Transitioning Submersible Chemical Analyzer Technologies for Sustained, Autonomous Observations from Profiling Moorings, Gliders and other AUVs

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LONG-TERM GOALS

To transition existing prototype autonomous profiling nutrient analyzers into commercial products that can be readily deployed on autonomous profiling moorings, coastal gliders and propeller driven unmanned underwater vehicles and used for sustained, autonomous ocean observations of chemical distributions and variability. A series of issues have been identified that that need to be addressed to convert prototype nutrient analyzers into commercial units that can be widely used by the community for sustained and accurate, stable, autonomous operation in the ocean. These issues are; (1) a more compact size, (2) reduced reagent and power consumption, (3) enhanced biofouling suppression, (4) ease of use by non-chemists, and (5) documented performance when deployed on different platforms.

Our plan to address those issues involves using recent advances in micro-fluidics and optical detectors (new SubChem and WET Labs technologies) to reduce sample flow rates and volumes and thus reagent and power consumption; (2) extend the length of field deployments by periodically isolating sensitive components so that back-flushing and chemical techniques can be used to suppress bio-fouling, (3) increase the ease of use by simplifying operation, pre-packaging reagents and outputting the data in engineering units, and (4) thoroughly documenting the performance by conducting demonstration experiments at field sites that have strong vertical and horizontal nutrient gradients and episodic phytoplankton blooms.

We intend to achieve these goals through this NOPP partnership. The industry partners will take the lead in developing the commercial versions of the nutrient analyzers while the university and government partners will provide guidance defining the initial performance criteria for the nutrient analyzers and in providing the deployment platforms and conducting the field testing and demonstration experiments.

OBJECTIVES

The primary objectives of this collaborative NOPP project are the technological advancement, verification, demonstration and commercialization of two autonomous profiling nutrient analyzers that have been developed to their present status with government and private funding. The Autonomous Profiling Nutrient Analyzer **(**APNA) and the Micro-AUV Ready Chemical Analyzer (MARCHEM) will be improved so that they are capable of deployment from profiling moorings, coastal gliders and other AUVs for sustained, autonomous ocean observations of nutrient concentrations, spatial distributions and temporal variability.

APPROACH

Our general approach to achieve these objectives involves a collaborative partnership between industry (Alfred Hanson, SubChem Systems, Inc., and Casey Moore, WET Labs, Inc.), university (Percy Donaghay, University of Rhode Island) and government (Richard Arrieta & Brian Granger, SPAWAR Systems Center - San Diego).

An existing APNA prototype will be modified by SubChem Systems and WET Labs to be a more compact, resource-efficient, autonomous profiling multi-nutrient analyzer (now referred to as APNA II and III), particularly suited for sustained deployments on autonomous moored profiling systems like the IOPC profiler, and other AUVs. The MARCHEM analyzer prototype will be similarly developed, but as a very compact single channel analyzer designed for ready deployment on autonomous underwater vehicles that have more stringent space and power limitations (i.e. coastal gliders and small UUVs). Both of these analyzers will utilize similar miniaturized electro fluidic, optical detection and instrument communication and control components to accomplish the autonomous chemical analysis with minimal utilization of power and reagents. The academic and government partners, URI-GSO and SPAWAR-SSC, will contribute to the further development of these nutrient analyzers by providing advice and guidance on the analyzer design and specifications for the purpose of integration onto specific oceanographic platforms and accomplishing specific scientific and ocean observation goals. As they are developed, the MARCHEM and APNA analyzers will be tested and demonstrated in the field by integrating and deploying them on various autonomous underwater vehicle test platforms, such as the ORCAS IOPC profiler (URI), REMUS AUV, and Slocum coastal gliders (SPAWAR-SSC).

WORK COMPLETED

Progress was made on multiple objectives during the second fiscal year of NOPP funding.

