Development of an Advanced Data Buoy Supporting MTPE Program

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ABSTRACT

Jackson and Tull (J&T), in cooperation with Woods Hole Oceanographic Institution (WHOI), has been awarded a NASA STTR Phase II contract titled “Modular Offshore Data Acquisition System.” J&T and WHOI have combined their expertise and capabilities to advance the state of the art in oceanographic observing system technology to meet the increasing demand for accurate and timely oceanographic data acquisition. Accurate modeling of the Earth’s environment depends on surface-based measurements to verify and augment Mission To Planet Earth (MTPE) satellite data. We are merging the latest technology in satellite communications, advanced data systems, oceanographic sensors, buoy structures, and moorings to create a breakthrough in buoy technology for long term earth observing activities. Our system will provide a two-way, near real-time, high-volume data and command link to remote oceanographic data platforms. In Phase I the team established the engineering requirements of the buoy subsystems and sensors. This was accomplished through analyses of the operating environment, data acquisition and processing requirements, and the science needs of the user community. Phase II encompasses the development of an operational buoy prototype based on the Phase I conceptual design with a one month deployment at sea to prove out the system. Using SeaWiFS as an example, we will prove the capability of our system to provide ground truth data in support of MTPE satellite missions inexpensively and in a timely manner.

INTRODUCTION

Jackson and Tull (J&T) has established a long-term cooperative partnership with Woods Hole Oceanographic Institution (WHOI) to bring aerospace technology to the oceanography community. Since 1995, we have been working to combine WHOI's knowledge of and experience with oceanographic data collection systems, and J&T's knowledge and experience with satellite technologies and, through their fusion, create a breakthrough in marine technology. The partnership began with the award of a NASA Small Business Technology Transfer (STTR) Phase I contract titled "Modular Offshore Data Acquisition System" (MODAS.) MODAS is a moored buoy system designed to address the challenge of providing near real-time *in situ* measurements of oceanographic data for NASA's Mission To Planet Earth (MTPE) program. With the award of the Phase II contract in January 1997, J&T and WHOI will conduct a demonstration of the use of two-way satellite communications and advanced data systems on moored buoys in coastal areas.

J&T and WHOI were subsequently awarded two SBIR Phase I contracts that continue to build on this partnership. The first is for the development of an air-deployable drifting buoy called the Nomadic Exploration Marine Observatory, or NEMO, that incorporates the advanced data and telemetry systems first developed for our MODAS buoy. The second is for the development of an Ocean Inhabitant Forecasting System for the Navy to predict the presence of whales and other large marine mammals in potential Naval operational areas. For this system we plan to use satellite data combined with *in situ* acoustic and other oceanographic data from our buoys plus WHOI's extensive whale database to locate and identify various marine species of interest to the Navy and other users. We have also collaborated on a number of other proposals currently in evaluation. The products currently being developed with the support f the SBIR program include MODAS, a large moored buoy for use in coastal areas, the subject of this paper; NEMO, a drifting buoy for deep-water, remote applications; AIOPS, a diving buoy for sub-surface measurements; and SeaSAW, an underwater winch system for taking profile data at various depths in the water column.

BACKGROUND INFORMATION

Jackson and Tull is a business engaged in providing engineering support services to the aerospace industry, including a wide range of satellite communications services. We provide high technology, engineering support services to the NASA/Goddard Space Flight Center (GSFC) and the Air Force Phillips Lab. This development effort is part of J&T's Research and Development initiative. It is the mission of the J&T's R&D Directorate to maintain J&T's position on the cutting edge of new technology. We conduct research that builds on the expertise of J&T's engineering staff and supports the strategic goals of our engineering directorates. Our aim is to develop commercially viable products based on the knowledge and expertise of J&T's engineering staff. We make use of J&T internal R&D funds as well as SBIR/STTR funding, Space Act agreements, and other funding arrangements designed to support basic research.

The Woods Hole Oceanographic Institution charter, which is "to study all aspects of oceanography," includes research and development of data buoy systems, buoy and mooring supported sensors, data collection and storage systems, and data transmission services to shore.

As the largest American, independent oceanographic research institution, WHOI is intensely engaged in improving technology relating to the proposed development of autonomous buoys to collect, store, and broadcast oceanographic parameters. Developing the technology of oceanographic observing systems has been a major effort at WHOI since its founding over 60 years ago. WHOI personnel have made major developments in oceanographic sensor, buoy, and mooring technologies as highly specialized engineering disciplines. These technologies are the basis for the cooperative R&D effort between WHOI and J&T.

