Project Number: 901112

Project Start: Jan1, 2016[1] **Project Duration (in years):** **Year 2 of 5**[1]

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

x		x	x	
Ship Time	**ROV**	**AUV**	**Wave Glider**	**Mini ROV**

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

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

Project Manager[3]: Tim Pennington
Principal Investigator: Francisco Chavez
Lead Engineer: Brent Jones

Project Title:

The Monterey Bay Time Series (MBTS), 2016-2020

[1] This date and number should remain the same for the duration of the project. If your project start date for 2016 is not January 1, please indicate the start date in the first cell of the milestone chart. Format for duration example: “Year 2 of 5”.
[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)

--- Not requested ---

2) PROPOSAL

b) Continuing Project (Year 2 of 5)

Current MBTS status and results to date

Overview and goals

Since 1989 the MBTS has collected time series data with ships and, increasingly, autonomous platforms including moorings, AUVs, gliders, satellites and models. In addition to tracking environmental change through time, the MBTS provides a contextual setting and data and infrastructure that support new ideas and process studies which use Monterey Bay as a natural laboratory for sensor and platform development.

For 2017 we continue with two overarching goals:

(1) Maintain the glider, mooring and ship-based observations, as dramatic new climate variations (see 'State of Monterey Bay', below) are playing out in the North Pacific --- forcefully and unpredictably. It is critical that these phenomena and their linkages be fully documented.

(2) Continue to automate the time series. The MBTS must be automated. Our roles and activities in CANON, MBON and the MBTS continue to push such development efforts forward. In CANON, engineers are learning to deploy their platforms in an operational environment and scientists are learning how to use them. In MBON, genetic techniques are being developed to survey plankton diversity. And in the MBTS we use these and our own developments to automate the time series.

Here we request 2nd year support for 901112, 2016-2020, to begin 1 Jan 2017; this project has under earlier proposals been underway since 1989. Below we (1) summarize the state of Monterey Bay oceanography, (2) update the MBTS automation plan, (3) summarize MBTS results for 2015-2016, (4) outline synergies with other projects, and (5) detail work proposed for 2017. Some of the work is supported by other proposals but all is founded on MBTS core data. As part of the autonomous MBTS, for 2017 we propose to build dedicated MBTS LRAUVs.

Oceanographic state of Monterey Bay

In fall 2013 a new and poorly understood phenomenon entered Monterey Bay. In association with the California drought, surface waters across the north Pacific warmed, producing a basin-scale layer of warm surface water now known as northeast Pacific 'Blob'. During 2013, 2014 and 2015, this warm and nearly oligotrophic Blob water pushed into outer Monterey Bay, compressing the productive upwelling habitat to shore and leaving narrow, nearshore refugia for blooming phytoplankton, large schools of forage fish, and their predators. As a dramatic consequence, feeding humpback whales were visible near-continuously from MBARI's Building A (Figure 1A), apparently targeting deep daytime schools of anchovies over the head of the Monterey Submarine Canyon (Figure 1B).

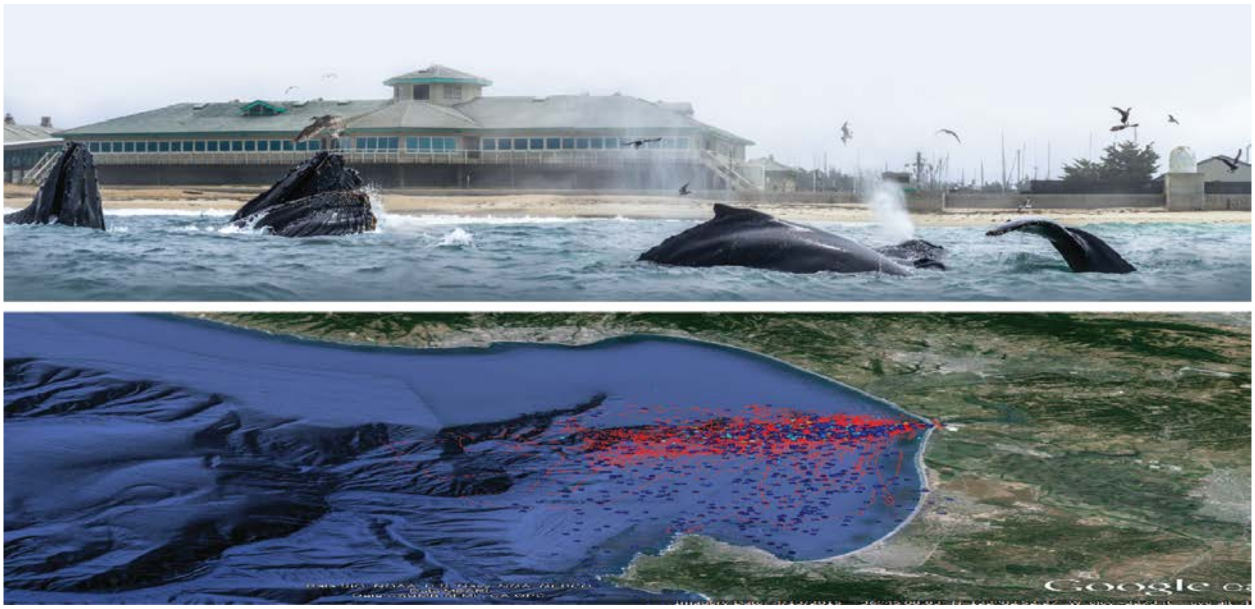

Figure 1. Humpback Hotspot: (Top) Whales at MBARI. During 2013, 2014 and 2015, whales were a near-daily sight from Building A (Photo, A.Gonzales); **(Bottom)** feeding humpbacks congregated over the head of the Monterey Submarine Canyon during these years (red lines, Fastraft tracks; blue dots, Monterey Bay Whale Watch sightings; see Pennington *et al*., http://www.mbari.org/wp-content/uploads/2016/01/CalCOFI-Whale-poster.pdf).

