Project Number: 901206

Project Start: Jan. 1, **2018** **Project Duration (in years):** **2 of 3**

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**[1]	**Research**	**Infrastructure**[2]	**Education**	**Time Series**	**Institute Initiative**

Project Manager[2]: Gene Massion
Principal Investigator: Ken Johnson
Lead Scientist: Ken Johnson
Lead Engineer: Gene Massion

Project Title: Coastal Profiling Float Transition to Science Applications

Please indicate which category best describes the project theme (mark only one).

X			
Ocean biogeochemistry	**Ecosystem dynamics**	**Ocean visualization**	**Exploration & discovery**

Please indicate percentage of effort on this project anticipated for 2019 toward these three highest institutional goals (percentage total should equal 100%).

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[1] Development and infrastructure projects must complete the risk matrix (see end of the proposal form).
[2] 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.

Goal	**Developing/adapting innovative technologies**	**Utilizing developments to explore and understand ocean systems**	**Technology/knowledge transfer[3]**
Percentage	30	65	5

[3] This category includes transfer of hardware, know-how, publications, presentations, etc.

1) ABSTRACT (new projects only)

[Paste abstract here]

2) PROPOSAL

a) All Projects

Statement of the challenge, why it is important

The continental shelves and slopes comprise only 5 to 10 % of the ocean area (depending on definition), but they contribute half of the global new primary production (Benway et al., 2015). Variability in this new primary production can be a major control on air-sea CO2 flux (Evans et al., 2015). The disproportionately high new primary production in coastal systems supports the vast majority of global fish production (Ryther, 1969), which may be significantly impacted by future climate change (Brander, 2007). Other than remote sensing of ocean color, there are no observing systems that provide a systematic view of ecosystem processes such as new or net primary production in coastal systems. As a result, the Coastal Carbon Synthesis (Benway et al., 2015) calls for greater use of autonomous platforms and sensors to assess carbon cycle processes, "All coastal regions of North America experience short-term events (e.g., winter storms, plankton blooms, hurricanes, upwelling and acidification events) that can strongly influence carbon delivery, processing, and fate, so there is a need to further develop our observational capacity (e.g., novel autonomous platforms) in all continental margin systems to be able to capture event-scale processes and quantify their impacts on coastal carbon budgets." Coastal profiling floats also provide an efficient means to monitor regional signals of ocean acidification (Chan et al., 2017) in open, shelf waters.

Relevance

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

The 3 overarching goals from the 2011 strategic plan can be summarized as "Develop or adapt innovative technologies … to explore and understand how natural ocean systems operate and how they respond to natural and anthropogenic change …[and] transfer the knowledge gained, solutions devised, and the technology developed to communities outside of MBARI". The CPF extends existing profiling float technology to allow a comprehensive suite of biogeochemical instruments to be deployed in the coastal zone and upper 500 meters of the world's oceans in order to understand the effects of a warming climate, increased use of nitrogen fertilizers, acidification, loss of sea ice, decreasing oxygen concentrations and a variety of other natural and anthropogenically driven processes. The end goal for the CPF is to transfer the technology to a commercial partner making it available to entire oceanographic community.

Does it relate to the Technology Roadmap? If so, please describe how.
Yes. The CPF fits in 2 of the 3 initiatives identified in the Technical Roadmap, "Taking the laboratory into the ocean" and "Advancing a persistent presence" and the "Biogeochemical cycles" challenge also identified in the Technology Roadmap.

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

The David & Lucille Packard Foundation U.S. West Coast Strategic Plan identifies 4 desired outcomes for their activities in the next 10 years. One of these is "Fisheries and protected area managers are equipped to implement ecosystem-based management and adapt to the impacts of climate change and ocean acidification". The CPF is targeted at providing precisely the kind of fundamental, economically sustainable, ecosystem wide data required by fisheries and protected area managers to make science driven, ecosystem-based policy decisions.

Overall approach to the challenge: Over the complete term of the project, what is needed to address the challenge (e.g., sensors, platforms, marine operations, de novo R & D, etc.)