SCIENTIFIC CONTEXT

Instruments on orbiting spacecraft can observe the entire surface area of the world's oceans - a practical impossibility with standard shipboard oceanographic survey techniques. For cloud free areas, a satellite can scan all of the world's oceans every 2 days, observing the ocean color in several bands in the visible spectrum. From ocean color, one can estimate the concentration of the phytoplankton near the surface. The color of the surface waters varies with the type of biological activity and quantity of chlorophyll present in different organisms. Although satellites can provide spatial and temporal information of the sea surface layer, supporting *in situ* observations are needed for calibration. Also, *in situ* observations can provide information about the vertical distribution of organisms and light and therefore carbon uptake, data central to global change research. They also can provide complementary information about nutrient distribution and other variables, such as the presence of suspended sediments that can affect ocean color. Therefore, *in situ* oceanographic platforms are required to make observations of not only ocean surface color as a calibration reference to satellite images, but also to provide additional observations that can support more direct estimates of primary productivity, biological processes, and carbon uptake and how these variables change with depth.

The Modular Offshore Data Acquisition System discussed here, addresses not only the ground truth of satellite ocean color observations, but also offers the capability of better estimates of primary productivity through appropriate instrumentation, thus also giving an added capability for improving our understanding of carbon uptake, global carbon cycles, and global change.

MODAS BUOY SYSTEM DESCRIPTION

In 1995, J&T, in collaboration with WHOI, was awarded a NASA Small Business Technology Transfer (STTR) Phase II contract entitled "Modular Offshore Data Acquisition System" or MODAS. J&T and WHOI proposed to combine their expertise and capabilities to advance the state of the art in oceanographic observing system technology to meet the increasing demand for accurate and timely oceanographic data acquisition. Together we are merging the latest technology in satellite communications, advanced data systems, oceanographic sensors, buoy structures, and moorings to create a breakthrough in buoy technology for long term earth observing activities. Our system will provide a two-way, near real-time, high-volume data and command link to remote oceanographic data platforms.

In Phase I the team established the engineering requirements of the buoy subsystems and sensors. This was accomplished through analyses of the operating environment, data acquisition and processing requirements, and the science needs of the user community. Phase II encompasses the development of an operational buoy prototype based on the Phase I conceptual design, as depicted in Figure 1, with a one month deployment at sea to prove out the system. Using SeaWiFS as an example, we will prove the capability of our system to provide ground truth data in support of MTPE satellite missions inexpensively and in a timely manner. The buoy will be equipped with a two-way satellite communication system, advanced data system, power source, and selected sensors to support the science mission. The main purpose of the Phase II effort is to demonstrate a reliable, autonomous two-way satellite communication link between the sensors on the buoy and the researcher's desk on shore.