1) **Extended Field Deployment of APNA II on the ORCAS IOPC Profiler in Monterey Bay:** The APNA II is a four channel autonomous profiling nutrient analyzer (nitrate, nitrite, phosphate, ammonia) that was designed for deployment on URI's ORCAS IOPC profiler (Figure 1). During the past year, WET Labs and SubChem engineers, and URI Scientists expended a considerable effort to improve the performance of the APNA II and to integrate and test it on an improved version the IOPC profiler. WET Labs specific efforts involved further improvements to the profiler winch and control systems and adaptation of the profiler's control and acquisition software to accommodate the APNA II. The APNA-IOPC was deployed in Monterey Bay during a field effort sponsored by the ONR directed research initiative "Layered Organization in the Coastal Ocean (LOCO)" during July 2006. It was programmed to collect hourly nutrient profiles for a two week time period. SubChem has also initiated the development of automated software for more rapid processing of APNA real-time raw data into useable real-time data products.

2) **Fabrication and initial testing of APNA III:** A third generation prototype of the APNA series of submersible nutrient analyzer was designed, fabricated, initially tested in the field. The APNA III is a five channel autonomous profiling nutrient analyzer (nitrate, nitrite, phosphate, silicate and ammonia) which is also configurable for multi-nutrient, time-series measurements for longer-term deployments on fixed moorings (cabled or battery). The enhancements to APNA III included a fifth channel (silicate), knotted reactors for faster signal response times, and software enhancements to accommodate two modes of time-series operation: a) continuous for short term profiling and b) intermittent sampling and measurement for longer-term monitoring applications. The APNA III analyzer was designed and fabricated by SubChem Systems and WET Labs provided the optical detectors and detector electronics. The first test deployment of the APNA III was conducted on a bottom mooring (Figure 2) in Monterey Bay as part of the LOCO field experiment during July 2006. It was programmed to collect hourly nutrient measurements for a two week time period.

3) **ChemFIN™ –** Conceptual design work was initiated by SubChem Systems on a new submersible chemical analyzer. ChemFIN™ is envisioned a small independent sensor payload, utilizing microfluidics, proposed for underway measurements on gliders and propeller AUVs.

4) **Integration of nutrient sensing capabilities into the Slocum Glider:** In addition to efforts involving improved operability of the MARCHEM to the REMUS100, strides were taken this fiscal year to work with SPAWAR to discuss and define an integration path and specification for a MARCHEM prototype to be hosted on the Webb Research SLOCOM Glider. Design work and info-exchange discussions focused on integrating the MARCHEM, "ChemFIN" or an alternate Chemical Sensor onto the Slocum Glider.

RESULTS

The nutrient analyzer development efforts of the NOPP partners continues to be collectively focused on developing improved fluidic pumping technologies, integrated optical sensing and mixing capabilities, advancing sensor technologies, and solving integration issues for autonomous profiling platforms. The development of new fluidic and integrated fluidic-detection technologies is required for the successful adaptation of APNA, MARCHEM and ChemFIN technologies for sustained autonomous deployments on profiling moorings and gliders. Some of the results from our work to date on this project were presented as an oral paper presentation during a special session on ocean observing technologies at the AGU-ASLO-TOS Ocean Sciences meeting in Febuary 2006.

Instrument software compatibility and capability: After the LOCO 2005 field experiments, it was evident that many of the integration hurdles to overcome had one main aspect in common. All analyzers shared common firmware while each analyzer was unique from the other by way of hardware configuration. Therefore, a major software overhaul was needed to allow each analyzer to be custom configured while allowing all user and host interactions to be the same. The analyzer software was written to configure itself per each analyzer's specific functions based on a configuration file. Thus, each analyzer maintained its own setup parameters. A second file scheme was developed to allow scripting of semi-autonomous and fully autonomous functions with a common command set. Therefore, all host platforms, to which the analyzers were integrated, could be given the same payload specifications for hosting the analyzer.

The field testing and demonstration of the APNA II and III analyzers in Monterey Bay: A second round of field testing that was recently completed within the matrix of the ONR LOCO "Thin Plankton Layers" experiment, is expected to provide some interesting results. At this time, we have only had the opportunity to examine a portion of the data that was collected during the recent 4-week field effort. A 10-day time series, comprised of ~240 hourly high-resolution vertical nutrient profiles, was obtained during the deployment of the APNA-II on the URI IOPC profiler in July 2006. The IOPC was programmed to turn on and off the APNA II, so it would acquire nutrient concentration data (1 reading per second) while the package ascended through the water column. The ascent rate was set at ~3 cm/sec in order to maximize the vertical resolution of the measurements. When the IOPC reached the surface after each profile, the nutrient data was transferred from the APNA's flash memory, via radio telemetry, to shipboard and land-based receiver stations.