Research

The Chem sensor lab has existing tools to handle the data from the proposed CPF. Understanding how to navigate the floats in support of a specific science experiment is a new expertise that spans research and engineering. This issue is addressed in more detail elsewhere in this proposal.

Engineering/Technology Development

Profiling floats have been in use by oceanographers for several decades. The primary new technologies needed to address the challenges for a coastal profiling float include the following. 1) Development of a buoyancy engine with significantly higher $\Delta V/V$ ratios (ΔV is the change in volume the float's buoyancy engine can produce and V is the overall volume of the float). Argo floats have a $\Delta V/V$ of $0.26/38 = 0.0068$. The current CPF's buoyancy engine had a $\Delta V/V$ of $3.5/40 = 0.0875$, an improvement of more than an order of magnitude. The 3.5 ΔV number for the CPF is easily scalable up and down to meet a particular application and we hope to reduce the V value of 40 when we finalize the CPF geometry. 2) Working in shallow coastal regions with target depths of 10s of meters requires better velocity and depth control than a profiling float designed for use in the open ocean with depths of 1000s of meters and lots of depth below the target depth. We addressed this issue early in the project and the existing velocity and depth closed loop control algorithms have been working quite well. 3) Keeping a float in a coastal region has an additional risk of the float drifting on shore or offshore to an ability to "navigate" a float with no horizontal actuators, limited power and volume is a challenge. We have 2 approaches to address this challenge: navigating by using ocean currents as discussed elsewhere in this proposal and potential development of a small, low power inertial sensor capable of inferring ocean current direction and velocity from a measurement of float acceleration. 4) Existing floats can support a limited number of sensors. We've designed the CPF to support the Chem Sensor lab's standard biogeochemical instrument suite (CTD, Oxygen, pH, Nitrate, Optical Radiometer, Fluorescence/Backscatter) plus at least 4 more instruments. 5) Development of a robust oceanographic platform capable of continued autonomous operation over long durations across a range of conditions is always a challenge. Our approach to this challenge is also described elsewhere in this proposal.