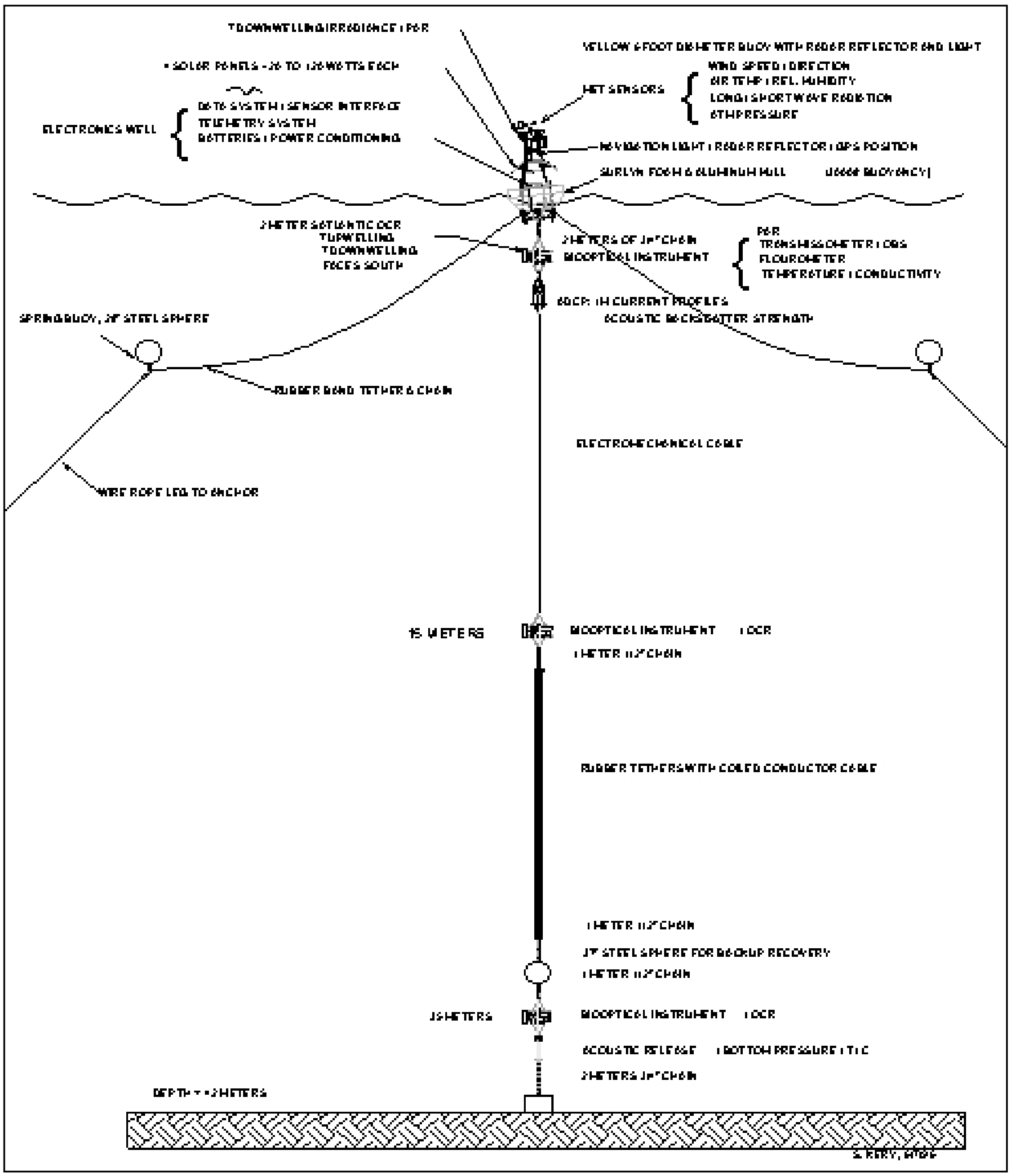

Figure 1 – Moored Buoy Conceptual Drawing

The following specific technical objectives will be achieved in the Phase II effort:

Satellite Link Capabilities

- Prove out the autonomous link between buoy and PI desktop
- Move large quantities of data via LEO satellite
- Provide two-way communication capability

Data System

- Provide powerful computing capability at the buoy
- Provide advanced command and telemetry capability
- Provide flexible failure recovery

Buoy Platform

- Demonstrate a cost-effective, durable, and easy to handle platform solution
- Provide an easily reconfigurable platform to support a variety of missions

Mooring

- Provide a highly stable platform in coastal regions
- Provide a reliable underwater electrical conductor

Science Objectives

- Demonstrate a reliable buoy system for collecting oceanographic data
- Demonstrate flexibility to support many different science programs
- Move large volumes of science data from a remote site to the PI in a timely manner

Two-Way Satellite Communications

Many long-term observation programs in the ocean generally allow data collection only after the experiment is completed and recovered. This is unsatisfactory in long-term, multi-year observational programs required for climate change and modeling efforts. Real-time availability of data is a decided advantage. Modelers need to get continual input of data to improve model development and improve model predictions for real-time environmental management. Communications systems presently in use for ocean buoys include electro-mechanical and fiber optic cables in very near-shore deployments, cellular phone and packet radio techniques in near-shore environments, and ARGOS and GOES satellites for low data-rate worldwide coverage. Other radio telemetry systems have been used for short or long distances, but require special transmitters and receiving equipment to maintain the link with generally low-rate telemetry capability. Currently available high data-rate satellite links require high power directional antennas which, on constantly rolling and rocking surface buoys, are not realistic.

There are several significant advantages of this proposed two-way data communication system:

1) It provides a very energy-efficient method of near real-time data transport to the investigator's desk;
2) Scientists have access to the data in near real-time, which increases the use of data sets and hence their importance;

3) The scientist can control the remote instrumented system in a manner similar to the NASA scientist working with a satellite;
4) The researcher is able to examine the remote sensor daily to determine if it is functioning properly, or if it is time to service the mooring;
5) The scientist can update the sampling program as seasons and signals change; and
6) The researcher can "talk" with the instrument to facilitate recovery from failures.