Also in 2015-2016, 'the Godzilla' of all El Niño's formed on the equator and was the subject of many seminars, a full conference, and any number of news stories --- Will Godzilla end the drought, will it knock out the Blob, and are they the one-two punch of Global Warming? As always, hindsight tells. It turns out that a newly-recognized form of El Niño --- El Niño Modoki --- has been increasing in frequency over the past two decades, and the 2015-2016 El Niño turned out not to be Godzilla, but Modoki. Under El Niño Modoki, the western and central equatorial Pacific *did* warm dramatically, but the warming failed to penetrate east of the Galapagos to Peru, and so was unable to reflect off the continents and propagate up the coast to California. Our 2015-2016 El Nino winter was thus muted due to this lack of a strong ocean connection. And instead of Godzilla, we had a mostly normal storm season that did, at least, partly ease California's drought. And now in spring 2016 --- even though El Nño lingered with unseasonable southerly winds and a warm ocean complete with red crabs (Figure 2, bottom) --- whales were rarely spotted from MBARI's Building A. And a new chapter is about to be written with La Niña appearing and likely returning drought to California.

These events and their consequences have been documented by MBTS and CANON cruises and platforms, and we, along with the rest of the oceanographic community, are still working out their relationships. In 2015 the Blob dominated Monterey Bay late until fall when El Nino took over. While relationships between these phenomena remain uncertain, both brought warm, low nutrient and phytoplankton biomass and production conditions to station M1 (Figures 2 and 3). In the MBTS we have been focused on primary production at the base of the Monterey Bay's food chain.

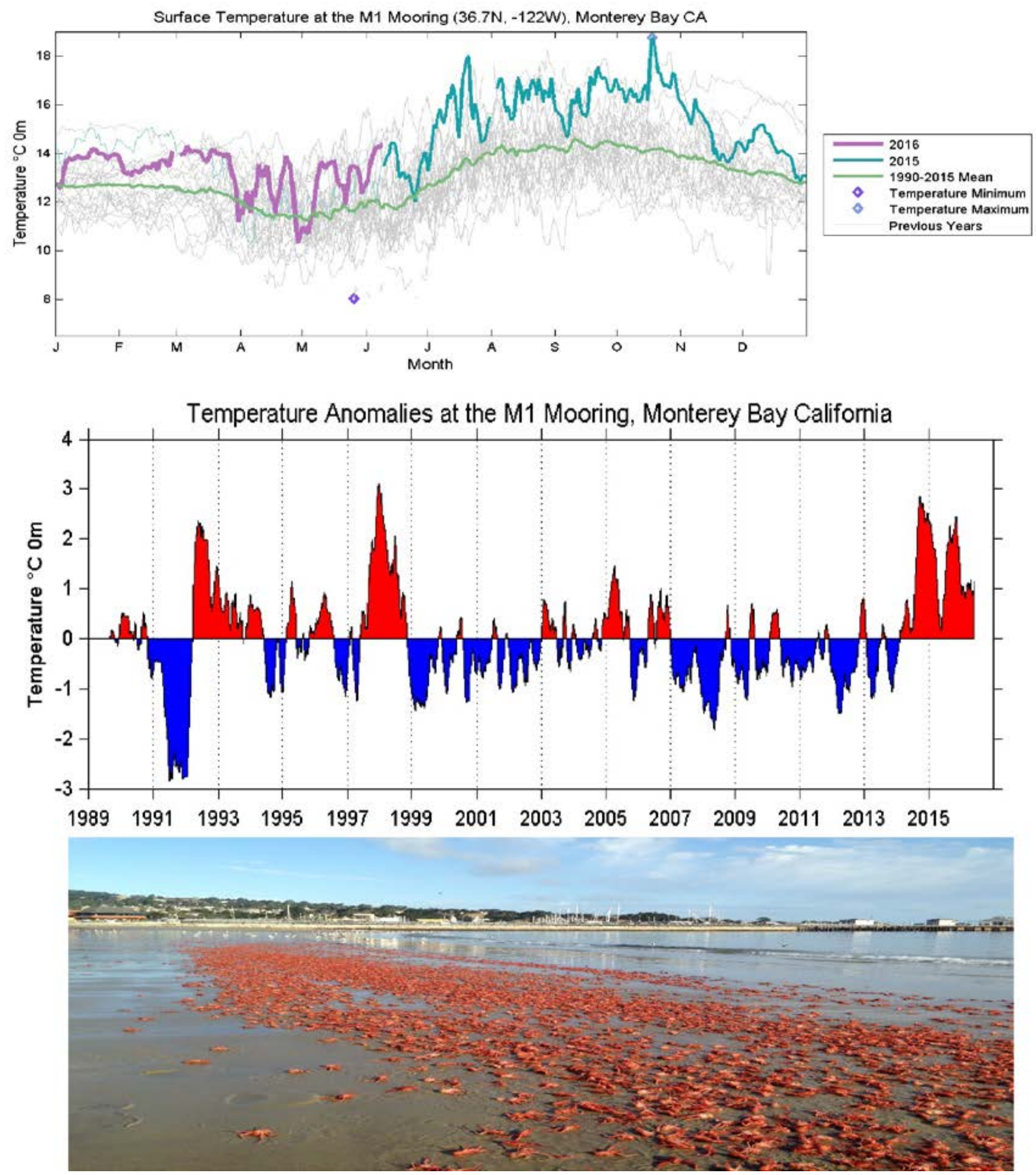

Figure 2. Monterey Bay surface temperature at the M1 mooring: (Top) 2015 (teal line to right) was extremely warm, mostly due to the Blob; 2016 (purple line to left) has been moderately warm, mostly due to El Nino; the climatological average temperature is the green line; **(Middle)** Dramatic Blob-associated warming began in late 2013 and was comparable in magnitude to that of the 1997-98 ENSO. El Nino is poorly seen as the ~1 degree red anomalies at the extreme right of the plot; **(Bottom)** Pelagic red crab washed ashore on the Monterey Peninsula in fall and again in spring, apparently in association with El Nino.

