Incorporation of Sensors into Autonomous Gliders for 4-D Measurement of Bio-optical and Chemical

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LONG-TERM GOALS

Our long-term goal is to develop distributed networks of autonomous underwater gliders that are capable of providing a detailed, four-dimensional view of ocean biology, chemistry and physics for extended periods of time. Gliders are flexible in that they can operate completely autonomously in either station-keeping or transect modes of operation, or accept new commands from shore during a mission to change observing strategies. Their range can be several thousand kilometers with mission durations of many months. The sensors are small and low power, and capable of measuring key biological, chemical and physical variables. The capabilities enabled through the successes of our NOPP project are important steps toward our long-term goal of developing affordable sensing networks for basic science, for sustained ocean observing, and for applied studies of relevance to national needs.

OBJECTIVES

The primary objectives of the overall NOPP project were to expand the operational capabilities of the autonomous underwater glider, Seaglider; to extend its measurement capabilities to include biogeochemical variables, specifically dissolved oxygen, phytoplankton biomass, and suspended particle concentration; and to demonstrate the power of this new autonomous mode of ocean observing. Seaglider can operate in both a transect mode or a station keeping mode. It moves horizontally and vertically using buoyancy and wings, diving as deep as 1000 meters, and transmitting data at the end of each dive cycle via Iridium satellite phone. The key to Seaglider's ability to operate continuously for many months at a time is its efficient hydrodynamic shape. The development of the biogeochemical sensors was guided by the need for these sensors to be unobtrusive to minimize drag, small to conserve space, and power stingy to maximize battery lifetime. The specific objectives of the past year were to demonstrate the capability of Seaglider to maintain a persistent presence in waters off the coast of Washington State, USA, and to interpret the optical and chemical data collected by Seaglider in context of a four-dimensional view of ocean biogeochemistry.

APPROACH AND WORK PLAN

The current NOPP partnership includes the University of Maine, the University of Washington, Western Environmental Technologies Laboratory (WET Labs), and the Washington State Department of Ecology. Mary Jane Perry, Emmanuel Boss and Lee Karp-Boss (University of Maine) are involved in the calibration of the optical sensors, in the interpretation of the optical data, and in ocean color satellite data analysis. Charles Eriksen (University of Washington) is responsible for Seaglider development and operation and engineering of the Iridium–GPS antenna. Casey Moore and Ronald Zaneveld (WET Labs) are engaged in advanced sensor designs for expanding fluorometric measurements to additional wavelengths and measuring diffuse attenuation. Jan Newton (Washington State Department of Ecology) oversees in-water validation of sensors.

The approach for the first three years of the partnership was to enhance glider operation and performance; to develop and test sensors for oxygen, chlorophyll fluorescence [a proxy for phytoplankton concentration] and two wavelengths of backscattering [a proxy for particle concentration]; and to develop and test a new Iridium–GPS antenna with a high baud-rate that allowed two-way transmission of complete data sets for each dive cycle and capability to change the sampling protocol during the mission. The approach in the fourth year was to continue improvements in Seaglider capabilities, to modify the Iridium–GPS antenna, to continue calibration and validation of the biogeochemical sensors, to extend the duration of Seaglider missions, and to interpret the biogeochemical data collected by Seaglider off the Washington coast. In the coming year we will continue Sealider operations of many months duration as a demonstration of the capability of Seagliders for sustained ocean observations.

WORK COMPLETED

Since the beginning of the project four years ago, Seaglider capabilities and accomplishments have increased dramatically. The first interdisciplinary glider mission – in which chlorophyll fluorescence, oxygen and optical backscattering were simultaneously measured, in addition to temperature, salinity and depth – was executed by a Seaglider. Seagliders were the first gliders to successfully carry out multi-glider missions. By deploying multiple gliders in the station-keeping mode, Seagliders also demonstrated the capability for resolving local changes from advective changes. In the last two years alone, Seagliders have logged in excess of a year of successful missions at sea. The longest glider mission – in excess of five months of continuous operation – was recently completed by a NOPP Seaglider. Operating continuously in Pacific Northwest waters off the coast of Washington between August 2003 and January 2004, Seaglider No. 5 made over 500 dives to 1000 meters, reporting complete profile data at the end of each cast (Figure 1, below). This recently completed deployment is a milestone in glider accomplishments.

Implementation of two-way Iridium communications has freed Seagliders from the restrictions of operating adjacent to coastal areas and has enabled Seagliders to operate in a global domain. A submersible antenna, also tuned to operate as a GPS antenna, was developed and perfected during the last year. The small, dual use (Iridium/GPS) submersible antenna has decreased overall vehicle drag by over 20% compared with cellular phone and commercial GPS antennas. The lower drag and smaller size (requiring less energy to lift the antenna across the sea surface) translates to a significant improvement in mission duration.

Optical data and oxygen measurements with the Sea-Bird oxygen sensor were measured in the upper water column during the five-month deployment in 2003 off the Washington coast. Satellite ocean color data from the SeaWiFS and MODIS sensors have been analyzed. The bb2f optical sensors developed for this NOPP project have performed well for Seaglider. The bb2f technology has been transitioned to a commercial sensor; their small size and low power consumption makes them idea for long-term ocean observing applications. These sensors have been incorporated into other gliders, floats, and moorings.

