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 partnership was to enhance Seaglider operation and performance; to develop and test sensors for oxygen, chlorophyll fluorescence [a proxy for phytoplankton concentration] and two wavelengths of backscattering [proxies for particle concentration]; to validate biogeochemical proxies; to develop, test and perfect 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; to interpret the biogeochemical data collected by Seaglider off the Washington coast; and to extend the duration of Seaglider missions for sustained ocean observations.

WORK COMPLETED

Under the University of Washington NOPP, a number of developmental hardware, software and communication challenges were successfully solved, using Washington coastal waters as the testing ground for Seaglider technology. With the Iridium antenna perfected, Seagliders were able to venture beyond cellular telephone range from shore. The Seaglider sensor suite was expanded from Seabird Electronics temperature and conductivity to include a SEB-43 dissolved oxygen and a WET Labs combination chlorophyll fluorometer / dual wavelength optical backscatter (BB2F). Under the University of Maine NOPP, WET Labs designed the BB2F specifically for Seaglider, with low power and minimal drag. 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 on autonomous and cabled platforms. Since August 2003, Seaglider operations in Washington slope waters have been nearly continuous. Two full 5-month missions have been accomplished, along with two of one month duration each and one of 4 months endurance. The initial goal of the Washington coast deployment was to demonstrate that Seagliders were an effective means of measuring a boundary current system; all partners participated to meet this goal with overwhelming success.

RESULTS

Seaglider has operated almost continuously in slope and oceanic waters offshore of Washington State since August 2003. We chose a V-shaped track from the continental shelf edge offshore 120 nautical miles to 47°N, 128°W (Figure 1). The track shape allows a single glider to alternately make sections normal to the slope at two relatively nearby locations. Continuous operation provides monthly round trips to the shelf edge. The typical dive depth is to 1000 meters, with approximately 5-kilometer spacing between the initiation and completion of a dive cycle. In Figure 1, the multiple 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.

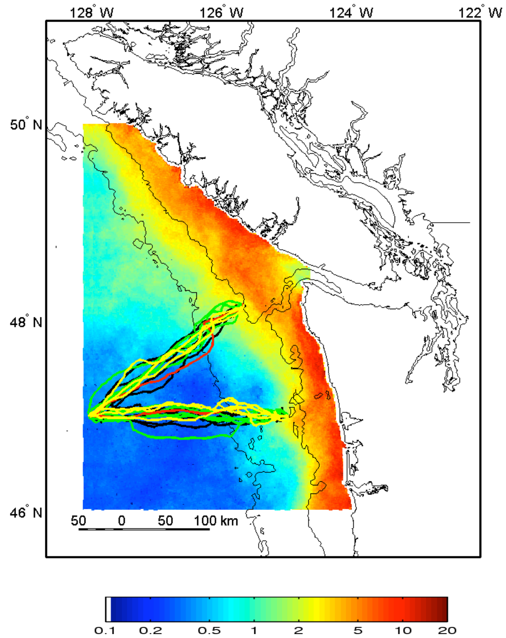

Figure 1. Seaglider "V"-shaped transect for multiple deployments in waters offshore Washington since August 2003. Units for the color bar are milligrams chlorophyll m^{-3}.

Seasonal and interannual baroclinic changes are evident in potential density depth-time series constructed from repeated Seaglider missions. Despite eddy noise present in individual sections, successive occupations vary coherently in time (Figure 2). During the latter half of 2003, isopycnals that slope downward from onshore (Figure 2; light, dotted vertical lines) to offshore (dashed vertical lines) mark the California Current. Despite this broadscale tilt, isopycnals close to the shelf tend to be depressed during this period, indicative of poleward shear narrowly trapped against the continental shelf edge. The pattern reverses during winter and spring, 2004, with uplifted offshore isopycnals and broad depression of those onshore.