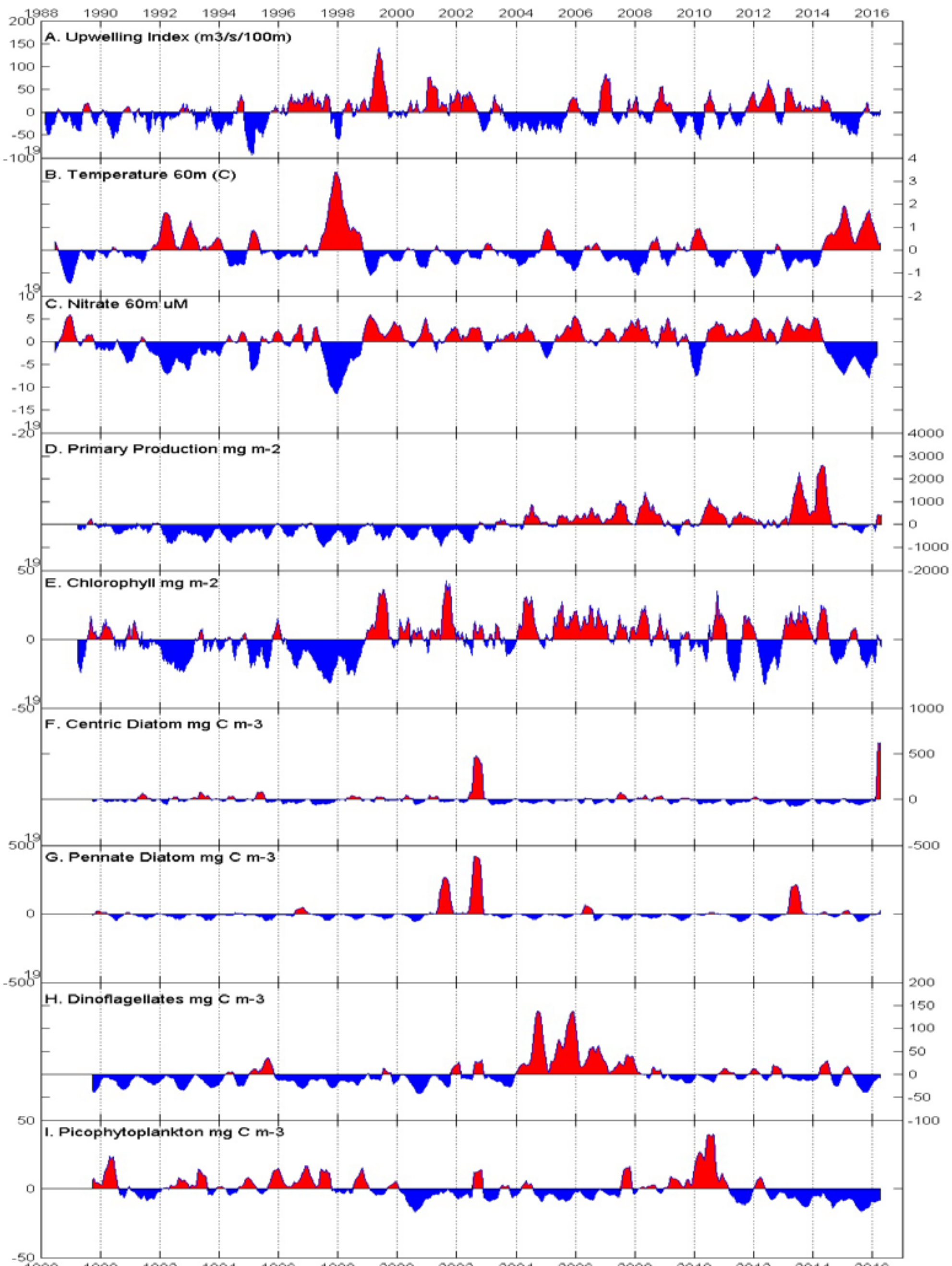

Figure 3. Anomaly plots for Monterey Bay, 1989-2015. Upwelling strength was below average in 2015 **(A)**, and with the Blob in Monterey Bay, surface temperature remained extremely warm **(B)** and nitrate levels very low **(C)**. Rates of primary production finally fell in late 2014 (they were high in 2013-early 2014) **(D)** as did chlorophyll **(E)**. The taxonomic data are problematic. The diatom records **(F, H)** are dominated by blooms and whereas dinoflagellate record is dominated by the so-called 'Age of Dinos' **(H)**. Picophytoplankton **(I)** --- small cells characteristic of oligogrophic waters --- have been less abundant after the 1997-98 El Nino, when Monterey Bay cooled.

Transition to an 'autonomous MBTS' --- 2016-2020

In last year's proposal we formulated a first-ever 'MBTS automation plan'. Here we refine that plan, looking forward to 2017. Table 1 lists the parameters currently measured, with parameters measured by sensors at top and those requiring water samples at bottom. Following Table 1 we outline a vision for transition to an autonomous MBTS by the end of 2020, and assess progress through 2016.

Table 1. Parameters measured during routine MBTS cruises and by automated platforms. '√' or '--' indicates parameter is obtainable or not, respectively, by ships or the autonomous platforms. The top 11entries are data types obtained by electronic sensors, the bottom 13 entries require laboratory processing of water samples.

Parameter	Manned ships	--- Autonomous platforms --- Mooring	Spray glider	Wave glider	AUV	Technique
From SENSORS:						
1. Currents	√	√	--	--	--	ADCP
2. Temperature	√	√	√	√	√	CTD sensor
3. Salinity	√	√	√	√	√	CTD sensor
4. Oxygen	√	√	--	√	--	CTD sensor
5. Nitrate	√	√	√	--	√	Colorimetry or ISUS
6. Zooplankton biomass	√	√	√	--	√	Acoustic backscatter
7. Particulate carbon	√	√	√	√	√	Optical backscatter
8. Phytoplankton biomass (Chl)	√	--	√	√	√	Fluorometry, HPLC, FRRF
9. pCO2	√	√	--	√	--	Infared absorption
10. Water clarity	√	--	√	√	√	Transmis., backscatter
11. Water optics	√	√	--	--	--	PAR or spectroradiometer
From SAMPLES:						
12. Primary production	√	--	--	--	√	C14 incubations
13. Ammonium	√	--	--	--	√	Fluorometry
14. Biodiversity	√	--	--	--	√	eDNA
15. Nitrite	√	--	--	--	√	Colorimetry
16. Phosphate	√	--	--	--	√	Colorimetry
17. Silicate	√	--	--	--	√	Colorimetry
18. Phytoplankton taxa, counts	√	--	--	--	√	Microscope, flow cytometry
19. Dissolved inorganic carbon	√	--	--	--	√	Infared absorption
20. Particulate nitrogen	√	--	--	--	√	Mass spectrometer
21. Dissolved inorganic nitrogen	√	--	--	--	√	Outside laboratory
22. Dissolved organic nitrogen	√	--	--	--	√	Outside laboratory
23. NO3, NH4 uptake	√	--	--	--	√	Mass spectrometer
24. Nitrification	√	--	--	--	√	Outside laboratory

