Project Number: 901513

Project Start: Jan. 1, 2015[1] **Project Duration (in years): 3** [1]

Please indicate if proposal includes requests for any of the following (mark all that apply).

[ ]	[ ]	[x]	[ ]	[ ]
Ship Time	**ROV**	**AUV**	**Wave Glider**	**Mini-ROV**

Please indicate what type of project is being proposed (mark only one).

[ ]	[ ]	[x]	[ ]	[ ]
Feasibility/Scoping [Less than 100 days effort]	**Development**[2]	**Research**	**Infrastructure**[2]	**Education**
	[ ]	[ ]		
	Time Series	**Institute Initiative**		

Project Manager[3]: Yanwu Zhang

Principal Investigator: Yanwu Zhang

Lead Scientists: James Bellingham
Francisco Chavez
Bruce Robison
John Ryan
Christopher Scholin
Robert Vrijenhoek

Project Title: Targeted Sampling by Autonomous Underwater Vehicles

[1] This date and number should remain the same for the duration of the project. If your project start date for 2015 is not January 1, please indicate the start date in the first cell of the milestone chart.
[2] Development and infrastructure projects must complete the risk matrix (see item #5 at the end of the proposal form).
[3] Not all projects will require all four titles to be filled in. Please indicate individuals only for those titles that are appropriate for your project.

1) ABSTRACT (new projects only)

Traditional ship-based methods for detecting and sampling dynamic ocean features, such as fronts, are often laborious and very difficult, and long-term tracking of such features is practically impossible. In this project, we utilize autonomous underwater vehicles (AUVs) and other autonomous platforms to achieve these goals via a method we call “targeted sampling”. We define this method as use of autonomous platforms to detect pre-specified oceanic features, and in turn adapt platform behavior to characterize the feature of interest by using on-board sensors and water sample acquisition systems. A targeted sampling capability allows researchers to direct a limited number of marine assets to specific regions of interest and collect desired measurements/samples absent a human presence. This work revolves around use of the Dorado gulper AUV and LRAUVs. Scientific insights into a variety of ocean processes are used to derive algorithms for carrying out a suite of targeted sampling activities while taking maximum advantage of the vehicles’ flexible behaviors and growing endurance.

This project is built upon a solid base of work we conducted in the past five years. The peak-capture in chlorophyll patches (Fig. 1) and detection and tracking of upwelling fronts (Fig. 2) exemplify progress made to date. The peak-capture algorithm has become a workhorse algorithm for the Dorado gulper AUV, and has been used repeatedly in CANON (Controlled, Agile, Novel Observing Network), ECOHAB (Ecology and Oceanography of Harmful Algal Blooms), and SIMZ (Sampling and Identifying Marine Zooplankton) experiments. Studies like these are likely to become increasingly common at MBARI in the future.

We propose to create a dedicated project that will meet that growing need for targeted sampling capability by forming a project team that combines the expertise of ocean scientists and engineers to tackle a suite of problems consistent with those outlined in the Technology Roadmap. To that end we aim to progress in the following directions: 1) multi-AUV collaboration for Lagrangian studies of plankton communities, 2) multi-AUV coordination for improved synoptic observation of ocean features, 3) plankton classification and long-range sensing, and 4) scientist-guided adaptation of AUV missions (see Section “**Approach to the problem**” for more details).