Developing a nutrient sensing capability for AUVs and Gliders: The MARCHEM (single channel nutrient) analyzer was developed to provide an initial baseline capability to assess the critical integration paths for long duration missions on an AUV. One such AUV would be the SLOCOM

Glider which is being made available through partnering with SPAWAR. The information exchange with partners from SPAWAR (Arrieta, Granger, et al.) has led to further defining what would ultimately be the best integration path for a single channel analyzer on the Glider. SPAWAR was able to provide SubChem with a standard payload section as well as the Glider manual, mechanical drawings and photographs of the Glider itself and operations.

While the MARCHEM analyzer is smaller in size and functionality than the APNA analyzer, it still presents difficulty when trying to design for glider integration. The MARCHEM maintains a total system flow-rate of nearly 2 ml/min in addition to small reagent pumps. The MARCHEM also requires the use of reagent bags. Reagent bag size is proportional to mission duration. While the design suits the endurance of a REMUS100, the SLOCOM Glider is designed for a substantially longer endurance. Therefore, all fluidics must be further scaled to accommodate less reagent and power usage. The critical design path has now moved to a micro-fluidics system that ultimately yields a flow-rate as low as 0.1 ml/min. At this flow-rate, reagent consumption is more in line with SLOCOM Glider endurance when sampling for dissolved nitrate. The ability to maintain a total sample flow of 0.1 ml/min allows for scaling the fluidics system to sizes achievable in MEMS technology manifolds, a space efficient and low power option when considering analyzer to Glider integration. Shifting the integration path to a micro-fluidic based analyzer would allow for a design of an externally mounted UUV/Instrumentation package called ChemFIN™. This design will lessen the need for bulkhead penetrations on a host platform. It will also lessen the need for internal dry space real estate. In addition, one of the major potential impacts to the SLOCOM Glider is having a wet/dry interface for the purpose of bringing a sample flow for analysis into the dry hull of the glider. The goal of the ChemFIN™ is to lessen or eliminate that need.

IMPACT/APPLICATIONS

Economic Development

It is a critical gap that the oceanographic community does not currently have the capability to make routine and sustained nutrient measurements, *in situ* and autonomously, at the same space and time scales that are possible for temperature, salinity, oxygen, and chlorophyll fluorescence. In recent years, though, there has been significant progress in the development and application of reagent-based optical multi-nutrient sensors. The on-going research for this NOPP project is giving us the opportunity to further develop, improve and demonstrate these autonomous chemical profiling technologies. These efforts represent substantial advancements in the development of this technology and bring us much closer to a demonstrated capability for sustained, autonomous ocean observations of nutrient distributions and variability.

RELATED PROJECTS

A related project is the ONR sponsored Directed Research Initiative entitled "Layered Organization in the Coastal Ocean (LOCO)". The LOCO program is focused on developing an understanding of the dynamics of thin plankton layers in coastal waters. New nutrient monitoring technologies developed in this NOPP project were demonstrated and utilized within the LOCO field research during 2005 and 2006. PIs Hanson (SubChem) and Donaghay (URI) both have LOCO projects.