We expect the MBTS to be fully automated by the end of 2020, but what will that MBTS consist of? What parameters, what platforms, what samplers? Of the 24 MBTS parameters now measured (Table 1), the upper 11 can be obtained by electronic sensors at high resolution, whereas measurement of the lower 13 parameters require human- and laboratory-based sample processing. Water for these parameters can, however, be collected by autonomous water samplers (Dorado/Gulper or Tethys/Sipper). In addition, several of the first 11 sensor measurements will require periodic laboratory calibration against water samples. Thus a combination of platforms, sensors and samplers can measure the high-value core parameters of Table 1. We are excited by this possibility.

The 13 parameters at the bottom of Table 1 could all be measured by autonomy if enough samples and sample water was available, which is not at present the case. For example we currently measure 4-5 parameters from each 100 ml Sipper sample bag. This last point is nontrivial and bears repeating: Relative to the CTD rosette with Niskin bottles, the automated samplers are limited in both sample number and volume. These considerations emphasize that the CTD rosette and Niskin bottles will remain a valuable part of any oceanographic toolkit and that there will be a continued need for manned cruises. The major contribution of autonomy will be to sample the ocean continuously and adaptively at high resolution, but for a reduced number of core variables. The autonomous platforms will conduct routine surveys (*e.g.*, the autonomous MBTS), but high value process studies involving experimentation and diverse and new sample types will continue, and require seagoing oceanographers and ships. Ships and personnel will also be required for future platform and sensor development.

With the autonomous MBTS, we are engaged in an ambitious transition during which we will need to harden the autonomous platforms, their samplers and their data systems so that the entire effort can be shifted to an operational basis. During this shift we will need to run parallel missions to build datasets comparing traditional ship versus autonomous data collections. This 'operational autonomy' is developing largely under CANON, and finds natural application and goals in the MBTS. The synergy between the programs is extremely encouraging.

Below we detail the main elements of an autonomous MBTS, including first-estimate operational scenarios for the number and types of platforms needed. These estimates should help scope internal budgets and the operational burden of the new MBTS. We expect continued rapid development of sensors, payloads and platforms and expect that many future developments will be tested and find use in the autonomous MBTS.

- <u>Moorings</u>. The M1 mooring is MBARI longest-running autonomous platform and provides high-frequency data for central Monterey Bay. It is the axis around which the MBTS revolves, and we envision deployment of the mooring indefinitely. Additional mooring functionality will evolve as new systems and sensors are developed. For example two inexpensive moorings are currently deployed north and south of Monterey Bay (and are being exported under contract), and a float under development may also serve as an 'anchorless' mooring.
- <u>AUV</u> occupations of the MBTS C1/M1/M2 stations will replace the Carson cruise series by the end of 2020. The AUV deployments must include vertical profiling and water sampling (Gulper, Sipper, or ESP) --- as discussed above, several of the Table 1 parameters (asterisks) can only be measured with samples returned to and processed by technical personnel in the laboratory (see Pennington *et al*., 2015, for validation of Gulper samples). At present these stations are occupied once each 3 weeks by ship; we believe two dedicated AUVs could maintain or increase this frequency. At present, LRAUVs can be deployed without a ship and have the range to occupy the full transect, whereas Dorado can collect larger-volume Gulper

samples. For 2017 (below) we will propose to begin building dedicated LRAUVs to replace the MBTS cruises by 2020.

- A Wave Glider will also occupy the MBTS transect, replacing the underway surface mapping systems now run on the Carson (CTD, fluorescence, backscatter, pCO2, FRRF). As with the AUVs, one dedicated Wave Glider can occupy the transect. In addition, Wave Gliders have undergone rapid technical enhancement that is likely to continue. For example, auxiliary solar-powered propulsion has been added, 'Tiny' often serves as air/sea communications link, and the gliding plane at 10 m has been instrumented.
- Spray glider occupations of CalCOFI L67 have been ongoing since 2007 and are a major automation success story. We did more than 60 multiday cruises on L67 (each spending nearly a year at sea), and these have been entirely replaced by glider 'operational autonomy'. The L67 transect provides California Current and basin-scale context to our Monterey Bay work. The L67 glider transects should continue indefinitely.

MBTS technologies for 2015-2016

The above autonomous platforms are all being used by the MBTS and CANON --- with the MBTS cruises serving as model and goal while the platforms and their associated systems (e.g., DMO and data) are shifting to an operational basis. Below we list our technology development efforts together with comments on their current status and their contribution to our drive to automate. Future plans are covered under 'New and Continuing Projects: Plans for 2017', below.

- Moorings --- M1 and Ocean Acidification moorings. The M1 mooring represents MBARI's first autonomous platform and remains core to our time series efforts (Fig. 1). We request continued support for its deployment. Small Ocean Acidification moorings (OA1 and OA2 equipped with pCO2 etc., developed with external funding) are currently deployed off Hopkins Marine Station and Año Nuevo Island. These small buoys are built and maintained by our lab group but we request a small amount of support for deployment and servicing.

- Spray gliders now collect L67 datasets as described above as part of MBTS. During CANON 2014 up to 6 gliders were deployed simultaneously. The gliders represent reliable and relatively inexpensive robotic tool with ever-increasing utility. The glider sections are supported by funding from CeNCOOS/IOOS.