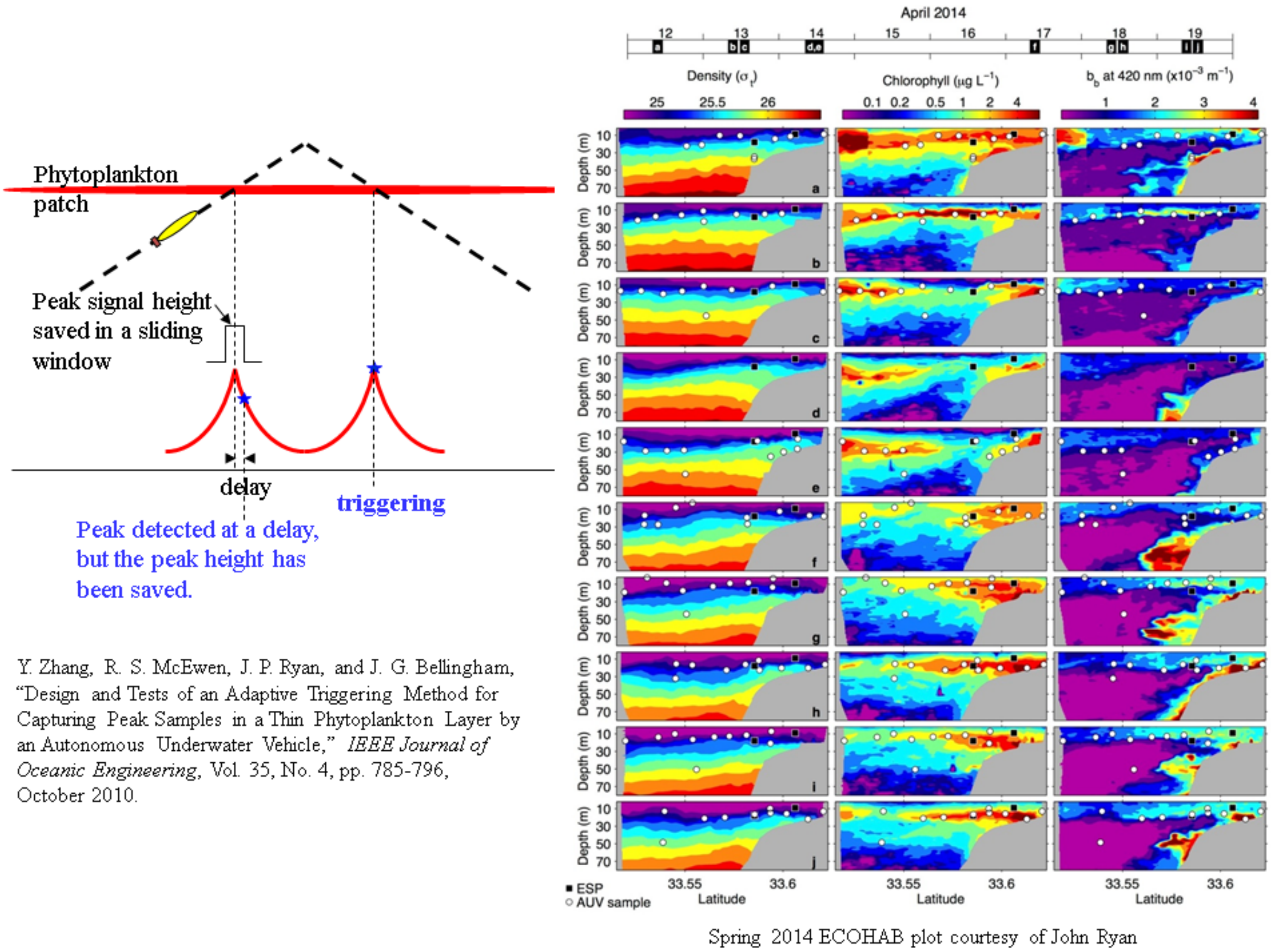

Fig. 1. Left panel: the principle of the chlorophyll peak-capture algorithm. Right panel: performance of the Dorado gulper AUV's peak-chlorophyll water sampling in the 2014 ECOHAB Experiment in San Pedro Bay. The gulpers' sampling locations are marked by the while circles (note that one control sample followed every 4 peak samples).

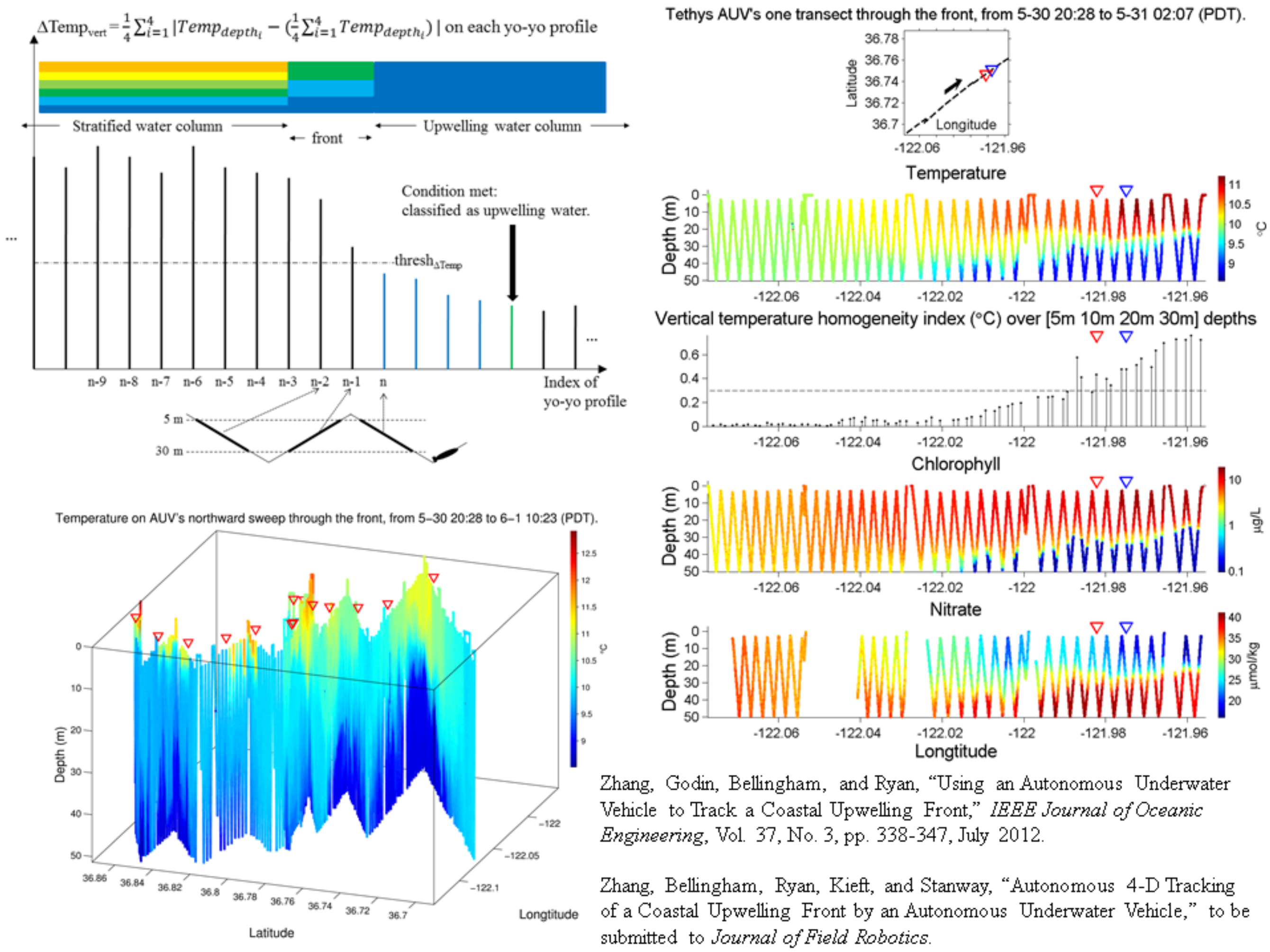

Fig. 2. Upper left panel: the principle of the autonomous upwelling-front detection algorithm. Right panel: one transect of the Tethys LRAUV during its 4-D front tracking mission in Monterey Bay in May/June 2013. Lower left panel: the AUV's temperature profiles on zigzag crossings of the upwelling front on a northward sweep.

2) PROPOSAL

a) <u>New Projects</u>

Statement of the problem, why it is important

We have vast oceans, but many important processes occur episodically in both space and time. We therefore need to develop methods to direct limited and precious resources to the most relevant and informative locations to reliably and repeatedly achieve observation and sampling at the right times. This is what we call targeted sampling --- quickly detecting particular ocean features and intensively sampling them as dictated by the science question at-hand. Targeted sampling greatly enhances the efficiency of ocean studies. As the old Chinese idiom goes, "Get twice the result with half the effort".