RESULTS

Seaglider continuously operated for a five-month deployment in slope and oceanic waters offshore of Washington State and Vancouver Island between August 2003 and January 2004. The typical dive depth was to 1000 meters, with approximately 5-kilometer spacing between the initiation and completion of a dive cycle. The “V”-shaped glider track shown in Figure 1 extended offshore to 1□□□W and was repeated a total of five times during the mission. In Figure 1, the glider tracks are overlain on a composite ocean color satellite image of chlorophyll concentration. The 250-meter bathymetry denotes shelf break and the 2200-meter bathymetry denotes slope/open ocean transition.

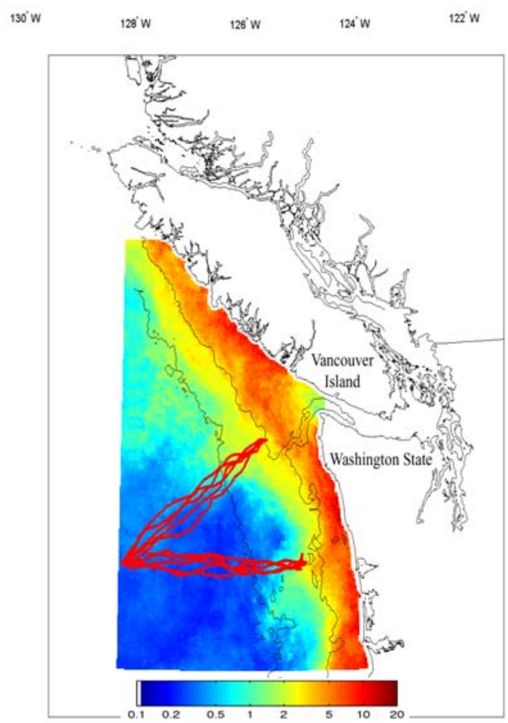

Figure 1. Seaglider transect during five-month deployment in waters offshore of Washington and Vancouver Island in 2003. The “V”-shaped transect was repeated five times during the mission. Units for the color bar are milligrams chlorophyll m^{-3}.

Chlorophyll fluorescence is a proxy for chlorophyll concentration, a measure of phytoplankton biomass. However, when living phytoplankton cells are exposed to bright light, particularly during mid-day, chlorophyll fluorescence is chemically quenched within the cell. The consequence is a decrease in the fluorescence-to-chlorophyll ratio and a serious bias in the computed chlorophyll concentration. By analyzing the temporal pattern of the fluorescence-to-backscattering ratio in the mixed layer, we were able to develop an algorithm to account for fluorescence quenching and thereby minimize the error in chlorophyll concentrations computed from near-surface samples with fluorescence quenching. Figure 2 shows the effect of fluorescence quenching on computed chlorophyll concentrations from the upper 5 meters and the results of our algorithm to account for the change in the fluorescence-to-chlorophyll ratio.

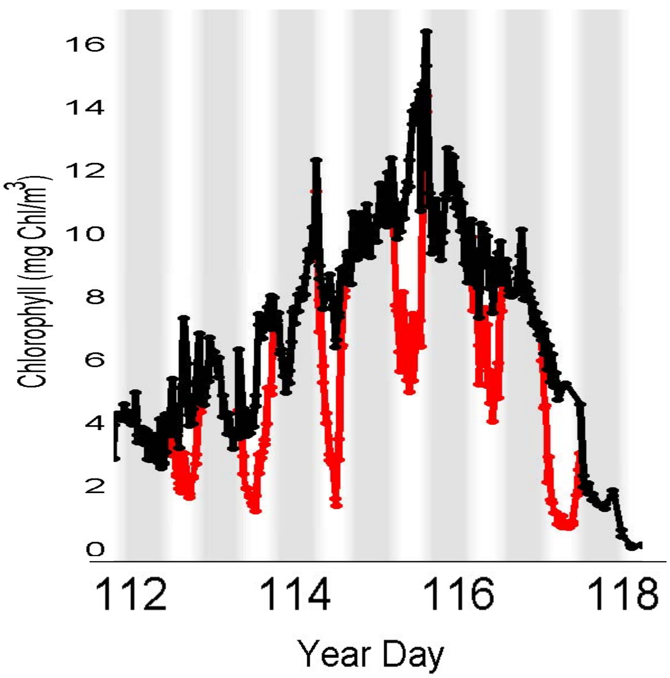

Figure 2. Near-surface chlorophyll concentrations measured on a Seaglider transect in waters overlying the Washington shelf in April 2002. The black line represents night-time and corrected chlorophyll concentrations in milligrams chlorophyll m^{-3}. The red line represents the day-time concentrations that are biased by the high-light quenching of chlorophyll fluorescence.

IMPACT AND APPLICATIONS

National Security

Seaglider can provide a discrete observing capability for physical, chemical, and optical properties of remote water masses.

Economic Development

The NOPP project has already had a positive impact on a small business with the commercialization of the bb2f optical sensor. Other optical sensors resulting from this project can also be expected to be commercialized as new products. The small robust sensors developed to meet the stringent requirements of Seaglider will be important in other ocean observing platforms, including other gliders, profiling floats, and moorings.

Quality of Life

The incorporation of interdisciplinary gliders in coastal monitoring will make a significant contribution to tracking pollution and providing early warning for harmful algal blooms. A better understanding of the ecosystem, measured on the space and time scales that are important to organisms, should also contribute to improving marine resources management strategies.

Science Education and Communication

The concept of an underwater glider, operating autonomously, captures the imagination. The glider and the data collected on glider missions will be intriguing way to engage students in ocean exploration.

TRANSITIONS

Economic Development

The bb2f optical sensor developed for this project has already been transitioned and is now a commercial product; it is anticipated that other sensors developed for this project will be commercialized in the near future.