Development of fluorescent induction and relaxation systems for the measurement of biomass and primary productivity on Webb Slocum gliders

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LONG-TERM GOALS

Despite their relatively small area continental shelves are disproportionately important in biogeochemical cycles; however quantifying the transport and transformation of organic matter on continental shelves is difficult due to the numerous processes operating over a wide range of space (meters to 100s of kilometers) and time (hours to years) scales. Traditional sampling strategies are hard pressed to sample the relevant scales; however autonomous underwater vehicles (AUV) have advanced to the point that they now allow scientists maintain a continuous presence in the sea. Over the last decade, the pump-and-probe and Fast Repetition Rate (FRRF) Fluorometers have provided unprecedented insight into the factors controlling phytoplankton physiology and primary production in the ocean. The use of the fluorescence kinetics is increasingly becoming an integral part of many oceanographic field programs, but its broad community use is limited by the complexity and high cost of the available instrumentation. These systems are limited to just a few labs even though these measurements are becoming increasingly central to field work and have been commercially available for almost a decade. To overcome these problems, we have designed and built a new instrument, called Fluorescence Induction and Relaxation (FIRe) System, to measure a comprehensive suite of photosynthetic characteristics in phytoplankton and benthic organisms. This NOPP will develop a miniaturized cost effective small biological sensor capable of measuring the concentration, physiological state and productivity of phytoplankton. Specifically, we will miniaturize a new compact FIRe system which will be combined with Aanderaa 3835 oxygen electrodes and mount them in Webb Sloccum Gliders. We will also begin the design strategies for the development of optically-based nitrate sensor. Our ultimate goal is to develop an autonomous patform that will be used to characterize the productivity of the contintal shelves.

OBJECTIVES

Minituraized sensor suites will be integrated into Webb Slocum Gliders. These sensor suites will complement existing backscatter-attenuation-absorption Glider sensor packages, to provide a complete particle productivity sensing capability on long duration autonomous AUVs. We will demonstrate the utility of this system by collecting measurements in an existing AUV shelf-wide time series focused on defining the physical forcing on particle dynamics on Mid-Atlantic Bight (MAB). We propose to use the FIRe-O2 sensor suite to study how shelf-wide processes drive summer upwelling, the associated phytoplankton blooms and determine the linkage to low bottom water Dissolved Oxygen (DO) in the MAB.

APPROACH AND WORK PLAN

The proposed time for this project is provided in Table 1. Efforts largely focus on development in year 1. The development of the FIRe system will be anchored by Rutgers (Max Grobunov and Falkowski) and Satlantic (Scott McLean). During year the oxygen electrodes will incorporated into Gliders by Webb Research. The miniaturization of the ISUS will be conducted by Rutgers and Satlantic. Integration into a Glider will occur in Year 2 by Webb. These O_2 Gliders will be tested in the MAB during the FIRe development phase. In Year 2, FIRe systems will be incorporated into the Gliders. These systems will be tested in MAB, and initial flights will allow for equipment optimization. In Year 3, the FIRe-O2 Gliders will be integrated into shelf-wide time series being conducted by Rutgers and Webb Research. Dr. Schofield will oversee the project, however this group has decade experience working together.

Table 1. *Timeline and responsibilities of the NOPP partners*

WHAT	WHO	WHEN
A) Build FIRe system	Satlantic, Rutgers	First 14 months
B) Integrate O2 electrodes into Webb Glider	Webb Research	First 12 months
C) Integrate FIRe system into Webb Glider	Webb, Satlantic	Months 15-20
D) Field test and collect preliminary data	Rutgers, Webb,	Month 20-24
E) Equipment optimization	Satlantic, Webb	Month 25-29
F) Integrate FIRe-O_2 into the MAB shelf time series	Rutgers	Month 30-36

This group is well-positioned to quickly transition these technologies to the wider community. Satlantic has over a decade of experience building and selling optical instrumentation to the wider community. Based on comments provided by the panel, the priorities for this NOPP are to integrate oxygen electrodes in Webb Gliders, develop and integrate a FIRe system in a glider, use the integrated glider science bay combined with a WetLabs inherent optical glider to map the productivity of the Mid-Atlantic Bight. This effort will be faciltated through several partnerships.