How does it relate/contribute to MBARI's mission and strategic plan?

MBARI's mission is to "achieve and maintain a position as a world center …, and to do so through the development of better instruments, systems, and methods for scientific research in the deep waters of the ocean." This project centers on development of targeted sampling methods for AUVs --- advanced robotic systems that carry a suite of navigational and scientific instruments. MBARI's mission "emphasizes the peer relationship between engineers and scientists as a basic principle of its operation." The successful development of the AUV's peak-capture algorithm and autonomous front tracking algorithm was an outcome of combining scientific understanding and AUV engineering expertise. Seamless scientist-engineer collaboration will continue to be the guiding principle of this project.

The MBARI Strategic Plan recognizes "Exploration and discovery", "Ocean Visualization", "Ecosystem dynamics", and "Ocean biogeochemistry" as the main research themes in this decade. Targeted sampling methods will help with advancements related to all of those themes. Our AUV algorithms for chlorophyll peak-capture and autonomous front tracking have already contributed to understanding ecosystem dynamics in Monterey Bay and San Petro Bay through the CANON and ECOHAB Experiments. The upwelling front tracking in Monterey Bay proved to be useful means for improving our understanding of ocean biogeochemistry across upwelling fronts. The Dorado gulper AUV runs the chlorophyll peak-capture algorithm to acquire water samples precisely from the center of phytoplankton layers, thus enabling an accurate "view" of plankton communities therein. Through this project, we will incorporate more acoustic and optical information in targeted sampling algorithm designs, so that AUVs can best utilize data classification schemes (visualization) to quickly find the target ocean processes under study and efficiently sample them. So doing, the targeted sampling techniques enhance our abilities for exploring the ocean.

How does it relate/contribute to the Packard Foundation's Ocean Visions Grantmaking policies?

This project supports the Packard Foundation's Ocean Visions goal of "Enhanced scientific understanding of the functioning of marine ecosystems". We enable AUVs to autonomously detect ecologically important ocean processes, track their temporal and spatial variations, so as to reveal the functioning of the complex marine ecosystems. Enhanced understanding of the marine ecosystems is a key step toward "protection and restoration of ecosystems" (a 2011-2020 focus of the Packard Foundation's Ocean Visions).

Does it relate to the Technology Roadmap? If so, please describe how.

Under the four research themes articulated in the MBARI Strategic Plan (see above), MBARI's Technology Roadmap outlined three engineering initiatives: 1) Taking the laboratory into the ocean, 2) Enabling targeted sampling, 3) Advancing a persistent presence. This project, by way of its title and plans, literally falls in Initiative 2. It is worth noting, however, that this project is also closely related to the other two initiatives. One of the focuses of this project is to design targeted sampling methods for the Makai-class LRAUVs, each of which carries a 3rd generation Environmental Sample Processor (3G-ESP). ESPs are robotic molecular analytical sensors. ESP-enabled AUVs are one step towards taking the laboratory into the ocean (Initiative 1), and are further realizing Mr. Packard's vision of "sending instruments to sea, not people; returning information to shore, not samples." We have enabled the Tethys LRAUV to autonomously track an upwelling front over five and one-half days. This work is an example of Initiative 3, advancing a persistent presence, but in this case a persistent presence locked on a dynamic ocean feature that varies over space and time.

Approach to the problem

The approaches of this project are illustratively outlined in Fig. 3.