This new way of working in the ocean will allow oceanographers to catch up with their space and meteorology colleagues. In the harsh ocean environment, satellite return of data will preserve the data in case of equipment loss and will show when the instrument failed, allowing informed repair or replacement decisions. This will reduce cost, and/or improve data return from an experiment, because the instrumentation can be serviced in an optimum manner; not according to a time schedule, but when problems emerge. In addition, the researcher can respond to strong signals such as hurricanes or El Niño events by turning on or off sensors, speeding up sampling rates, or immediately retrieving data, in order to support models aimed at protecting life and property.

The buoy telemetry system will use LEO satellites and the Internet to establish two-way communications between the remote buoy system and the Principal Investigator's desktop. The system will collect and store data on the buoy until the satellite passes overhead, at which time the data is transferred to the satellite memory and remains there until the satellite passes over a compatible ground station with an Internet link to reach the ultimate destination - the Principal Investigator's desktop computer. Conversely, commands will be generated at the PI's desktop, transferred to the ground station via Internet to await satellite contact, be stored on the satellite until it passes over the remote buoy, then relayed to the buoy data system.

There are many proposed commercial constellations of low earth orbiting (LEO) communications satellites currently under development or actually being deployed. Any one of these so called "Little LEO" systems could potentially provide access to the autonomous buoys. The growth in demand for this type of service, coupled with the number of companies intending to provide these services, should make this a very inexpensive method of communicating with buoys. In addition, there are a number of experimental and amateur satellites already on-orbit and in operation. These are the types of satellites we plan to use for the Phase II demonstration since the commercial systems are not yet fully operational.

The system is baselined to operate with Surrey store-and-forward communication satellites -- based on amateur satellite designs -- with the following typical parameters:

	Uplink	**Downlink**
Data Rate	9600 bps	9600 bps
Frequency	149 MHz (VHF)	400 MHz (UHF)

With this data rate, the following conservative computation can be made:

4 passes/day * 10 minutes/pass * 70% efficiency @ 9600 bps ~ 2 MBytes/day

There are several "like" satellites available with similar data rates that can be utilized by this system as designed with minimal configuration changes for compatibility. It is anticipated that a suite of satellites can be used in the future to increase the data throughput and decrease the delay between the PI desktop and the buoy.

Buoy Data System

The data system is based on the Intel 80486 microprocessor, with 8 Mbytes of RAM, 2 Gbytes of non-volatile storage, and separately-protocoled serial ports for sensor interfacing. Packaged on PC-104 format cards (supplied, for example, by Ampro or WinSystems), the entire system fits within a space 10-cm square 30 cm high. The system consumes 10 Watts of power, but we have several options for reducing its requirements to fit within more constrained power budgets. We use Linux, a freely available Unix clone, as the operating system.

The data system is designed to collect sensor input, telemeter data and respond to remote commands, and control and monitor the NEMO subsystems. It operates autonomously, although it can be controlled or reprogrammed remotely. Remote programming is useful, for instance, when the telemetered data show that a rare event is approaching and the observing program needs to be altered to capture more extensive data (easily buffered in non-volatile storage until it can be fully telemetered). The buoy is also equipped with an ethernet interface to connect it to a computer network while on deck or in the laboratory, so that the internal data system is fully accessible to an external computer for reprogramming or testing.

We include a Global Positioning System (GPS) interface to determine location and time, both of which are critical to the functioning of the buoy. Communicating with LEO satellites demands that the computer clock be highly accurate and that the buoy's location be well known. Scientifically, GPS information is incorporated into the sensor data records to facilitate more effective utilization of the data sets within the MTPE community. Operationally, GPS information is vital for location and recovery of the buoy should it break free of its mooring.

Buoy Platform And Mooring System

The platform design will be similar to WHOI's GLOBEC Crest Buoy used on Georges Bank, as shown in Figure 2. J&T funded a separate IR&D effort to upgrade the GLOBEC buoy and fabricate it in our own shop. Our design changes make the buoy easier to construct and handle as well as less expensive in parts and labor. It consists of an electronics well, base frame, floatation collar, and tower. The well at the center of the buoy is made of galvanized steel with easily removable trays for batteries, radio, computer, and power distribution. It has electric conductor links to the solar panels, antennas, and sensors through watertight connectors. The center well is surrounded by a semi-spherical flotation collar of Surlyn foam, a cost effective, durable and easy to handle material. The tower is made of aluminum angle and serves to position the solar cells at optimum angle and provide attachment points for met sensors, satellite antennas, guard light and radar reflector. A base frame of galvanized steel provides underwater sensor and mooring attachment points, ballast to help keep the buoy stable in the water, and allows for stable storage on deck during deployment or recovery operations.