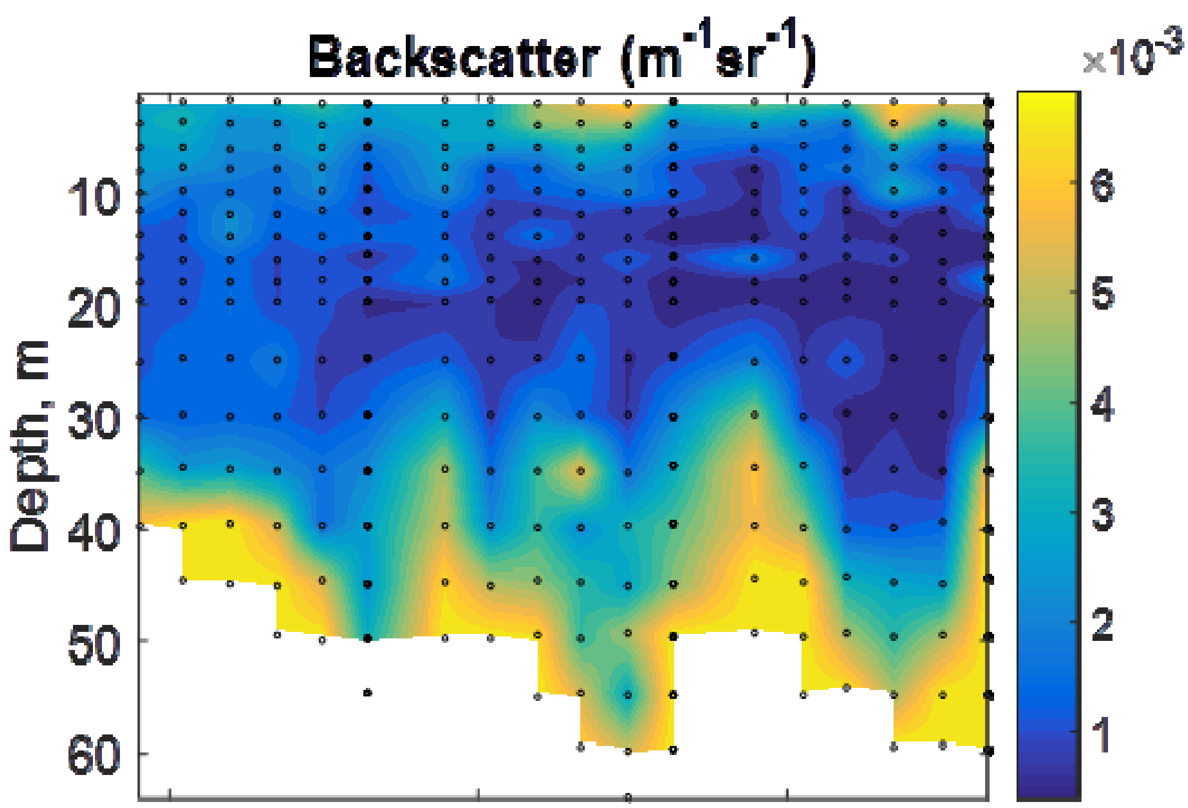
Marine Operations/Field Programs

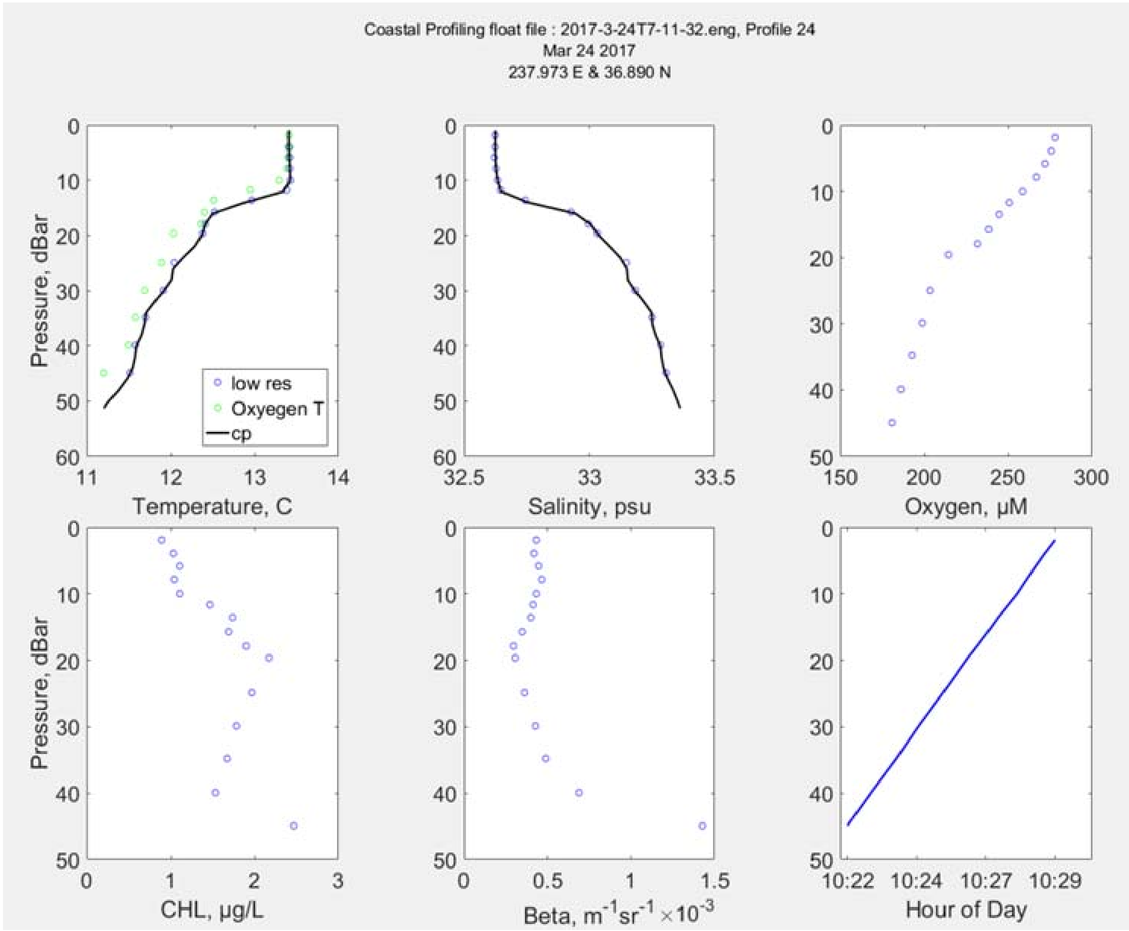
Operation of a few coastal profiling floats along the coast doesn't pose any particularly challenging marine operations. Running our long term goal of science experiments covering large coastal regions with 100s of floats economically is a challenge. Luckily, the Paragon is an ideal example of the kind of coastal research vessel required for this kind of experiment.