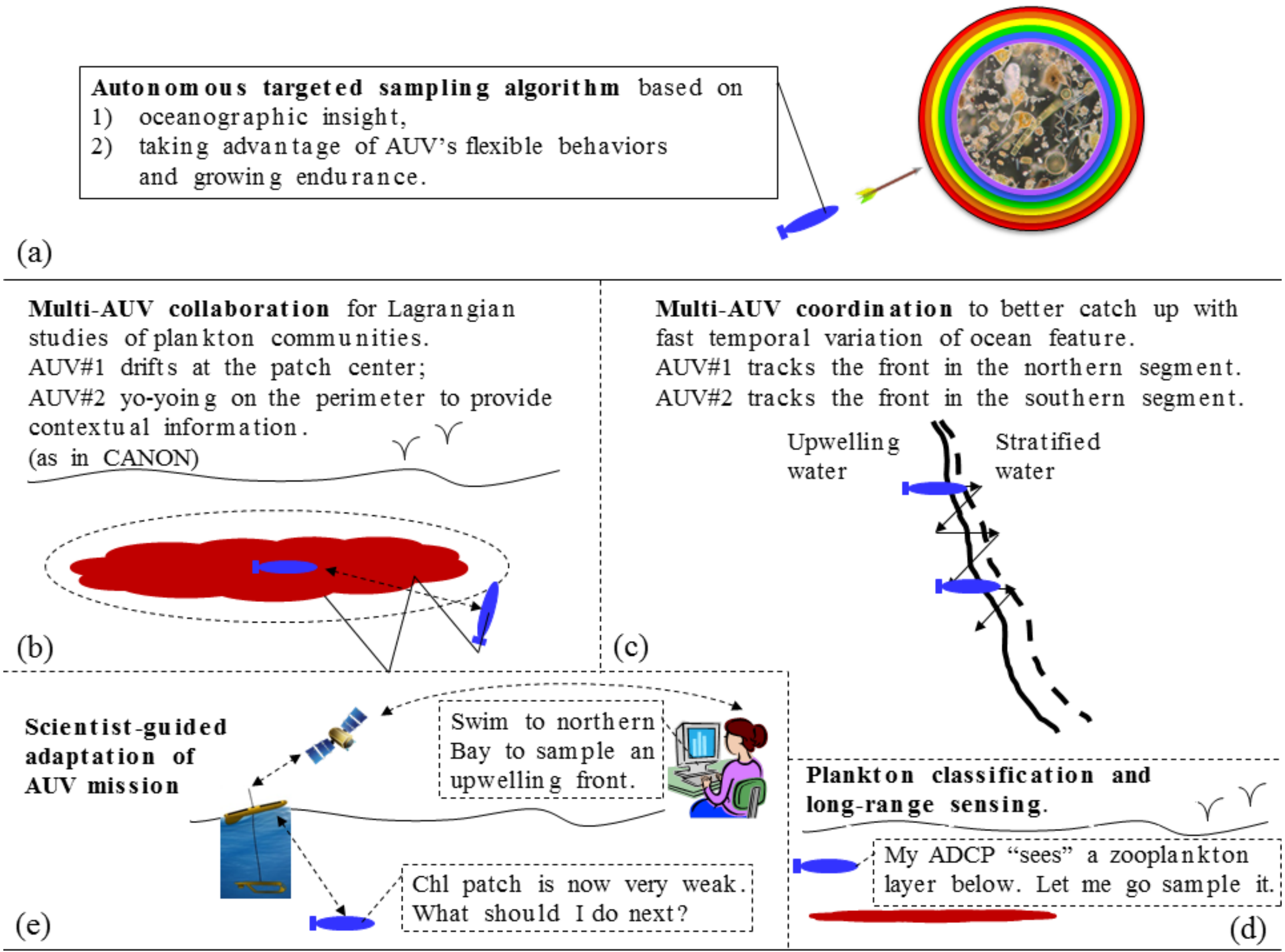

Fig. 3. Approaches of the project. (a) The design principles. (b)-(e) Research directions.

(a) The design principles of targeted sampling methods are
1) Oceanographic insight.
2) Taking advantage of AUV's flexible behaviors and growing endurance.
The derivation of the "vertical temperature homogeneity index (VTHI)", the key metric for an AUV to autonomously distinguish between upwelling water columns and stratified water columns (see Fig. 2),

exemplifies this strategy. Oceanographic insight pointed to the vertical temperature structure as the distinct feature for classifying these two types of water columns. Based on this insight and in consideration of the AUV's behaviors, we established the VTHI metric that best suits real-time calculation on each AUV yo-yo profile. In this project, we aim at progressing in the following directions:

(b) Multi-AUV collaboration for Lagrangian studies of plankton communities (see Fig. 3 (b)).
To track and observe a plankton community over time, we task one AUV to stay near the center of the plankton patch, and another to survey the perimeter of the patch to provide contextual information (this capability will be tested during the 2014 Fall CANON Experiment). Acoustic tracking and communications are required for vehicle collaboration. Team members Stanway, Kieft, and Hobson have demonstrated acoustic homing of an LRAUV to a Wave Glider, which laid important groundwork for the planned collaborative multi-AUV missions.

(c) Multi-AUV coordination for improved synoptic observation of ocean features (see Fig. 3 (c)).
During the autonomous 4-D front tracking experiment in 2013 (see Fig. 2), it took one LRAUV (Tethys) more than two days to complete one cycle of northward and southward sweeps (between 36.7ºN and 36.88ºN). The upwelling front's movement over two days was significant. Finer scale temporal and spatial resolution can be achieved by deploying two AUVs (each covering one segment of a long front) to halve the sweep cycle, so as to generate a more synoptic view of the front.

(d) Plankton classification and long-range sensing (see Fig. 3 (d)).
A next-level task is to enable an AUV to classify different groups of plankton in real time, and then adapt vehicle/sampler behavior to sample the targeted group. For example, the ratio of fluorescence to backscatter can be used to distinguish between diatoms and dinoflagellates, which has shown promise from AUV data postprocessing led by two of the lead scientists (Bellingham and Chavez). Incorporation of more sensory information (e.g., the Dorado gulper AUV's LISST-100 particle-size spectrum and LISST-Holo image data) into the algorithms will improve the capacity and accuracy of targeted sampling. For long-range sensing of zooplankton patches, the Dorado gulper AUV and the LRAUVs can utilize their ADCP's echo intensity (i.e., RSSI) signal.

(e) Scientist-guided adaptation of AUV missions (see Fig. 3 (e)).
AUV autonomy is premised on prior knowledge of the targeted ocean process, and the vehicles' deployment plan is based on atmospheric and oceanic conditions. When ocean conditions change beyond expectations, the AUV will need human guidance for adapting its mission. For example, an AUV may initially be tasked with sampling a subsurface chlorophyll patch. If the patch then disperses and weakens, an on-shore scientist can redirect the vehicle to find and sample a different ocean process as desired.

(f) Oceanography-inspired key information extraction (see Fig. 4).
Due to the limited bandwidth of inter-vehicle underwater acoustic communications and vehicle-to-shore satellite communications, an AUV needs to extract key information from the raw measurements and transmit it to other nearby platforms or to shore. Data decimation and statistics-based data reduction are very helpful, but due to the high sampling rates of AUV sensors, reduced data streams can still overwhelm communication channels. To address this problem, we devised methods to extract the key

signals that result in a very succinct, yet very informative data product for a scientist to evaluate in relation to their overall objective or goal. One example is the vertical temperature homogeneity index (VTHI) for upwelling front detection. On each yo-yo profile, the AUV calculates the VTHI by temperature measured at a few (e.g., four) depths (see Fig. 4 for the simple formula). Thus, on each yo-yo profile, hundreds of temperature data points are distilled to one single value, the VTHI, which is then used by the AUV to make its autonomous front-detection decision, and/or transmitted to shore for review by a scientist. Another example is the LRAUV's real-time extraction of the maximum chlorophyll fluorescence value (and the corresponding depth) measured on each yo-yo profile, used for tracking a phytoplankton patch. On each yo-yo profile, hundreds of chlorophyll data points are distilled to two values --- the maximum chlorophyll and the corresponding depth. The LRAUV not only uses this distilled information for autonomous patch tracking, but also transmits this very succinct information to shore for display on the graphical user interface (GUI).