- Wave Glider is a promising surface platform that cobbles together the important functionalities of unpowered propulsion, solar electrical charging, high spatiotemporal coverage and large payloads; the payloads are undergoing rapid development (currently pCO_2/pH/CTD). Wave Gliders can also (1) remain deployed for long periods (months), (2) track oceanographic features (fronts, upwelling centers, eddies), and (3) serve as sea/air communications stations which can track and control subsurface assets (AUVs, drifting sediment traps, animal tags). For MBTS, in 2016 Wave Gliders are occupying the MBTS C1/M2 transect on a near-operational basis, with the goal of eventually replacing the surface underway mapping data currently collected by the Carson. For 2017 we propose to develop a subsurface sampler for Wave Glider.

- Dorado/Gulper. We are using the 1.5L Gulper sample collector to obtain samples on the C1/M1/M2 transect for eDNA and domoic acid analyses, again in parallel with MBTS cruises. During 2016 we have demonstrated that Dorado can be deployed/recovered from Moss Landing Harbor and run missions without a support ship. We request continued support for these operations; Dorado instruments provide

- Water sampler. In 2015, a 15-bag 'Sipper' water sampler has been designed and built by Larry Bird and Brent Jones to fit in a LRAUV. At present, 100 ml samples are drawn into disposable plastic bags; the bags can be pre-charged with tracers, nutrients, or fixatives and returned to ship or shore for post-treatment. We have carried out similar comparisons as for *Dorado*/Gulper (Pennington *et al*., 2015) and shown the sample bags and fittings to be nontoxic to growing phytoplankton. The Sipper is undergoing field testing in the LRAUV *Tethys* and further refinement (see plans for 2017). The *Carson* and *Tethys* engaged in 'joint operations' and met six times in 2015 and obtained side-by-side Niskin:Sipper profiles at MBTS stations (Figure 4), with good comparisons for 4 of 5 parameters, and a persistent problem stemming from airborne ammonia contamination has recently been eliminated. The Sipper will find widespread use in the autonomous MBTS for those Table 1 parameters that require periodic sample calibration or laboratory processing.

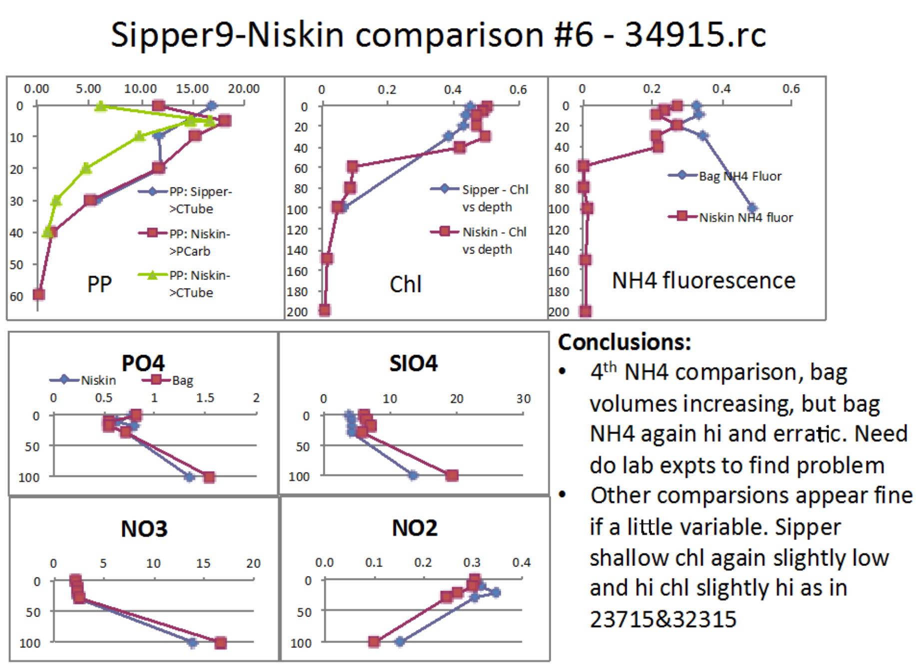

Figure 4. Sample validation, CTD rosette/Niskin bottles versus LRAUV/Sipper: MBTS and CANON now engage in joint operations, with the Carson and Tethys meeting every 3 weeks at MBTS stations to collect parallel samples. The data comparisons are in general good (left and middle plots), except for a persistent ammonia contamination problem (right plot, high blue values).

Integration with other projects, 2015-2016

CANON. As discussed above, MBTS and CANON synergy is increasing, with the ship-based MBTS cruises serving as a template and goals for the future 'autonomous MBTS'. Thus many of the platforms originally developed and tested under MBTS or external funding are finding excellent use in CANON (Moorings, drifters, AUV and LRAUV, Spray and Wave Gliders), and increasingly, CANON developments are finding their way back into the MBTS. For example, the gliders, Wave Gliders and LRAUV/Sampler are regularly occupying the MBTS C1/M1/M2 transect, with the eventual goal of replacing MBTS cruise sampling (see 'MTBS automation plan', above). Thus CANON has been evolving away from focusing on one or two intensive process studies annually, and is now supporting more regular, operational activity. In the 2015 and 2016 spring and fall CANON process studies, however, we focused on (1) the biological pump and nitrogen transformations at the base of the Monterey Bay euphotic zone, (2) phytoplankton, including harmful algal, blooms and (3) Ecosystem Hotspots (i.e. Año Nuevo and Moss Landing, sharks and whales, respectively).

Integrated time series (ITS). The coalescence of the upper-, mid- and bottom-water column time series data (Chavez, Robison, Smith) is ongoing. The analysis should determine relations and pinpoint critical parameters to measure. Past analysis has focused on species diversity and abundance comparisons. For 2017 it has been decided to compare carbon fluxes between the surface MBTS (chlorophyll, primary production and particulate carbon) through the midwater to the bottom at Station M (particulate carbon).