Data

What data products will be generated?

A science data log is sent by the CPF after each profile via Iridium satellite. The data is processed on shore and examples of the data products we are currently generating are shown below. Detailed engineering logs are also generated for each profile and stored on the CPF. They are too large to be telemetered and are downloaded after the CPF is recovered.





How will the data products be managed?

We have been working on the data management task since the first floats have been deployed and have developed the shore side infrastructure required to process and visualize the data telemetered from the floats. Data management will be handled in the existing FloatVIZ web site.

Describe data availability outside of the project team.

All CPF science data will be publically available in near real time on the FloatVIZ web site.

Describe data storage requirements.

Science data files are ~50K per profile. Engineering data files are ~2Mbytes per profile. As a rough estimate assume 100 days of operations per year with 4 profiles per day. 4 profiles/day * 100 days * 2.05 Mbytes/profile = 820 Mbytes per year.

Anticipated Impact

The CPF project is targeted at developing a platform with that can support a broad suite of biogeochemical instruments that can be operated economically over large coastal ocean regions and for years at a time. We believe this technology is well suited to address the challenges described in more detail in the Statement of the Challenge section in this proposal including primary production, air-sea CO2 flux, ecosystem processes in coastal systems and ocean acidification in open, shelf waters.

Who are the consumers of the instruments, methods, systems, and data that will be generated?

We hope the CPF will be of use to oceanographers who need a long term, economical presence in the coastal zones of the world oceans. It is reasonable to expect that data generated by CPFs will be of use to policy managers responsible for fisheries management and other regulated activities in the coastal zone.

We are pleased to note that the CPF, even while still in the development process, has been used by MBARI researchers including the Chavez group as part of the CANON project, Tom O'Reilly and Ivan Masmitja as a platform of opportunity for jelly tracking work with the waveglider and is being proposed for use in the VIPER project in Ken Smith's lab.

It has always been our intent to pursue commercialization of the CPF with an appropriate partner. We believe completion of the proposed 2018/2019 science experiments is a reasonable predecessor to this task.

b) Continuing Projects

If the proposed project includes multiple individual projects, please list each of these projects as a subheading in the proposal. For each subheading, please address the following:

Current status of project and results to date

The first of the 3 CPFs were building this year is built, has finished bench testing and is starting tank testing. Almost all of the parts required for the final 2 CPFs have been built or purchased. We're waiting on shared resources to build them up.

What percentage of labor and budget have been used through the 1st half of year?

Through July 16, 2018 labor hours spent are 35%. Budget dollars spent are 58%.

Will you complete the current year's scheduled work?

We do expect to finish production of all 3 CPFs and will have started preliminary science operations by the end of the year.

If you are at less than 50% resource usage, what is the plan to complete, or what work won't be done this year?

Budget dollars are about on track. Labor hours are short basically because techs have been busy on other projects but we hope to get them back on CPF tasks in the second half of July and most of August.