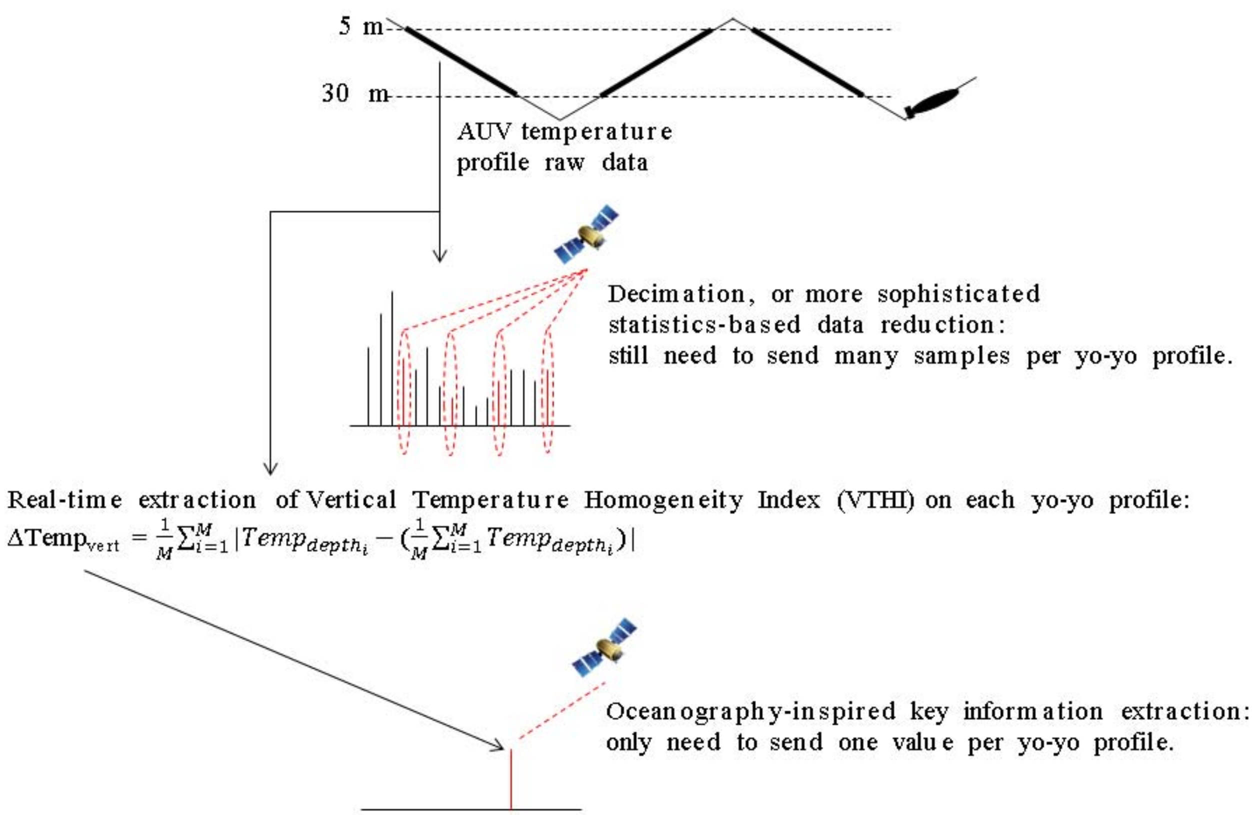

Fig. 4. Comparison between data decimation (or statistics-based data reduction) and oceanography-inspired key information extraction.

Publications (from other projects over the last 5 years)

1. M. J. Stanway, B. Kieft, T. Hoover, B. Hobson, A. Hamilton, and J. G. Bellingham, “Acoustic Tracking and Homing with a LRAUV,” to appear in *Proc. MTS/IEEE Oceans'14*, St. Johns, Canada, September 2014.
2. J.P. Ryan, J. B. J. Harvey, Y. Zhang, and C. B. Woodson, "Distributions of invertebrate larvae and phytoplankton in a coastal upwelling system retention zone and peripheral front," *Journal of Experimental Marine Biology and Ecology*, Vol. 459, pp. 51-60, 2014.
3. J.P. Ryan, M.A. McManus, R.M. Kudela, M. Lara Artigas, J.G. Bellingham, F.P. Chavez, G. Doucette, D. Foley, M. Godin, J.B.J. Harvey, R. Marin III, M. Messie, C. Mikulski, T. Pennington, F. Py, K. Rajan, I. Shulman, Z. Wang, and Y. Zhang, "Boundary influences on HAB phytoplankton ecology in a stratification-enhanced upwelling shadow," *Deep Sea Research II*, Vol. 101, pp. 63-79, 2014.
4. Y. Zhang, J. G. Bellingham, J. P. Ryan, B. Kieft, and M. J. Stanway, "Two-Dimensional Mapping and Tracking of a Coastal Upwelling Front by an Autonomous Underwater Vehicle," *Proc. MTS/IEEE Oceans'13*, pp. 1-4, San Diego, CA, U.S.A., September 2013.
5. D. Thompson, D. Caress, D. Clague, D. Conlin, J. Harvey, E. Martin, J. Paduan, C. Paull, J. Ryan, H. Thomas, and Y. Zhang, "MBARI Dorado AUV's Scientific Results," *Proc. MTS/IEEE Oceans'13*, pp. 1-9, San Diego, CA, U.S.A., September 2013.
6. Y. Zhang, "Adaptive Ocean Observation," *Advances in Earth Sciences* (Chinese journal with English abstracts), Vol. 28, No. 5, pp. 537-541, May 2013.
7. Y. Zhang, J. P. Ryan, J. G. Bellingham, J. B. J. Harvey, and R. S. McEwen, "Autonomous detection and sampling of water types and fronts in a coastal upwelling system by an autonomous underwater vehicle," *Limnology and Oceanography: Methods*, Vol. 10, pp. 934-951, 2012.
8. J. B. J. Harvey, J. P. Ryan, R. Marin III, C. M. Preston, N. Alvarado, C. A. Scholin and R. C. Vrijenhoek, “Robotic sampling, in situ monitoring and molecular detection of marine zooplankton,” *Journal of Experimental Molecular Biology and Ecology*, Vol. 413, pp. 60-70, 2012.
9. B. Hobson, J. G. Bellingham, B. Kieft, R. McEwen, M. Godin, and Y. Zhang, "Tethys-Class Long Range AUVs - Extending the Endurance of Propeller-Driven Cruising AUVs from Days to Weeks," *Proc. IEEE AUV'2012*, pp. 1-8, Southampton, U.K., September 2012.
10. J. Harvey, Y. Zhang, and J. P. Ryan, "AUVs for Ecological Studies of Marine Plankton Communities - Intelligent Algorithms on Dorado and Tethys AUVs Enable Precise Water Sampling for Plankton Research," *Sea Technology*, Vol. 53, No. 9, pp. 51-54, September 2012.
11. Y. Zhang, M. A. Godin, J. G. Bellingham, and J. P. Ryan, "Using an Autonomous Underwater Vehicle to Track a Coastal Upwelling Front," *IEEE Journal of Oceanic Engineering*, Vol. 37, No. 3, pp. 338-347, July 2012.
12. Y. Zhang, J. G. Bellingham, M. A. Godin, and J. P. Ryan, "Using an Autonomous Underwater Vehicle to Track the Thermocline Based on Peak-Gradient Detection," *IEEE Journal of Oceanic Engineering*, Vol. 37, No. 3, pp. 544-553, July 2012.
13. Y. Zhang, J. P. Ryan, J. G. Bellingham, J. Harvey, R. McEwen, F. Chavez, and C. Scholin, "Classification of Water Masses and Targeted Sampling of Ocean Plankton Populations by an Autonomous Underwater Vehicle," *AGU 2011 Fall Meeting Abstract OS21A-1609*, San Francisco, CA, U.S.A., December 2011.