The requirement for ocean color radiometer observations below the sea surface led to a special mooring design, since shading of the underwater radiometer by the surface buoy should to be avoided. This is achieved with the installation of two side leg moorings, anchored east and west of the buoy to prevent rotation of the buoy and its center mooring. The radiometer connected to the surface buoy and mooring will be oriented to the south, thereby minimizing the effects of the buoy's shadow.

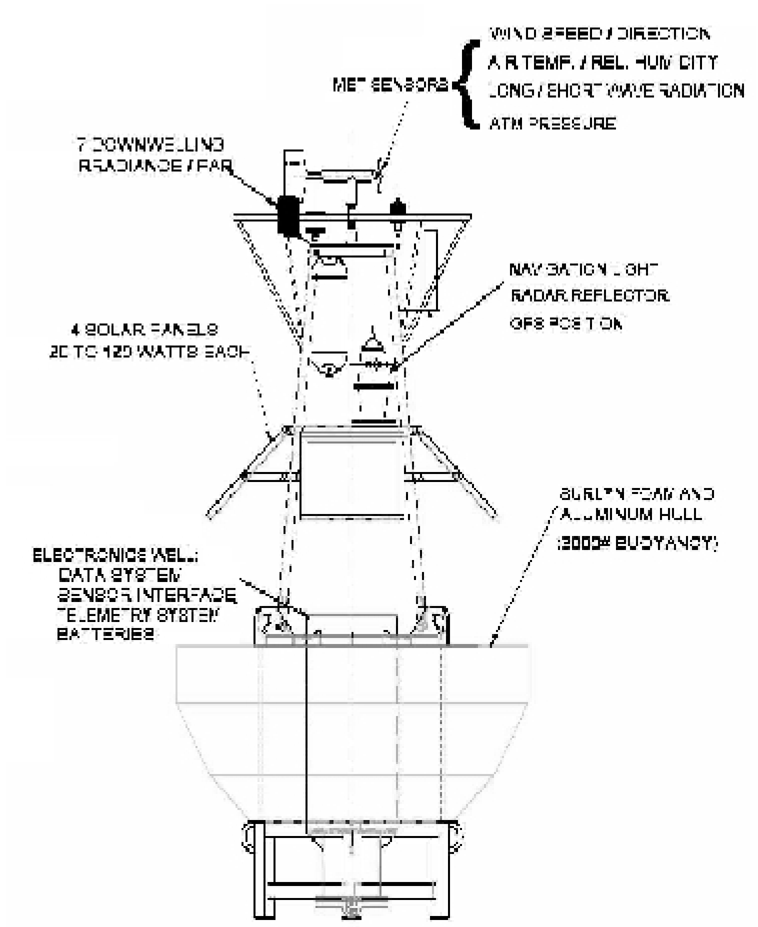

Figure 2 - Buoy Platform Design

Shallow water moorings are more difficult to sustain due to the fact that surface waves command a much larger portion of the water depth, requiring mooring links with considerably more stretch than in deep water. Technologies such as compliant moorings with rubber-like stretch (and strength) were developed by WHOI for 40 to 80 meter deep sites on George's Bank. Inclusion of a rubber-like stretch member reduces shock loading and tension fluctuations caused by surface wave generated heave motions of a surface buoy, thereby lowering mooring dynamic stresses and providing a more stable surface platform in waves.

Twelve meter high waves have been observed at the 43 meter deep WHOI buoy farm site off Cape Cod, where the proposed demonstration of the buoy system will be located. With sufficient reserve buoyancy, a surface buoy will stay at the sea surface at all times, stretching and relaxing the mooring some 5 to 12 million cycles per year.

Conventional mooring ropes can not stretch sufficiently to keep a buoy at the surface in continental shelf depth waters. Without current or wind excursions, a vertically taut mooring at the buoy farm has to have an elastic stretch of over 35 percent. This is far more than the maximum allowable long-term elastic elongation of 15 percent for nylon rope, 5 percent for polyester rope, and less than 1 percent for Kevlar, Vectran, and steel ropes as well as electro-mechanical cables. For this reason, the use of elastomeric mooring members made of Natsyn rubber or polyurethane with working elongations of up to 100 percent or higher is mandatory for the construction of a reliable taut mooring at the buoy farm or other coastal sites. In order to form an electrical conductor path with similar stretch behavior, a coiled and reinforced conductor assembly, similar to a large telephone cord, will be used. The coil will be arranged around one of the five or more Natsyn parallel rubber bands which form the elastomeric mooring link.