Significant changes from previous project proposal

The timeline has been delayed by roughly 3 months due to resource constraints for building up the CPFs.

Over the past two years, what peer-reviewed publications, education and/or outreach activities have resulted directly from this project? Please be brief.

None

c) All Projects: Specific Plans for 2019

Research Activities
During fall/winter of 2018, we will begin preliminary science experiments in Monterey Bay using the CPF array and will continue these experiments in 2019. The primary science focus will be the influence of lateral nutrient transport from upwelling plumes versus canyon upwelling on the development of high chlorophyll levels in the Monterey Bay "upwelling shadow" (Graham et al., 1997; Ryan et al., 2010). High concentrations of chlorophyll (Ryan et al., 2008) and high rates of net primary production (Johnson and Needoba, 2008) regularly occur in the northern part of the bay. The floats will be deployed in a grid and data will be collected both during the vertical profiles every 2-6 hours and every 15 minutes (or so) while they are parked on the bottom. That will enable detection of internal waves as they pass along the bottom, as well as plumes of surface water entering the northern area of the bay. All floats will be recovered at the end of each experiment.

The CPF has the capability to park at a specified depth in the water column or on the sea floor based on commands received over the Iridium satellite network. A primary focus associated with the experiments will be using this capability to navigate individual floats during an experiment to maintain the desired array geometry. The approach for this effort is to use high-resolution 3D model projections of the current field to select float parking depths with a current that will move each float in the desired direction. This experiment will use output from the ROMS ocean model operated by the Cooperative Ocean Prediction System (COPS, http://west.rssoffice.com/) that is led by Yi Chao. They operate a high-resolution model in real time with a three-day forecast. The forecast data are available on line in netCDF files. Each float sends its current position along with the science data after each profile. We currently have the tools to plot each float's track in Google Earth. Navigating wayward floats will require finding a specific subsurface current from the forecast with a direction roughly toward the desired position for each float in the array. After a float surfaces and its offset from the desired position is determined, the depth of the desired current will be set as the new park depth for that float. If a serendipitous current is not found, we would park the float on the sea floor to minimize drift in any direction. Figure 1 shows an example of the predicted trajectories for floats at three depths in northern Monterey Bay. While there are not always days with complete reversals in current direction, it should be possible to maintain an acceptable array geometry by careful selection of parking depths. Our first attempt at navigating the floats using sub-surface currents was in July of 2017. You can see in Figure 2 that we were able to keep this CPF much closer to the original deployment position than the un-navigated March 2017 track.

