

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 Slocum Gliders. We will also begin the design strategies for the development of optically-based nitrate sensor. Our ultimate goal is to develop an autonomous platform that will be used to characterize the productivity of the continental shelves.

OBJECTIVES

Miniaturized 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 be 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 O₂ 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 O ₂ 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
G) Begin design for a miniaturized ISUS sensor for Webb Gliders	Rutgers, Satlantic	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, and finally begin the design of a miniaturized ISUS system. This effort will be facilitated 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 accessible Webb Gliders. WetSat 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.

WORK COMPLETED

This is the first year of this three year project with funds be delivered for the partners being delivered in late September of 2005. Despite the slow start, much progress has been made and this NOPP is off to a terrific start. The progress has been achieved through development of 3 tracks in this initial year of the project. The following sections highlight the progress for each of the top three priorities for Year 1.

Gliders: This last 6 months was focused on continuing to refine our ability to fly Webb Slocum 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 the 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 integrate irradiance sensors into Webb Gliders (Figure 2). 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 (Fig. 2) 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: Plans for the integration of oxygen electrodes have proceeded and oxygen electrodes should be integrated into Gliders by June 2006. Our proposal initially called for the integration of Anderra Optodes in part because the Oregon State University had already begun. 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. Unfortunately we have ascertained that the slow response of even the new generation Optodes can take several minutes. Therefore we do not believe the Optodes will not be able to equilibrate given a typical ascent and descent rate of 20 cm/s. This has led us to re-explore the faster response of membrane electrodes. Currently two electrodes developed by Obis-Sphere and Falmouth Scientific oxygen electrodes are the leading candidates based on long duration deployments conducted by scientists from Bar-Illat University and Woods Hole Oceanographic Institute. The final decision and purchase of the electrode will be made by the end of the month January. The science bay will be built and will be tested during late spring and early summer when

