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

Oscar Schofield
Rutgers University Coastal Oceanography Laboratory
71 Dudley Road, New Brunswick, NJ 08901
phone: (732)-932-6555 fax: (732) 0932-8578 email: oscar@marine.rutgers.edu

Maxim Grobunov, Paul Falkowski, Scott Glenn
Rutgers University Coastal Oceanography Laboratory
71 Dudley Road, New Brunswick, NJ 08901
phone: (732)-932-6555 fax: (732) 0932-8578
email: gorbunov@imcs.marine.rutgers.edu, falko@marine.rutgers.edu, glenn@imcs.rutgers.edu

Clayton Jones
Webb Research Coporation , 82 Technology Park Drive
East Falmouth MA, 02536
phone: (508)-548-2077 fax: (508)-540-1686 email: cjones@webbresearch.com

Scott MaClean
Satlantic Inc. Richmond Terminal, Pier 9 , 3481 North Marginal Road
Halifax, Nova Scotia B3K 5X8 Canada
Phone: (902)-492-4780 Fax:(902)-492-4781 email: scott@satlantic.com

Award Number: NA05OAR4601089
http://marine.rutgers.edu/cool

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 elcetrodes in Webb Gliders, develop and integrate a FIRe system in a glider, use the integrated glider science bay combined with a WetLabs inhernt optical glider to map the productivity of the Mid-Atalntic Bight, and finally begin the design of a minutarized ISUS system. This effort will be faciltated through several partnerships. Rutgers has been awared a Glide technical Center by the Department of Defense to devlop a capability to provide researchers a fleet of accesible Webb Gliders. y 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.