14. Y. Zhang, M. Godin, J. G. Bellingham, and J. P. Ryan, "Ocean Front Detection and Tracking by an Autonomous Underwater Vehicle," *Proc. MTS/IEEE Oceans'11*, pp. 1-4, Kona, HI, U.S.A., September 2011.
15. M. Godin, Y. Zhang, J. P. Ryan, T. Hoover, and J. G. Bellingham, "Phytoplankton Bloom Patch Center Localization by the Tethys Autonomous Underwater Vehicle," *Proc. MTS/IEEE Oceans'11*, pp. 1-6, Kona, HI, U.S.A., September 2011.
16. F. Cazenave, Y. Zhang, E. McPhee-Shaw, J. G. Bellingham, T. P. Stanton, "High-resolution surveys of internal tidal waves in Monterey Bay, California, using an autonomous underwater vehicle," *Limnology and Oceanography: Methods*, Vol. 9, pp. 571-581, 2011.
17. Y. Zhang, R. S. McEwen, J. P. Ryan, J. G. Bellingham, H. Thomas, C. H. Thompson, and E. Rienecker, "A Peak-Capture Algorithm Used on an Autonomous Underwater Vehicle in the 2010 Gulf of Mexico Oil Spill Response Scientific Survey," *Journal of Field Robotics*, Vol. 28, No. 4, pp. 484-496, July/August 2011.
18. J. P. Ryan, A. M. Fischer, R. M. Kudela, M. A. McManus, J. S. Myers, J. D. Paduan, C. M. Ruhsam, C. B. Woodson, and Y. Zhang, "Recurrent frontal slicks of a coastal ocean upwelling shadow," *Journal of Geophysical Research (Oceans)*, 115, C12070, December 2010.
19. J. G. Bellingham, Y. Zhang, J. E. Kerwin, J. Erikson, B. Hobson, B. Kieft, M. Godin, R. McEwen, T. Hoover, J. Paul, A. Hamilton, J. Franklin, and A. Banka, "Efficient Propulsion for the Tethys Long-Range Autonomous Underwater Vehicle," *Proc. IEEE AUV'2010*, pp. 1-6, Monterey, CA, U.S.A., September 2010.
20. J. P. Ryan, S. B. Johnson, A. Sherman, K. Rajan, F. Py, H. Thomas, J. B. J. Harvey, L. Bird, J. D. Paduan and R. C. Vrijenhoek, "Mobile autonomous process sampling within coastal ocean observing systems," *Limnology and Oceanography: Methods*, Vol. 8, pp. 394-402, 2010.
21. Y. Zhang, R. S. McEwen, J. P. Ryan, and J. G. Bellingham, "Design and Tests of an Adaptive Triggering Method for Capturing Peak Samples in a Thin Phytoplankton Layer by an Autonomous Underwater Vehicle," *IEEE Journal of Oceanic Engineering*, Vol. 35, No. 4, pp. 785-796, October 2010.
22. Y. Zhang, J. G. Bellingham, and Y. Chao, "Error Analysis and Sampling Strategy Design for Using Fixed or Mobile Platforms to Estimate Ocean Flux," *Journal of Atmospheric and Oceanic Technology*, Vol. 27, No. 3, pp. 481-506, March 2010.

b) <u>Continuing Projects</u>

N/A

c) <u>New and Continuing Projects: Plans for 2015</u>

Research Activities

Past and future targeted sampling research activities are outlined in Fig. 5 (green: completed; red: to be conducted). 2015 research will focus on the circled bullets.

