systems can control a variety of measurements, receive data from most sensors types (e.g. analog voltages, FM signals, RS232, RS422 and RS485 serial data), provide data processing, compression and storage, and telemetry to assimilative predictive models. It is an exciting time to be working in the field of ocean observations, and new technologies are giving us the capability to increase our knowledge of oceanic variability and its connection with large scale weather systems and climate change.

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