Mexican and Southern California pCO_2 moorings. We have been exporting pCO_2-sensing moorings, developed in support of ocean acidification, to CICESE in Ensenada with Mexican funding. The data sets allow for a comparative analysis between upwelling systems and drive the need for hardened operations. Off Baja California, one mooring is currently deployed off northern Baja and a second at Cabo Pulmo within the Sea of Cortez. A pCO_2 mooring will be delivered later in 2016 to the Orange County Sanitation District so they can monitor the effects of sewage outfalls on oxygen and ocean acidification. CeNCOOS is also interested in using these moorings for a regional array.

MBON --- Plankton taxonomic surveys via genetics, or 'eDNA'. Our ability to census marine organisms remains incredibly weak. For the past 25 years we have microscopically enumerated 3 samples for phytoplankton and micro-zooplankton abundance from each MBTS cruise. This classical approach has produced a valuable and highly-published dataset, yet is not supportable in the long term. Further, we know far too little about the other biota that inhabit the surface ocean, particularly crustacean zooplankton and larger animals. Any improvement in this area will be a major contribution. With Stanford and the COS we are collecting MBTS cruise and Gulper samples to be subjected to broad genetic surveys --- assaying water samples for DNA sequences from phytoplankton, zooplankton, fish and mammal species. While still early, it is our hope that this work will eventually provide routine assays of Monterey Bay genetic diversity (species) that can be autonomously collected by LRAUV. We have also archived over 10 years of GFF filters in liquid nitrogen that can be analyzed genetically, and have correlated the results using an anchovy-specific DNA probe with the humpback counts of Figure 1B. It turns out the anchovy:humpback correlations are excellent --- high PCR-based abundances of anchovies at MBTS station C1 co-occur with the humpbacks *only after* the Blob pushed into Monterey Bay in late 2013 (Figure 5). The analysis provides ecological links between basin scale oceanography and molecular genetics.

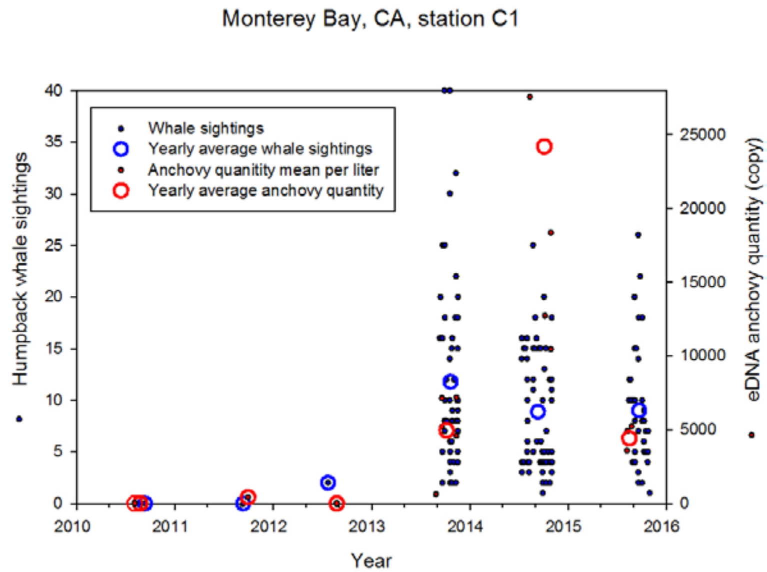

Figure 5. Humpback whale sightings and anchovy eDNA at MBTS station C1 over the head of the Monterey Submarine Canyon (see Figure 1). In late 2013 the warm, low productivity Blob pushed into outer Monterey Bay and the whales appeared off Moss Landing. When the eDNA on our archived filters from C1 was analyzed eDNA, anchovies --- a main humpback food --- appeared at the same time.

Significant changes from previous project proposal, 2015-2016

- None

Publications based on the results of this project only, last 5 years

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c) Continuing projects: Plans for 2017

Research Activities

During 2017 we will continue automating the MBTS, as outlined in the automation plan above. This effort will entail (1) continuing, with CANON, to harden the autonomous platforms and their samplers, (2) beginning build of dedicated LRAUV(s) and Wave Glider to replace the time series cruises, and (3) running parallel cruise and autonomous missions along the C1/M1/M2 transect to validate autonomy and build comparison datasets.

Engineering/technology development

MBTS LRAUVs. Dedicated LRAUVs will be needed by 2019 to replace the time series cruises to be discontinued after 2020. We envision three vehicles – an LRAUV/ESP, an LRAUV/Sampler, and a LRAUV/ESP/sampler. Below we distribute the builds over 3 years to spread costs and time demands, with completion by 2019 and operational use in 2020. In the first year we propose to purchase LRAUV parts, some assembly could be completed by EE and ME techs when they have time between projects. In Year 2 required labor for completing the core vehicle assembly and parts for ESP and sampler would be requested. In the third year we would purchase instruments, integrate and test vehicles for operational deployment in 2020, the last year of this proposal. This approach distributes the capital costs and labor over 3 year.

- 2017, MBTS proposal Year 2: Acquire all components necessary for initiating LRAUV system fabrication (106K per LRAUV).
- 2018, MBTS proposal Year 3: Construct LRAUVs and acquire components for sampling modules (ESP and water sampler) and LRAUVs.
- 2019, MBTS proposal Year 4: Purchase sensor packages, build sampling modules, integrate and begin testing.
- 2020, MBTS proposal Year 5: MBTS LRAUV operations begin in tandem with ships.

Wave Glider. We will continue to work with Liquid Robotics and external collaborators to improve on present payloads and add new capabilities. In addition, Brent Jones plans to develop a water sampler (see below) for a Wave Glider.