Sensor Package

The data collected by the sensors is the entire reason for the existence of the program, so their selection and use is a very important part of this program. We have selected a general suite of commercially available sensors which can answer basic science questions related to both primary productivity, and ocean color ground truthing of satellite observations. The data system has standard sensor interfaces which are quite flexible in accepting a variety of inputs from different sensors. In order to maximize the use of the data system's capabilities, we use a distributed processor approach which uses a suite of "smart" sensing systems that will properly sample the environment, and return the results to the main data system via a serial link or analog voltage. The main data system can then pre-process the data (average, normalize, filter, compress, etc.), temporarily store the results, and interface with the telemetry link as needed. Many of the sensors are capable of storing data internally as a backup. Although slightly greater in cost, this redundancy reduces the risk of data loss in case of system failure since the data is recorded elsewhere and can be retrieved for later analysis.

With separate sensing systems utilizing a serial data bus, additional sensors and sensing systems can be added, changed, or removed with no hardware change in the data system which would require the mooring system's retrieval. For example, a remote temperature and conductivity sensing pair found to be working improperly can have its power shut off remotely via the telemetry link and the data system remotely reconfigured to eliminate that sensor pair's data from the data stream. Thus, the buoy system can continue to operate the rest of the sensors without interruption and avoid a costly trip to retrieve the buoy for repair.

The basic sensor suite planned for the demonstration buoy covers the biological and physical parameters required to estimate primary productivity, carbon dioxide uptake, and ocean color ground truthing of the SeaWiFS satellite. It can support bio-optical packages at several depths as appropriate for obtaining profiles of ocean color and primary productivity to extrapolate to the surface, and to provide depth dependent information. Each bio-optical package would have a fluorometer for chlorophyll-a concentrations, a transmissometer or optical backscattering sensor for suspended particulate concentrations, photosynthetically active radiation sensor for radiation, and upwelling radiance and downwelling irradiance spectral energy observations in the 7 SeaWiFS bands. The ocean's physical environment can be sampled with temperature, conductivity, pressure, and acoustic Doppler water velocity sensors. Temperature and conductivity sensors could be incorporated in the bio-optical package, and additional pairs could be added elsewhere in the mooring as desired. A pressure sensor located on the anchor at the bottom would be burst sampled to measure the surface waves and also sampled at low frequency to obtain tidal and low-frequency sea level fluctuations. The acoustic Doppler current profiler (ADCP) would be mounted at the top (or bottom) of the mooring and provide profiles of the current velocity structure in 1 meter vertical bins. The ADCP also measures acoustic backscattering profiles which can be combined with the optical transmission (or optical backscattering) observations in determining vertical phytoplankton distribution and density. Finally, the meteorological forcing will be measured with wind speed and direction sensors, air and sea surface temperature and relative humidity, precipitation, barometric pressure, and incoming radiation measured with long and short wave radiation sensors as well as the incoming spectral radiation in the 7 SeaWiFS bands.

CONCLUSION

This end-to-end system utilizes a number of innovations, all of which are of significant technical merit. Chief among these is the two-way satellite telemetry link. This two-way telemetry will create an interactive link among remote and drifting buoys, research vessels, and research aircraft and the PI's desktop, allowing the scientist to move large quantities (2 megabytes per day per platform) of near real-time data utilizing LEO communications satellites currently on orbit.

The recent surge in interest in LEO satellite communication systems will provide the commercial infrastructure to support store and forward data collection. Many different satellite systems are planned for deployment in the next few years, thus providing viable commercial competition for these services. Much interest has been shown in collecting data, including oceanographic data, using this commercial resource. As new and innovative requests for data collection arise, Jackson and Tull intends to produce products to meet those needs.

The combination of J&T and WHOI represents a unique melding of aerospace and oceanographic technical expertise. WHOI is well known for advancing the state of the art in marine technologies but is not in the business of commercializing those developments. Jackson and Tull has taken good advantage of the NASA STTR program to establish a partnership with WHOI and make the transition to the commercial market. As a result of that partnership WHOI's excellent work will be available to the entire oceanography community at a reasonable price. In addition, J&T is bringing our expertise and experience in the aerospace industry to bear on the oceanography community, and making advanced aerospace technology available to communities outside of their traditional uses.