Rutgers has been awarded a Glider technical Center by the Department of Defense to develop a capability to provide researchers a fleet of accesible Webb Gliders. Satlantic and WetLabs has joined in a cooperative venture (WetSat) which leverage off each others expertise to best prepare for the proposed national and international ocean observing initiatives. Dr. Falkowski's developed and patented all currently available pump-probe and FRRF technologies used by the oceanography community. This experience is crucial to develop a robust and user-friendly system. The budget cuts in 2005-2006 resulted us in postpoing any efforts for the ISUS and thus have focused on the FIRe and oxygen electrodes, which are combined with integrated irradiance sensors leveraged from funding from ONR Optics.

WORK COMPLETED

Currently the work is progressing quickly. The following components are making progress.

Fluorescence Induction and Relaxation (FIRe) System for the Glider: The propotype FIRe system has been constructed (Figure 1). The system's configuration is as follows. There is a small external excitation unit (1.75 inch diameter, about 8 inch long) that is installed on the side of the glider similar to the current CTD position, but it will be located on top the wing (to avoid shading the sounding volume). We are considering installing another (blank) excitation unit on another side for balance and better hydrodynamics. The excitation light is emitted up through the glass window to create the excitation spot centered about 1 inch above the top surface of the flasher (Figure 1). The fluorescence emission is collected horizontally through another window on the main science module and recorded by a detector inside. The working prototype (with complete electronics and optics) is 1.75 inch in diameter and 5 inch long with a headcone and tailcone certainly. The design allows for milling in titanium or black anodized aluminum. The rod is slightly milled flat on the sides to provide good spot for connections to the main science module. There are only 3 connection wires (ground, +10V, and +5V TTL trigger) and is easy to install an O-ring between the flasher and the main body with the screws inside the O-ring (to eliminate the need of an external cable).

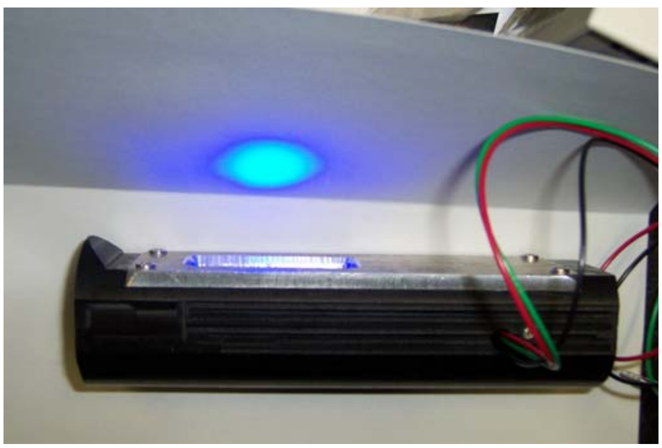

Figure 1. The prototype FIRe system for the Glider. Visible is the blue excitation light.

The other major development effort for the FIRe system is the design and development of the operating software. Great progress has been made. The software has both and a Command and Operating mode. In Command mode, the user will be able to configure the instrument for deployment. In Operating mode, the instrument will sample, log, process and send data in accordance with the setup parameters. The current plan is to have the instrument automatically boot up in Operating mode when power is supplied, so that there is no chance the user could mistakenly deploy the instrument in Command mode. This also eliminates the requirement for the Glider to ping the instrument to take a sample. When the user wants to enter the Command mode, a break command is sent over the serial port.