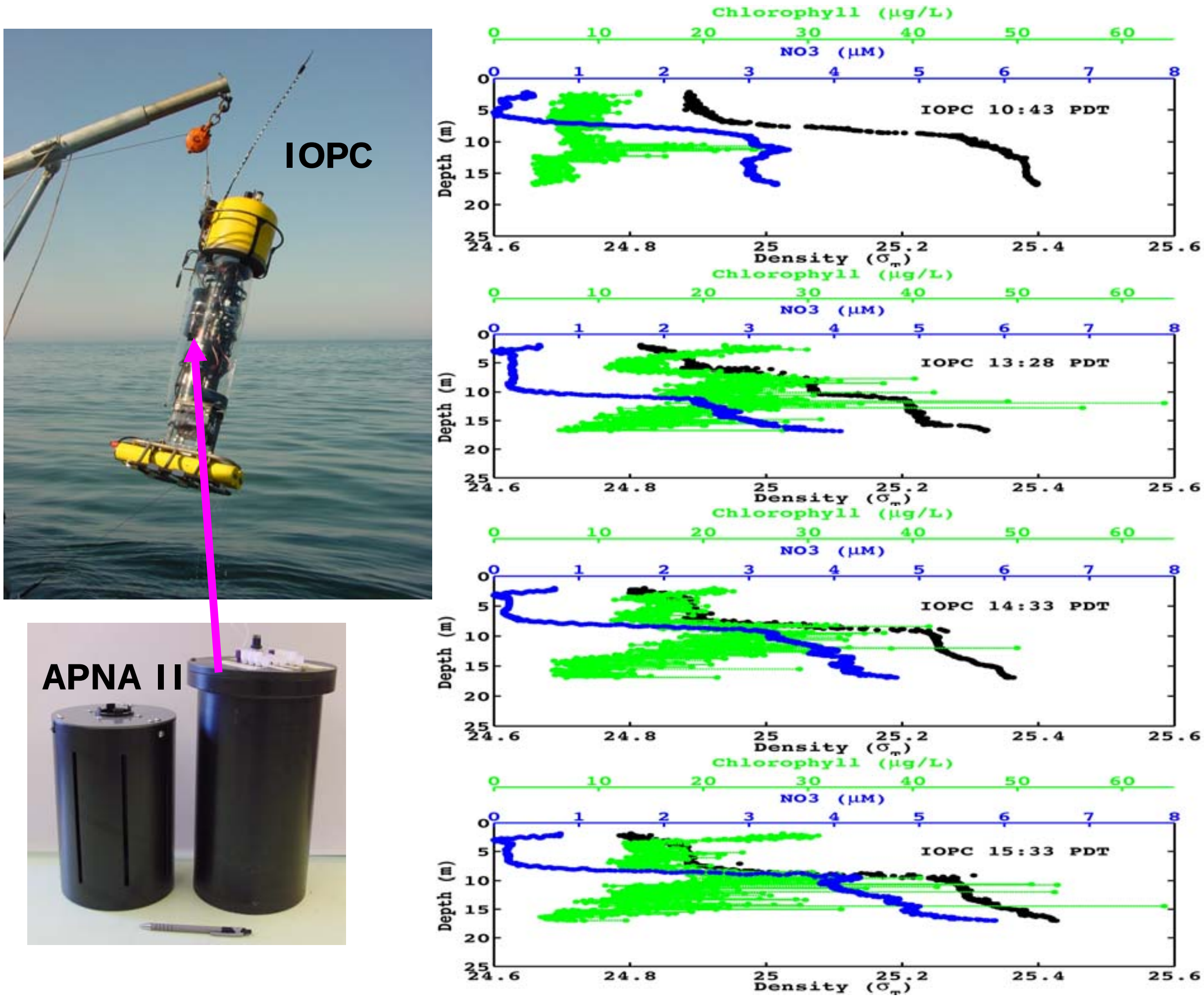

Figure 1. The IOPC profiler with the APNA II nutrient analyzer payload ready for deployment in Monterey Bay from the R/V Shana Rae and examples of hourly profiles for nitrate (blue), chlorophyll (green), and density(black) that were obtained autonomously with the system in Monterey Bay.

[The URI IOPC profiler is an autonomous, battery operated moored-profiler that may be deployed in the coastal ocean for weeks at a time. It contains a full suite of instruments and sensors for monitoring the physical, optical, biological and chemical properties of the water. The profiler can be programmed to make repeated profiles, from the bottom to the surface, on a pre-set time schedule, to send the multi-parametric results by radio telemetry to a shore- or ship-based receiver station, and then return to the bottom to wait for the time to start the next profile.]