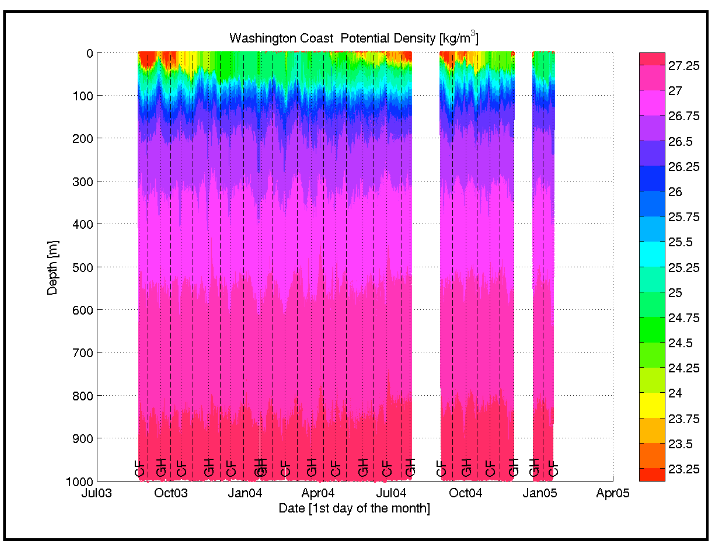

Figure 2. Depth-time color contour plot of potential density.

Interannual differences in autumn water masses are evident from temperature-salinity scatter in the pycnocline (Figure 3). The autumn halocline is about 1°C warmer in 2004 than 2003 on isopycnals with potential density anomalies between about 25 and 26 kg/m3 (magenta vs. red dots). Autumn 2004 also exhibits less than half the T-S scatter in this density range. The halocline warmed from autumn 2003 to winter 2004 (blue dots), continuing through summer 2004 (green dots), with pycnocline water mass variability decreasing in summer.

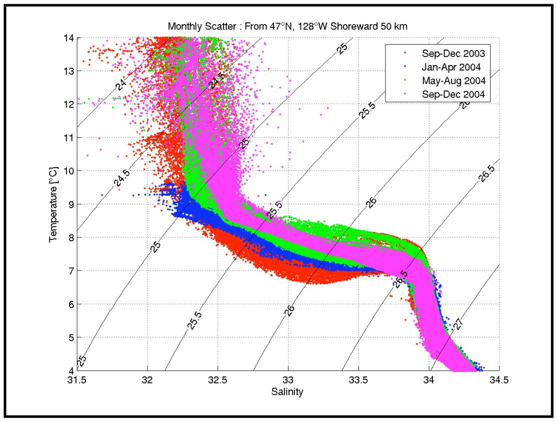

Figure 3. Temperature-salinity scatter for 4 consecutive 4-month periods for locations up to 50 km shoreward of 47°N, 128°W collected by Seagliders. Temporal sequence in color by red, blue, green, and magenta (insert box). Contours indicate potential density anomalies in kg/m3.

As strong density gradients are established in spring on the outer slope (the tip of the "V" transect), vertical mixing is reduced thereby shutting off the supply of new nutrients to surface waters. Satellite images show low phytoplankton biomass in surface waters at the outer edge of the glider transect and biomass-based productivity models suggest that primary productivity is also low. However, the highest abundance of phytoplankton occurs at the base of the surface mixed layer, at the intersection of decreasing light and increasing nutrient gradients. Figure 4 shows the annual pattern with a sequence beginning in autumn 2003 with a clearly defined layer that is eroded in late autumn as the mixed layer deepens, is re-established in late spring as surface stratification intensifies, and continues into the late autumn when it is once again eroded by deep mixing. The oxygen supersaturation associated with this layer is suggestive of the layer's important contribution to offshore primary productivity.

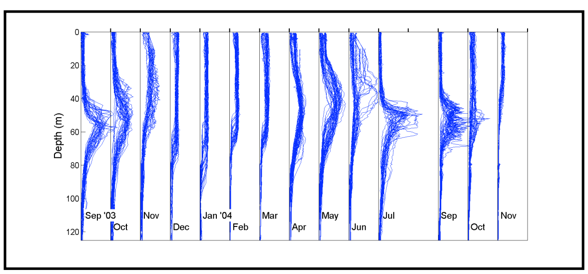

Figure 4. Chlorophyll fluorescence at 47°N, 128°W (outer tip of the "V" transect). Right: Fluorescence profiles by month from Seaglider tracks.

In addition to profile data, Seagliders also measure depth-averaged current vectors by taking the difference between displacement derived from GPS fixes at the start and end of each dive and modeled displacement through the water. Regressions of onshore and alongshore components of glide speed through the water against the corresponding speed components over the ground suggest that model glide speeds are accurate to within a few percent. These depth-averaged flow estimates provide a reference for depth-integrated geostrophic shear obtained from lateral density gradients measured along glider sections. The year and a half of nearly continuous Seaglider operations reveal clear interannual variability in both mass transports and water properties. Depth-averaged currents offshore Washington show both coherent seasonal and interannual variability.

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 theBB2F optical sensor. 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. Seaglider is being transitioned to other user groups through a University of Washington cost center.