Gliders: This last 6 months was focused on continuing to refine our ability to fly Webb Sloccum Gliders anywhere in the world controlled from a shore-based station located in New Jersey. To that end, gliders were adaptively controlled and flown in thr Mid-Atlantic Bight, Hawaii, California and a Glider is being deployed offshore the South American Antarctic penisula on January 7th 2007 (Figure 2). Results demonstrate that gliders will provide a long duration platform will revolutionize exploration of the oceans. This NOPP has benefited from efforts leveraged through the Office of Naval Research that has developed a Glider Consortium, three Glider technical centers (one of which is located Rutgers University). Integration of of a downwelling irradiance sensor into Webb Gliders (Figure 3) was not funded by this NOPP but was critically important as the calculation of phytoplankton productivity rate will information on the *in situ* light field. Given this, we have leveraged money from the Office of Naval research to integrate a Satlantic OCR-500 micro-sensor

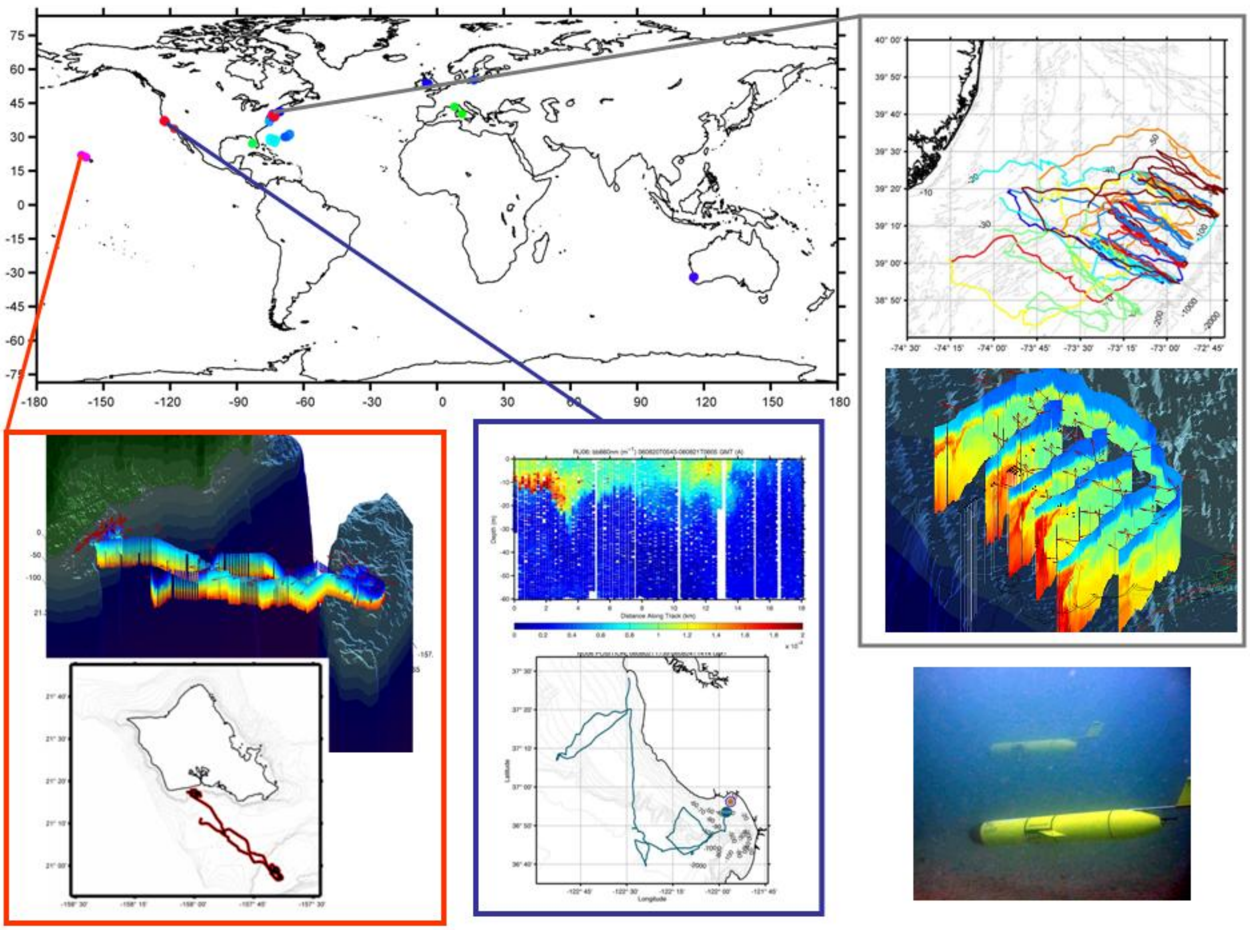

Figure 2. The Rutgers glider deployments in Summer 2006 that demonstrated the ability to remotely fly gliders remotely anywhere on Earth simultaneously. In June 2006, a Rutgers Glider joined the RIMPAC efforts offshore Hawaii. The July through August Gliders were flown simultaneously offshore California and New Jersey. The New Jersey mission was part of the ONR SW06 and NLWI efforts, and consisted of coordinating a fleet of Gliders.

series (Figure 3) into all the optical gliders. Taken together the glider will now measure downwelling irradiance, particle load, photosystem II activity, and oxygen. This will provide the capability to derive robust phytoplankton productivity rates from gliders. The glider deployments have continued and our ability to fly gliders globally has been actively demonstrated. Current deployment statistics for the Rutgers Gliders since Fall 2003 are: 26,181 kilometers flown underwater during 93 deployments representing 1312 days at sea.

Figure 3. The irradiance sensor were incorporated into Glider science bays in 2006.

Oxygen electrodes: Our proposal intially called for the integration of Anderra Optodes in part part because the Oregon State University had already begun this effort. To this end, we hosted company representatives of the Anderra Optodes in July 2005. The advantages of the Anderra system result in their small size and the lack of instrumental drift ideal for long duration deployments. There were rumours that the slow reponse of even the new generation Optodes can take several minutes. Therefore we were concerned that the Optodes would not be able to equilibrate given a typical ascent and descent rate of 20 cm/s. This has lead us to re-explore the faster response of membrane electrodes; however we required data; therefore during the ONR-sponsored the SW06, in which