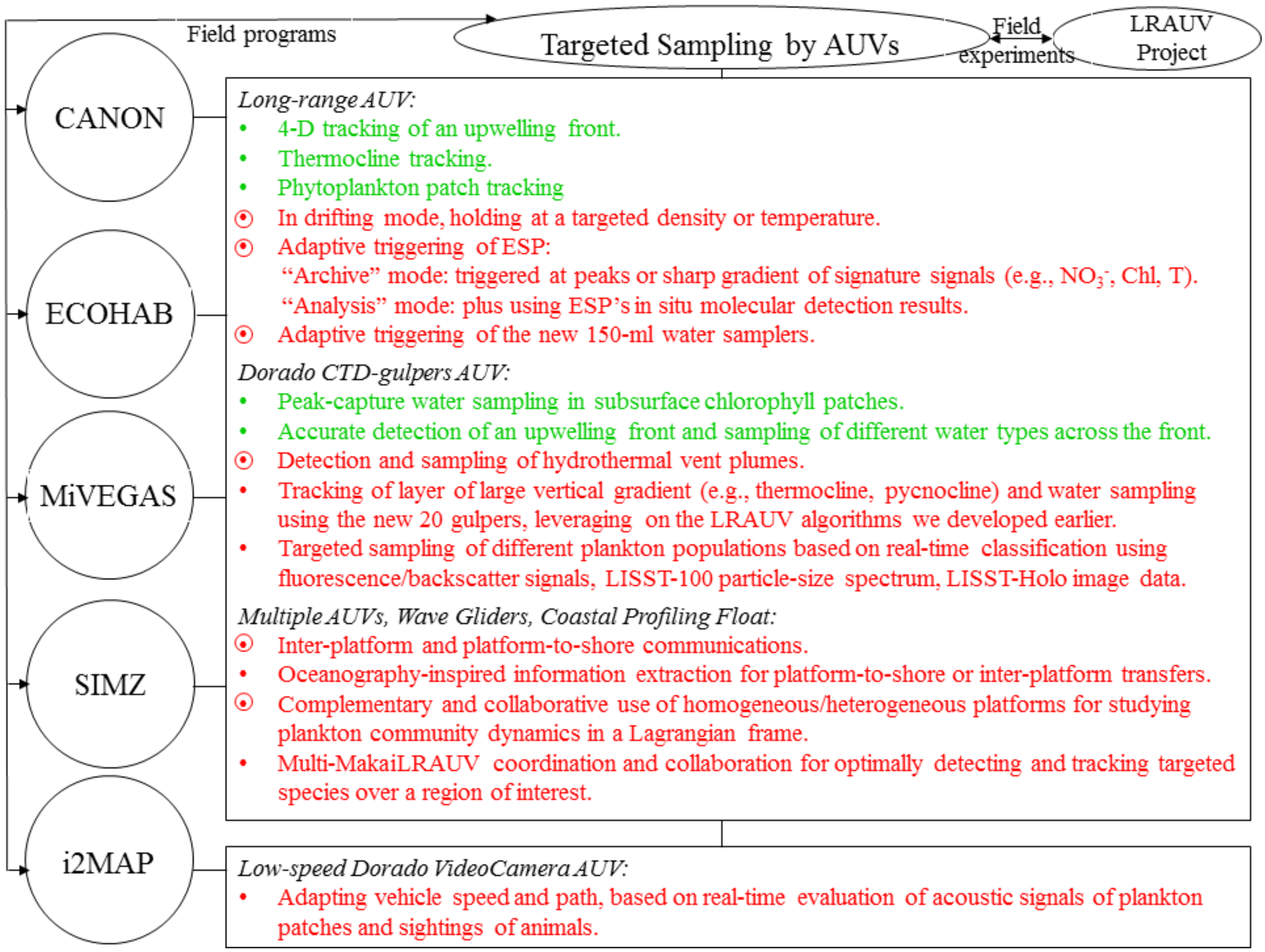

Fig. 5. Targeted sampling research activities as related to other projects.

Engineering/technology development

Please refer to Fig. 5 for the engineering development items. Additional notes on three items are as follows:

1) Targeted sampling design for the 3G-ESP on the Makai LRAUV.
This work will start from the ESP's "archive" mode, i.e., when the ESP collects and preserves water samples but does not conduct in situ molecular analysis. For moored 2G-ESPs, team members Preston, Roman, and Ryan have devised adaptive sampling schemes to trigger water sampling when contextual measurements meet particular conditions (e.g., when nitrate reaches or exceeds a certain high level).

Such adaptive sampling schemes have been used on shallow-water and deep-water ESPs. On shore, we were able to monitor the impinging of an upwelling front on the ESP mooring based on the falling rate of near-real-time mooring temperature data, and quickly inform the chief scientist (Ryan) for adjusting the ESP sampling plan during the Spring 2013 ECOHAB Experiment in San Pedro Bay.

With the 3G-ESP on an AUV, contextual measurements are no longer confined to a fixed location. This opens up many opportunities for further developing ESP targeted sampling. For example, the AUV can trigger water collection when detecting an upwelling front or the water types on either side of the front. Since the 3G-ESP water filtration can take tens of minutes to an hour to complete, the Makai LRAUV needs to stay within the targeted water mass, coordinating its behavior with ESP sample collection requirements.

2) Detection and sampling of hydrothermal vent plumes by the Dorado gulper AUV.
We have enabled the Dorado gulper AUV to trigger water sampling at peaks of optical backscatter signal in intermediate nepheloid layers (INLs). Hydrothermal vent plumes contain high levels of suspended particulate materials, thus high backscatter signals are also expected when an AUV flies through them. When a hydrothermal vent plume rises up to some neutrally buoyant height, it spreads laterally and forms a layer of high backscatter signal, much like an INL. Using previous hydrothermal vent plume data provided by Dr. David Clague, we will adapt the INL peak-capture algorithm for autonomous detection and sampling of hydrothermal vent plume waters.

3) Targeted sampling work on Project i2MAP (Mid-water autonomous platform)
As the i2MAP Dorado AUV and its imaging system mature, we anticipate a need for increasingly complex vehicle behaviors that will evolve from simple transecting to organism centric tracking. For 2015, we will work to understand use case scenarios for the i2MAP-type AUV, and derive requirements for meeting science objectives as projected by Robison et al.

Field programs (detail ship requirements/deployments/diver requirements)

We request 20 days of LRAUV time to conduct the following field tests:
- 3G-ESP targeted sampling (on a single Makai LRAUV).
- Targeted sampling using the CANON 150-ml water samplers (on a single LRAUV).
- Targeted sampling by multi-vehicle coordination and collaboration (2 to 3 LRAUVs).

The requested 20-day LRAUV time (and the corresponding R/V Paragon ship time) will be allocated from Project 901400 (LRAUV: Coordinated Observations of Marine Organisms and Ocean Features) led by Hobson, and please cross-reference to that proposal.

This project does not make separate requests of Dorado gulper AUV time and the corresponding ship time; those requests are covered under other projects and associated field programs (see below).

The methods outlined above will be used in the following field programs:

- Spring 2015 field experiments of the 3G-ESP Makai LRAUVs.