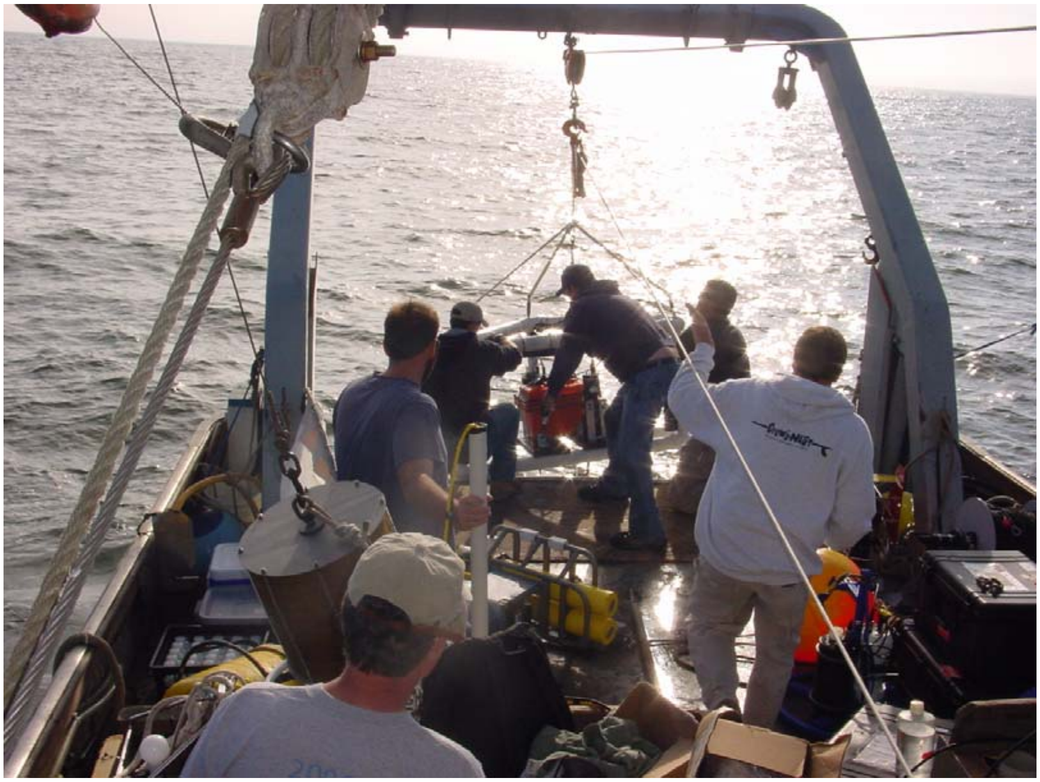

Figure 2. Scientists on the stern of the R/V Shana Rae recovering a battery-powered mooring that had been placed on the bottom in Monterey Bay for a 2 week time-period to test the performance of three different types of autonomous submersible chemical analyzers, including the APNA III.

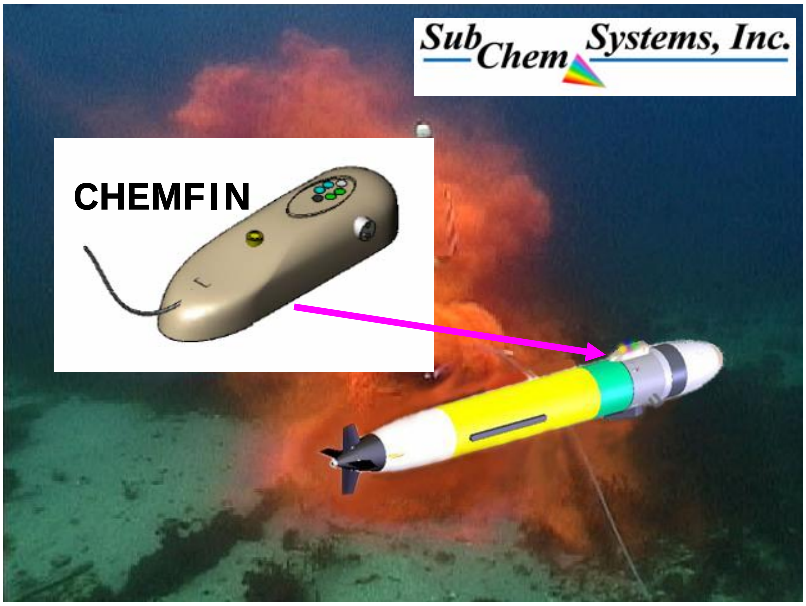

Figure 3. SubChem Systems's conceptual vision for ChemFIN^{TM} the next generation chemical sensing payload for AUVs and Gliders.
[The ChemFIN^{TM} would be an independent compact payload containing a micro-fluidic chemical analyzer that minimizes the power and space demands on the AUV platform.]