the OSU Glider participated, a Glider outfitted with an Optode was flown in summer 2006 offshore New Jersey. We are currently anaylzing this data. We also have been in discussion with two companies who have alternative oxygen electrodes. Currently two electrodes developed by Obis-Sphere and Falmouth Scienfitic oxygen electrodes are the leading candiates based on long duration deployments coducted by scientists from Bar-Illat University and Woods Hole Oceanographic Institute. The disdavantage of this system is that they are expensive, have more propietary roadblocks, and will biofoul much more dramatically then the Optode. We therefore would have spent time working with Anderra to overcome the slow sensor response time. These new sensors are being tested in collaboration with the Environmental Protection Agency, the New Jersey Department of Environmental Protection, and Rutgers at the Long term Ecosystem cabled Observatory (LEO)

RESULTS

This is the second year of this engineering and development project therefore scientific results have yet to be generated. Our expectation is that as sensors are developed and integrated, we will be able to collect data in coming year.

IMPACT/APPLICATIONS

National Security

The gliders have demonstrated a great deal of potential for National Security issues. Rutgers gliders have already conducted joint exercises with United States Atlantic and Pacific naval fleets for mine counter and anti-submarine warfare efforts. The advantage of these platforms is that provide a covert long duration capabiltiy to patrol the water column. A great deal of these applied efforts have required significant upgrades in the sensor capabilties of the gliders. This NOPP directly serves these purposes by dramtically expandng the environmental sensing capabilties for long duration gliders.

Economic Development
The completion of this NOPP will promote economic development. Both Webb and WetLabs are commercial companies with a long history of being at the fore-front of providing state-of-the-art oceanographic sensors and platforms. The new sensors and expanded glider capabilties will be of great interest to many researchers.

Quality of Life
Hypoxia and anoxia significantly impact coastal ecosystems. The causal mechanisms behind the hypoxia/anoxia are often related to cultural eutrophication or a response to climate with the manifestation of the low DO areas being a function of coastal circulation patterns. Our proposal will provide the capability of unraveling the factors regulating the spatial extent and intensity of hypoxia/anoxia. The coastal waters of Mid-Atlantic Bight (MAB) routinely experiences hypoxia and anoxia and this is one of the largest concerns currently for the New Jersey State of Environmental Protection. The development of a glider capable f mapping water column oxygen concentrations is a high priority for the state, and they are excited about this NOPP program.