- April 2015 Gulf of California expedition (Vrijenhoek leg, using the Dorado gulper AUV for detection and sampling of hydrothermal vent plumes).
- Spring CANON/ECOHAB Experiment in Monterey Bay, using the LRAUVs and the Dorado gulper AUV.
- Fall CANON/ECOHAB Experiment in Monterey Bay, using the LRAUVs and the Dorado gulper AUV.

Specific deliverables

1. Targeted sampling methods and computer code on the Dorado and LRAUVs successfully used in field programs.
2. Methods and field results resulting in conference presentations and publications in high-rank peer-reviewed journals.

Milestones (see personnel classification list)

2015 Project Start Date: MM/DD/2015	**Milestone 1**	**Milestone 2**	**Milestone 3**	**Milestone 4**	
Milestone Date	**3/31**	**6/30**	**9/30**	**12/31**	
Milestone Description	**1. Preliminary design of adaptive triggering of 3G-ESP on Makai AUV. 2. Design of hydrothermal vent plume detection and sampling by Dorado gulper AUV to be used in the April Gulf of California expedition (Vrijenhoek leg).**	**1. Summer CANON/ECOHAB Experiments. Adaptive triggering of 150-ml water samplers. 2. Improved design of adaptive triggering of 3G-ESP on Makai AUV, based on spring experiment results.**	**1. Design and field tests of targeted sampling by multi-AUV collaborations. 2. Targeted sampling of different plankton populations.**	**1. Analysis of field data to evaluate targeted sampling performance, and devising improvements to algorithms. 2. Publications.**	**Total Resources**[4] for each resource category for all milestones listed here
EE					
SE	**20 hrs (Roman) 20 hrs (McEwen) 40 hrs (Kieft) 40 hrs (Stanway)**	**20 hrs (Roman) 40 hrs (Kieft) 40 hrs (Stanway)**	**20 hrs (McEwen) 20 hrs (Kieft) 60 hrs (Stanway)**	**20 hrs (Roman) 20 hrs (McEwen) 20 hrs (Kieft) 20 hrs (Stanway)**	**60 hrs 60 hrs 120 hrs 160 hrs** } 400 hrs
ME	**5 hrs (Hobson)**	**5 hrs (Hobson)**	**5 hrs (Hobson)**	**5 hrs (Hobson)**	**20 hrs**
EE Tech					

[4] This number should be the same number you entered on the resource requests for this particular resource.

SE Tech					
ME Tech					
Machine Shop					
Divers					

Budget justification

MATLAB license renewal fee: $500
Attending Oceans'15 Conference: travel & lodging $2200 + registration fee $500 = $2700

Project team

Yanwu Zhang: Project lead. Designing targeted sampling methods; coding core algorithms into the LRAUV and Dorado gulper AUV software; field experiment design and data analysis.
James Bellingham: Targeted sampling using advanced optical and acoustic signals. Sampling strategy design to achieve scientific goals.
Francisco Chavez: Lead scientist of CANON.
Bruce Robison: Lead scientist of i2MAP.
John Ryan: Lead scientist of ECOHAB/CANON.
Chris Scholin: Lead scientist of MiVEGAS.
Robert Vrijenhoek: Lead scientist of SIMZ.
Julio Harvey: SIMZ experiment design; processing and analysis of water samples; Participating in design of Doroda gulper AUV targeted sampling methods.
Christina Preston and *Brent Roman*: 3G-ESP targeted sampling software development.
Brian Kieft and *Jordan Stanway*: Instrumentation and software development for inter-platform (and platform-to-shore) communications and multi-AUV collaborations.
Brett Hobson: Guiding instrumentation and field tests of LRAUVs.
Robert McEwen: Instructing software development for the Dorado gulper AUV.

Time requests/allocations on each team member are as follows:

Yanwu Zhang:
- 960 hrs on CANON, simultaneously for ECOHAB and MiVEGAS.
- 320 hrs on SIMZ
- 320 hrs on targeted sampling design and tests on LRAUVs (related to Hobson's LRAUV project 901400)
- 80 hrs on i2MAP

Total = 1680 hrs for this proposal.
(Outside of this proposal, Zhang is expected to spend 160 hrs on Ryan's PASFER proposal 901502. Grand total will be 1840 hrs.)

Stanway (160 hrs), Kieft (120 hrs), Roman (60 hrs), McEwen (60 hrs), Hobson (20 hrs):
See "Milestones" Table above.

Time of Bellingham, Chavez, Robison, Ryan, Scholin, Vrijenhoek, Harvey, and Preston spent on this project will be covered by their respective main projects. This proposal does not make separate time requests on them.

Project lab space

No lab space requested. Instrument installations on Dorado and LRAUVs will use the respective AUV lab space.

Data availability outside project team, uniqueness

Field experiment data will be accessible through ODSS (Oceanographic Decision Support System) and STOQS (Spatial Temporal Oceanographic Query System).

Export Regulation
Does the project team anticipate any foreign collaborations or international travel?

No foreign collaboration.

Travels for international conferences or lab visits possible, but on conditions of 1) The conferences or lab visits are very beneficial for MBARI research and is of high academic caliber, 2) Attending as an invited speaker and the host will cover travel expenses. In 2014 Zhang gave invited talks at the 1st Xiamen Symposium on Environmental Sciences, City University of Hong Kong State Key Lab of Marine Pollution, and Nanjing University Lab of Ecological Toxicology and Environmental Health. Expenses for those trips were covered by the Chinese hosts (similar visits to Norway and Portugal in previous years). International travel for continued academic exchanges is possible in 2015.

No plan to export controlled purchases, shipments, or transfers of items (e.g., research instruments, proprietary data, hand-carried tools or samples) outside the U.S. either temporarily or permanently.

Monterey Bay National Marine Sanctuary SESAs (General map)
Projects will need to indicate whether or not work will be conducted within one of the Monterey Bay National Marine Sanctuary's Ecologically Significant Areas (SESAs).

Not expected since the proposed work is in the water column only. See MiVEGAS, CANON, ECOHAB, SIMZ, and i2MAP projects for additional information.