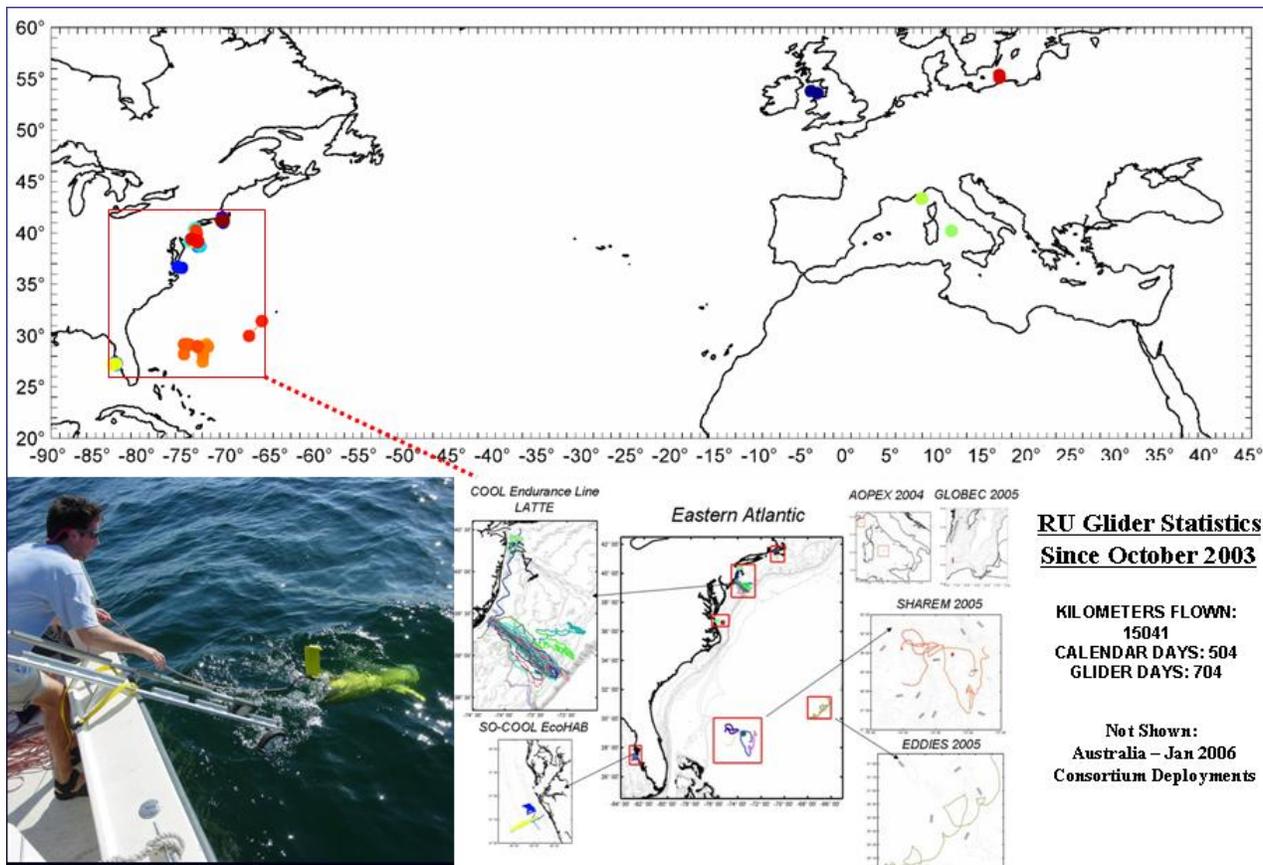


Figure 1. The Rutgers glider deployments and statistics since October 2003 that are demonstrating the ability to fly gliders remotely anywhere on Earth. These platforms are robust and ready for operational transitions. Two of three European deployments occurred within the last 6 months during this NOPP.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

oxygen levels are dynamic reflecting the relative interplay between the primary productivity in the euphotic zone and the relative efficiency of the export flux. Initial deployments will be conducted on the Endurance line off the coast of new jersey in late summer fall-autumn 2006.



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

Fluorescence Induction and Relaxation (FIRe) System: design and lay-out for the minutaized FIRe has begun. The commercially available FIRe systems were demonstrated to be able to detect phytoplankton and their physiological state in the ultraligotrophic waters in the Pacific. This ultrasensitivity requires high output light sources and sensitive detectors which are power intensive, which is a big issue for glider technology. Therefore we are currently designing the a new optical system and choosing the appropriate digitizers. This development phase should be completed by spring 2006. Construction and bench top testing will be soon to follow.

RESULTS

This is the first year of this project therefore scientific results have 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 capability to patrol the water column. A great deal of these applied efforts have required significant upgrades in the sensor capabilities of the gliders. This NOPP directly serves these purposes by dramatically expanding the environmental sensing capabilities 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 capabilities 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 of 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 (Fig. 3). 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 initiated 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.

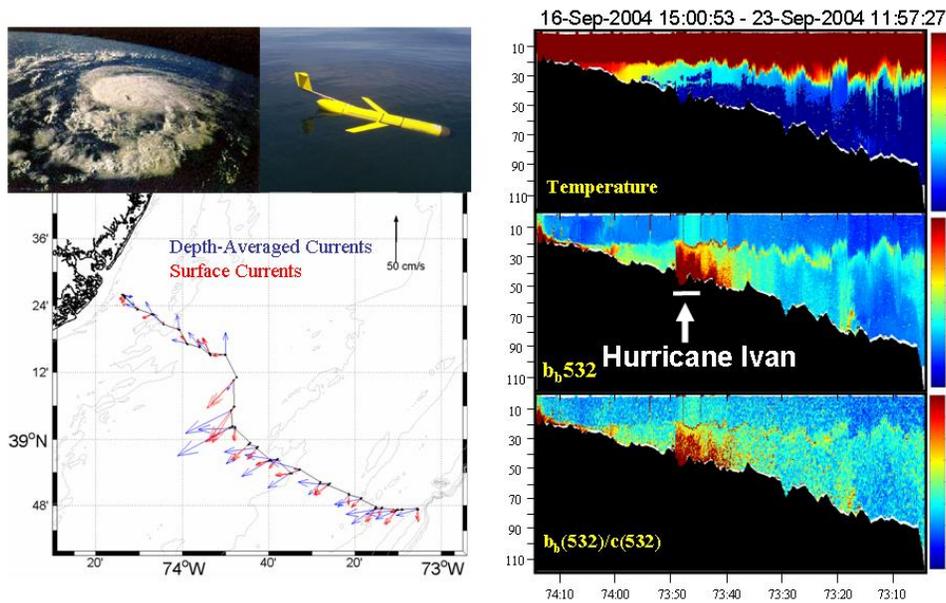


Figure 3. A glider flying through Hurricane Ivan. The in situ data for temperature, backscatter (bb), and backscatter/attenuation (bb/c) are shown.

Quality of Life

The New Jersey Department of Environmental Protection is actively considering in purchasing a glider to monitor the oxygen concentrations 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 concentrations 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 affiliated with this NOPP effort. The Office of Naval Research (ONR) is providing significant to develop glider capabilities. 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 technical 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. Coordinated activity of multiple gliders is also being funded through ONR field experiments (SW06 and OASIS) in the coming year and the experience gained will directly benefit this NOPP.