Science Education and Communication
Gliders are proving to be a robust platform for conducting research under extreme conditions not easy to sample using ships (Figure 4). The ability to maintain sustained and high resolution spatial time series will revolutionize the manner in which oceanography research and exploration is being conducted.

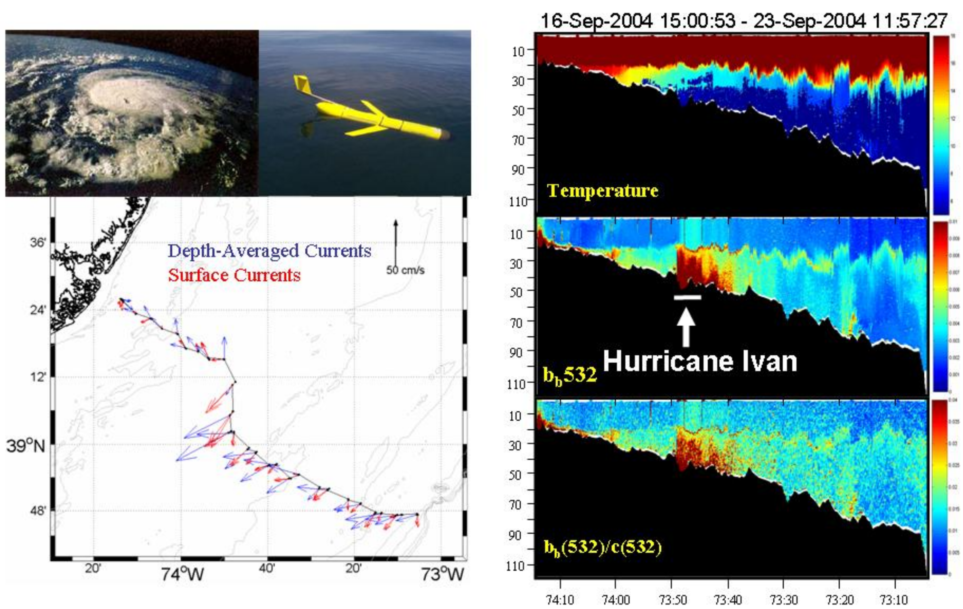

Figure 4. A glider flying through Hurricane Ivan. The in situ data for temperature, backscatter (bb), and backscatter/attenuation (bb/c) are shown.

TRANSITIONS

National Security
The success of the gliders in joint academic and naval exercises has resulted in NAVOCEANO to begin buying the gliders for active use in the field. They have also intiated a training effort with

Rutgers, Scripps, and U. Washington scientists so that Navy personnel can operate gliders. This has also resulted in the Naval academy in beginning to set-up an internship with Rutgers to allow cadets to receive glider training.

Quality of Life

The New Jersey Department of Environmental Protection is actively considering in purchasing a glider to monitor the oxygen concetrations along the new jersey coast. They will use the results generated by this project to justify that purchase. They plan on using the glider to monitor the coastal water oxygen concetrations trying to determine location and timing of bottom water hypoxia/anoxia.

Science Education and Communication

Monitoring the state of the ecosystem requires estimates of both microbial biomass and metabolic activity. This glider package will be the first to provide microbial rate processes from a glider.

RELATED PROJECTS

Several projects are closely affliated with this NOPP effort. The Office of Naval Research (ONR) is providing signifcant to develop glider capabilties. ONR has developed a glider consortium (APL-U. Washington-Scripps-WHOI-Rutgers) to expand and unify glider command/control capabilities. ONR has provided funds to develop three glider techncial centers (U. Washington, Scripps, Rutgers) to provide ONR researchers platforms to be made available to ONR researchers. ONR has funded the development of inherent (attenuation, backscatter) and apparent (spectra irradiance) optical sensors for gliders. These sensors will directly complement the sensors being developed by this NOPP. Coorniated activity of multiple gliders is also being funded through ONR field experiments (SW06 and OASIS) in the coming year and theexperience gained will directly benefit this NOPP.