Autonomous water samplers. As described above, water samplers are an important component of the autonomous MBTS. Gulper has been an important step in this direction (see Pennington *et al*., 2015) and Brent Jones and Larry Bird have now designed a 'Sipper' water sampler that is capable of collecting 15, 100 ml samples in disposable plastic bags in the nose of the LRAUV (above, Technologies for 2015-2016). For 2017 the water sampler needs operational hardening (stronger rotation motor, pump). In 2017 Brent will lead the development of a water sampler for Wave Glider to be deployed in a tow body. There are many advantages to this approach: 1) A new and fresh approach to water sample collection can be made using lessons learned to date; 2) there is a need to debug using a Wave glider tow body (MBARI owns several but they have yet to be made operational) given interest by other scientists (e.g. Benoit-Bird and Chavez are interested in implementing acoustics) in taking advantage of this platform and this will become easier after a sampler is implemented; and, 3) the sampler developments from the Wave Glider effort can feed back into LRAUV or forward into an airborne drone (UAV).

Field programs

MBTS cruises. We remain committed to building consistent climate-quality ship-based datasets on the MBTS C1/M1/M2 transect for at least two and perhaps four more years. We thus request support to continue the MBTS cruise series in 2017 16 times annually, with 12 cruises aboard the Rachel *Carson* at 3 week intervals, filling in with 1 Fulmar when Carson leaves the area (Pacific Northwest) and other cruises as possible.

Autonomous MBTS. In conjunction with the MBTS cruises we will continue the operational hardening of AUVs and Wave Gliders with routine parallel missions on the MBTS transect, building comparison datasets. We anticipate one more year of parallel missions, melding CANON development efforts with these deployments.

In conjunction with these deployments we will continue the development, hardening and validation of AUV samplers --- *Dorado*/Gulper, LRAUV/Sipper and LRAUV/ESP. These are required to return samples to shore for laboratory analysis as will be needed when ship occupations of the transect end. Dorado/Gulper returns higher volumes of seawater. In 2017 *Dorado*/Gulper in particular will be useful because of the larger volumes of water Gulper can collect, even though the 1.6L gulps collect far less water than we typically use during MBTS cruises (36, 10L Niskins/day). *Dorado*'s utility for automation requires that it not be dependent on a ship (*Carson)*. We request AUV support for *Dorado* **without** *Carson* to work out the logistics of towing to/from the harbor, rather than requiring use of a *Carson* day for launch, mission following and recovery. We thus request 6 *Dorado*/Gulper deployments on the C1/M1/M2 transect, also on MBTS cruise dates. Additionally we propose to run parallel and concurrent Wave Glider and LRAUV/Sampler+ESP missions, with the Wave Glider deployed near-continuously, as feasible. Brent Jones will play and important role in the transition to operations and we hope to have continued support from him through the end of this proposal.

CANON 2017. CANON developments are being used to automate the MBTS. CANON personnel will support the MBTS transect occupations above, and MBTS personnel will lead a spring 2017 CANON experiment to focus on locating and tracking the continental slope-associated upwelling front/eddy edge offshore of Año Nuevo with autonomous vehicles and models.

Hawaii transit. We plan to participate with the Worden lab in the outbound Hawaii transit, providing foundational data on hydrography, nutrient chemistry and phytoplankton biomass and production.

ALOHA LRAUV's. At the time of writing, we are developing plans to provide foundational data near Station ALOHA, in support of the initial science missions with the ALOHA LRAUV's. As CANON 2016 and 2017, the Hawaiian experiment will also focus on identifying and tracking eddies with autonomy.

Isotope Usage

As for the past 26 years, we plan to use radioactive C14 and non-radioactive N15 as biological tracers in vans aboard both the Carson and Flyer. We maintain and hold Radioisotope Use Licenses from both California state and the federal government. There have been no safety issues during the 2.6 decades of use.

Specific deliverables

Continued improvement of our predictive understanding of how the ocean and its inhabitants respond to natural processes and human perturbations.

Milestones (see <u>personnel classification list</u>)

2017 Project Start Date: MM/DD/2017	**Milestone 1**	**Milestone 2**	**Milestone 3**	**Milestone 4**	**Milestone 5**	**Total Resources**[4] for each resource category for all milestones listed here
Milestone Date						
Milestone Description						
EE						
SE						
ME						
EE Tech						
SE Tech						
ME Tech						
Machine Shop						
Divers						

2017 Budget

Below is the monetary and ship time request; the labor request is also below under 'Project Team'. It is larger than for 2016 ($87,700) as it includes one Fulmar day ($3,900), DNA sequencing costs for our incoming postdoc ($20,000), development of a Wave Glider sampler ($15,000), two Hawaii expeditions ($13,000), and the first year of a dedicated MBTS LRAUV build ($318,000). Without these items our regular MBTS budget amounts to $77,700 that is less than 2016. This budget is also entered in the web-based form where it also includes expense, labor and ship time requests.

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

Grand total	$447,600
Item	**Cost**
Ships and platforms	
Fulmar (1 days x $3900)	$3,900
Rachel Carson, 12 MBTS days	--
Paragon, 25 days	--
Wave Glider, 50 days	--
General lab expenses	
A285 science lab supplies and maintenance	$5,000
Computer software upgrades and contracts	$4,000
Supplies and analysis	
Cruise equipment --- normal upkeep	$5,000
MBTS cruise supplies, C14	$2,800
MBTS cruise supplies, other expendables (16d x 3sta x $133/d)	$6,400
Outside subcontracts, POC, N15, HPLC, FCM samples	$10,000
Outside subcontract, epifluorescence microscopy counts of Phytoplankton (84samples x 10hrs x $25/hr)	$21,000
DNA sequencing costs, new MBARI postdoc	$20,000
pCO2 mapping	
Infrared analyzer calibration, maintenance	$1,000
Primary gas standard	$1,000
Chemicals and supplies	$1,500
Sea surface and water column TCO2	
Infrared analyzer calibration, maintenance	$1,000
Standard reference materials	$2,000
Chemicals and supplies	$1,500
Satellite communications	$5,000
Ocean acidification moorings	
Supplies	$4,000
Conferences	
Domestic conferences, Pennington, Michisaki (2 people x $2000 ea)	$4,000
Travel for Chavez	$2,500
Autonomous water sampling	
Sipper operational hardening and adaption to Wave Glider	$15,000