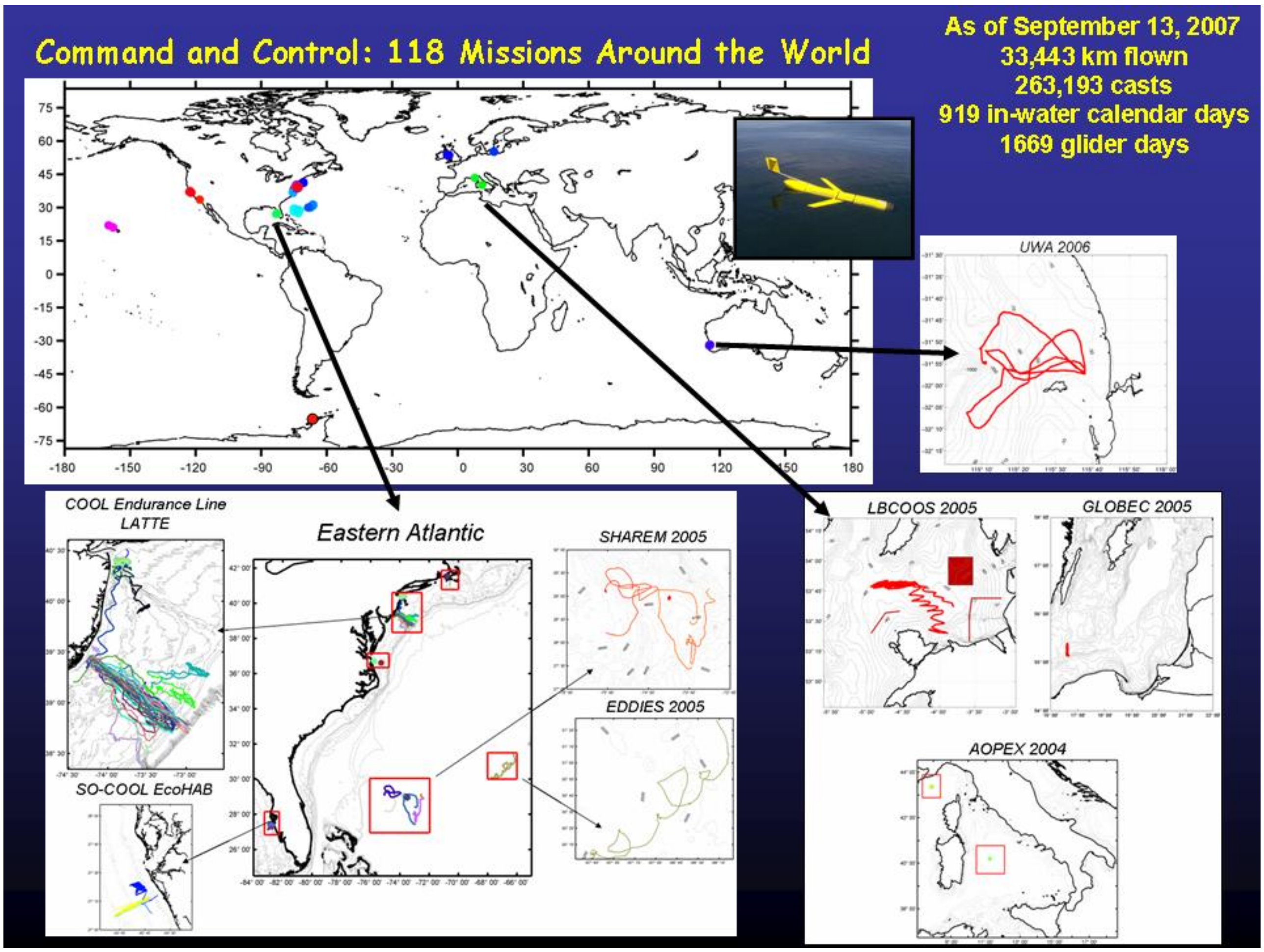

Figure 1. The Rutgers glider deployments and statistics since October 2003 that are demonstrating the ability to fly gliders remotely anywhere on Earth. These platforms are robust and ready for operational transitions. Two of three European deployments occurred within the last 6 months during this NOPP. The Australian glider deployment is occurring this week as this progress report is being submitted.

WORK COMPLETED & RESULTS

Despite substantial budget cuts in years 2 and 3 of this project, great progress has been made. The project is enterting the exciting phase where the new sensors are now being incorporated and flown in the ocean on Gliders. An over-view of the progress is listed below.

Fig. 2. The irradiance sensor being incorporated into Glider science bays in 2006.

Gliders: This last 6 months was focused on cotnuing 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, Martha's Vineyard, Perth Australia, Sargasso Sea, Baltic Sea, and Liverpool Bay (Figure 1). Results demonstrate that gliders will provide a long duration platform will revolutionize exploration of the oceans. This NOPP will benefit 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), and funds to ingetrgate irradiance sensors into Webb Gliders (Figure 2). This sensor is currently being tested on a glider that has been flying off Martha's Vineyard and has collected almost 5000 vertical profiles since the system was deployed in mid-August (Figure 3). Though not funded by this NOPP it was determined that calculation of the productivity rate will require robust estimates of 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 series 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.

Oxygen electrodes: The Anderra oxygen Optode has been integrated into a glider in 2006-2007. The optode test will be conducted next month with the oxygen Glider flying offshore the waters of the Oregon in collaboration with OSU scientists. To further test the robustness of the Optdoes we deployed a second electrode on the Long term Ecosystem Observatory and collected a time series to test its stability (Figure 4). The degraded siganls at the end of the deployment largely reflects ground fault interrupts in the cable and not the sensor itself. The observed variability agrees with the observed oxygen ranges measured by the NJ Department of Environmental protection in these waters. After the intial tests, the oxygen Glider will be deployed monthly as part of ongoing DoD and NOAA IOOS field efforts. These leveraged funds allowed for a range of field testing despite the tight budgets.

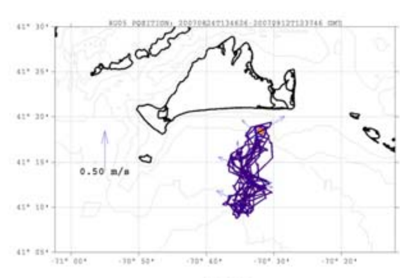

Fig. 3. The Glider trajectory carrying the OCR radiometer off Martha Vineyard in August and September 2007.

Fluorescence Induction and Relaxation (FIRe) System: The prototype FIRe system has been built and the accuacy of the system has been tested in bench top mode side by side with a standard FIRe system (Figure 5). In the Glider-FIRe system, the FIRe profile is characterized by a slower fluorescence rise (~ 50 us versus 30 us in the bench-top FIRe) due to lower photon flux density of the excitation light. Yet, the realized photon flux density is high enough to saturate fluorescence yield within less than 100 us (the requirement of the optimal FIRe protocol). The blank signals (lower profiles) were recorded in a filtered sea water. Although the blank is higher (~ 3x) in the Glider-FIRe design, it is still low enough to ensure accurate measurements at extremely low chlorophyll concentrations of phytoplankton in the open ocean (see Figure 6).