Hawaii transit	
Expendable cruise supplies (as per MBTS cruises, 8d x 3sta/d x $133/sta)	$3,200
Air fare (3 people x $400 one way)	$1,200
Hotel (3 people x 2 nights x $200/night)	$1,200
Meals (3 people x 2 days x $100/day)	$600
Station ALOHA LRAUV cruise	
Expendable cruise supplies (as per MBTS cruises, 8d x 3sta/d x $133/sta)	$3,200
Air fare (3 people x $600 round trip)	$1,800
Hotel (3 people x 2 nights x $200/night)	$1,200
Meals (3 people x 2 days x $100/day)	$600
MBTS LRAUV build, three vehicles	
Purchase vehicle components (not sensors, $106K x 3 vehicles)	$318,000

Project team

- Francisco Chavez (Sr. Sci.) is responsible for project direction, connection to other MBARI programs and the scientific community, data synthesis, publications --- 230 days (1840 hr).
- Tim Pennington (Res. Spec.) is responsible for month-to-month oversight with emphasis on project management, data collection, quality, processing, presentation and publication --- 230 days (1840 hr).
- Reiko Michisaki (Res. Tech.) is responsible for month-to-month management with emphasis on data and database management, analysis and graphics --- 230 days (1840 hr).
- Brent Jones (Engineer) is responsible for the LRAUV/Sampler and development of an automated sediment trap sampler --- 230 days (1840 hr) allocated approximately 35% Lagrangian Sediment Traps, 40% Water Sampler; 15% LRAUV development and logistics, 10% other operational and technical support.
- Monique Messie' (Res. Spec.) will work on two projects associated with analysis of sharks in relation to climate: (1) shark distribution in relation to large scale oxygen patterns; (2) white sharks behavior in relation to environmental conditions at Año Nuevo --- (40 days) 320 hr.
- Marguerite Blum (Res. Tech.) processes and quality controls nutrient samples, analyzes O2 and TCO2 samples, organizes and participates in cruises --- externally supported.
- Chris Wahl (DMO support engineer) --- Wave Glider and OA moorings --- 15 days (120 hr).
- Jared Figurski (Ocean Observatory Technician) --- Wave Glider and OA mooring support --- 10 days (80 hr).
- Jules Friederich (Res. Tech.) works on O-Buoy, Mexican moorings and wavegliders --- externally supported.
- Kris Walz (Res. Assistant) run genetic 'eDNA' analysis of MBON filters collected during MBTS cruises --- externally supported
- Paul McGill (Electrical engineer), integrate PIC24 into Sampler controller board--- 100 hr
- Larry Bird (Mechanical engineer), LRAUV-Sampler development --- 400 hr

- Machinist, LRAUV-Sampler fabrication --- 100hr
- AUV support of 160 hours is requested for deployment and recovery of Dorado on 6 CTD days by towing in and out of harbor
- LRAUV support (Hobson (20 hrs), Kieft (40hrs), Stanway (40hrs), Klimov (20 hrs) and Mellinger (20 hrs) is requested for operational support for the 12 comparisons with *Carson*.
- DMO-CTD Instrumentation technician Erich Rienecker will operate CTD and other systems on MBTS cruises --- 192hrs (16MBTS days x 12hr/day) We request at-sea and data-processing support from Erich on non-MBARI vessels (Fulmar) as part of MBTS and CANON.

Project lab and office space requirements

In addition to any changes to current space usage, please also include anticipated office and lab needs for students, postdocs, collaborators, etc.

Our current lab space is excellent.

Data storage requirements (see Todd Ruston for assistance)

BOG personnel are now analyzing DNA sequence data, we will need significant data storage capability in particular with the addition of a new postdoc.

Data availability outside project team, uniqueness

None

R/V *Paragon* Requests

If the project team will be requesting time for the R/V Paragon, please specify the operators in the group and provide estimates of their availability to operate the vessel.

Jones, Wahl and Figurski are requested and can operate the Paragon

Export Regulation

Does the project team anticipate any foreign collaborations or international travel? If so, please identify collaborators by name, institution, and country.

We have many collaborations. A routine foreign collaborator is

- Dr Carmen Castro, Higher Council for Scientific Investigations, Vigo, Spain

Does the project team plan or anticipate export controlled purchases, shipments, or transfers of items (e.g., research instruments, proprietary data, hand-carried tools or samples) outside the U.S. temporarily or permanently? If yes, please identify country or countries and indicate whether these items will remain under MBARI control while abroad or controlled by others. Will the items be exported to more than one country? Please include foreign collaborator information as described above.

Monterey Bay National Marine Sanctuary (MBNMS)

General Permit

Projects teams need to indicate if any work will be performed that is either: (1) currently authorized under our general permit; or (2) will require that we obtain authorization. The current permit can be viewed at http://mww.mbari.org/pco/permits/mbnms-2015-002_feb2015.pdf. Please see Mandy Allen for questions.

Is a permit with MBNMS required for your work?

Yes

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). An interactive map can be found on the Sanctuary's SIMoN webpages at http://sanctuarysimon.org/maps/sesa/. (*Note: It may take a moment for the page to load, so please be patient. Also, if prompted for a login, hit "Cancel" and then you will be able to access page.*) To determine if your work will occur in a SESA, specific coordinates can be entered using the locator function (click on the red "target" button in the toolbar at the top of the map). If your work will be conducted in one of these areas, please indicate which area, by number.*

CTD stations 67-50 and 67-55 are in in SESAs #6 and 9, respectively. CTD station and mooring M2 are also in SESA #9. The CTD station work is in the upper water column, typically to 1000m, and does not involve the benthos.

Authorizations/Permits from other Agencies or Organizations

Is the project team aware of any other permits or authorizations that will be necessary to perform the proposed work? If so, please list below along with status of authorizations (obtained, pending, need to apply, etc.). Please see Mandy Allen if you have questions.

- *Radioactive isotope user permit, State of California.* We currently hold and renew this permit annually.
- *Radioactive isotope users permit, US government.* We currently hold and renew this permit annually.

Active Acoustics

We are compiling information on active acoustic use at MBARI. If the project involves using active acoustic instrumentation, please describe plans.

EK500 on the Western Flyer
EK15 on Dorado

Risk matrix (development and infrastructure projects only)

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