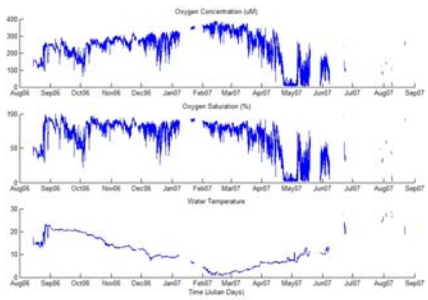

Fig. 4. Oxygen dynamics measured with the Optode now mounted in a Webb Slocum glider.

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.

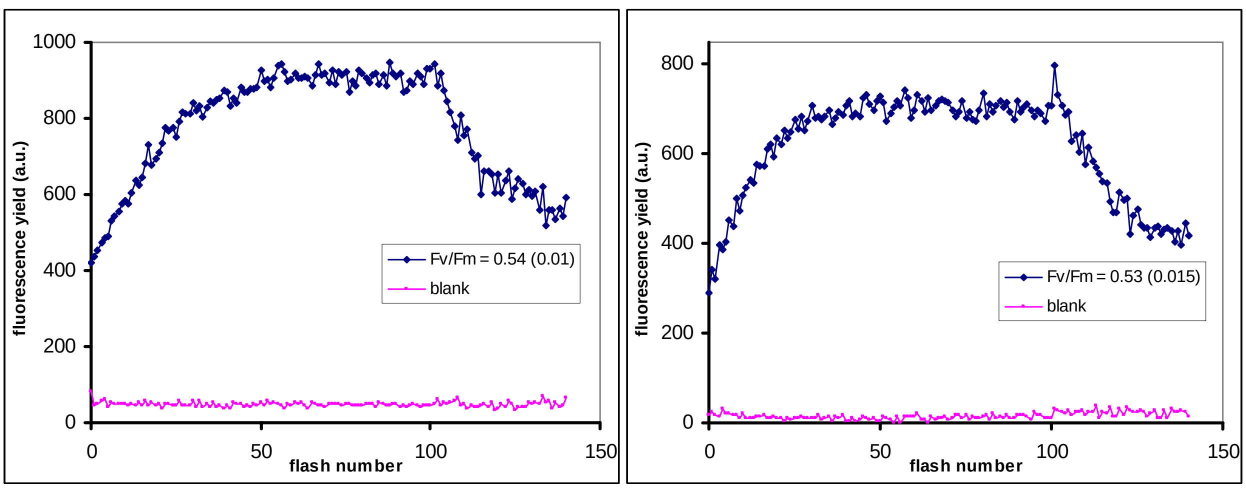

Fig. 5. FIRe fluorescence profiles recorded in a diatom, *Thalassiosira weissflogii,* using a bench-top FIRe fluorometer (left panel) and a new prototype Glider-FIRe optical chamber (right panel). The chlorophyll-a concentration in the sample was 0.50 mg/m3 (typical for mesotrophic ocean and coastal waters). N=15 iterations (1.5 seconds at 10 Hz sampling rate) were required to reach a good signal-to-noise ratio. At the operational down-welling speed of the Slocum Glider of ~ 1 m/s, this sample period corresponds to the vertical resolution of 1.5 m.

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.

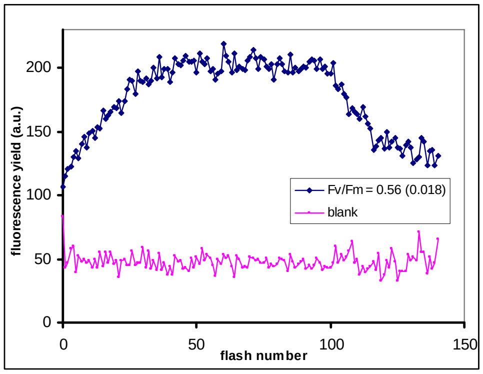

Fig. 6. FIRe fluorescence profiles recorded in a diluted sample of a marine diatom, *Thalassiosira weissflogii*, using the prototype Glider-FIRe optical chamber. The chlorophyll-a concentration in the sample was 0.1 mg/m3 (typical for oligotrophic open ocean waters). N=60 iterations (6 seconds at 10 Hz sampling rate) were required to reach a good signal-to-noise ratio. The blank signal (lower profiles) was recorded in a filtered sea water.

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. The ability to maintain sustained and high resolution spatial time series will revolutionize the manner in which oceanography research and exploration is being conducted.

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 (MURI and OASIS) in the coming year and theexperience gained will directly benefit this NOPP.