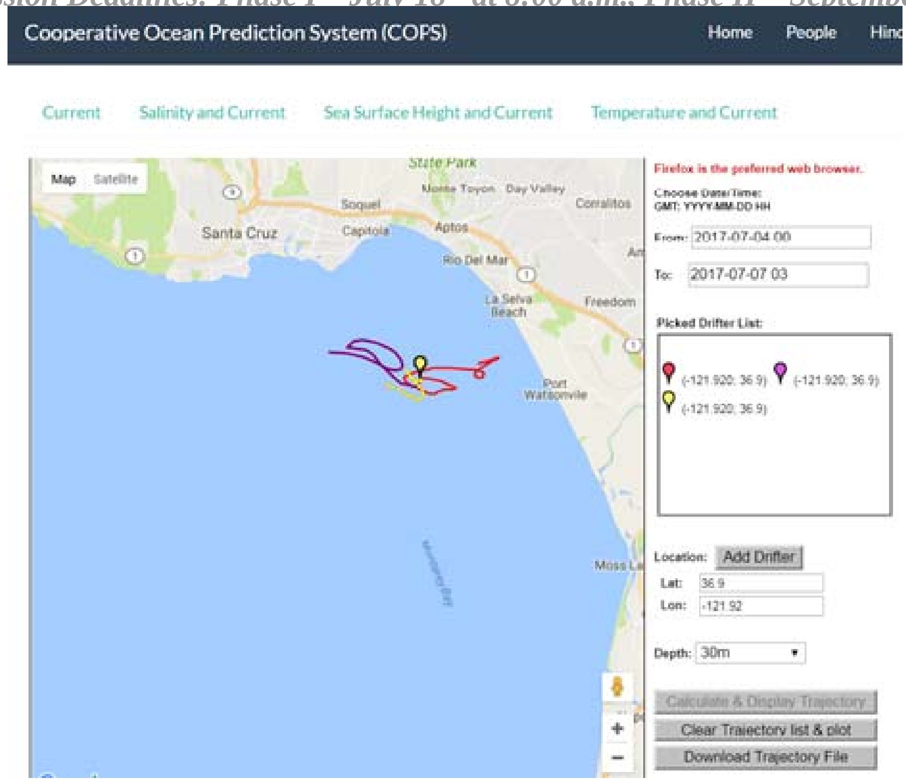


Figure 1 Predicted trajectories (4 Jul 2017 to 7 Jul 2017) at 1 m (red), 20 m (purple) and 30 m (yellow) computed using the Drop-a-Drifter interface to the COPS high resolution model.

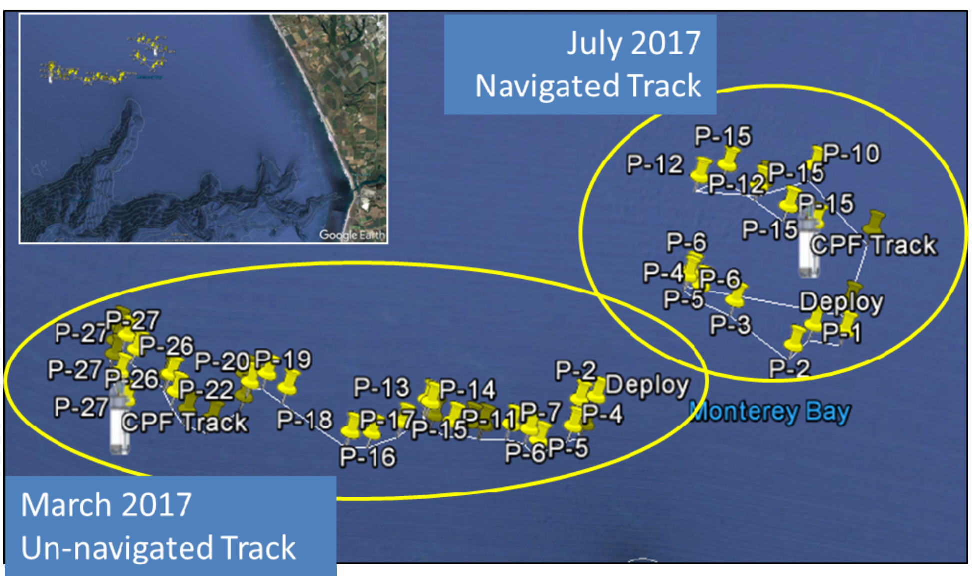


Figure 2 Results of July 2017 "navigated" mission vs March 2017 "un-navigated" mission

This experiment will include efforts to calibrate/validate the pCO_2 values estimated from float pH using Wave Gliders equipped with pCO_2 sensors. Operating the Wave Glider around the float array will provide independent assessments of the accuracy of carbon parameters estimated from float pH measurements, as well as the consistency of observations across the array and the influence of sub-mesoscale processes such as fronts. This will be of great value for the SOCCOM project in the Southern Ocean, where such comparisons are exceptionally difficult to obtain.

Engineering/technology development

Engineering/technology development will focus on extending mission duration, continuing to "robustify" the CPF, completion of the high energy density battery pack and development of a digital I/O card.

Extending mission duration: The tallest bars in our energy histogram are pumping oil to submerge and de-anchor. We have been and will continue to optimize these processes. We are continuing the refine the process of how and when to turn off and on individual subsystems in order to conserve energy. The development of a high energy density Li-ion battery pack for the CPF has been put on hold until the battery safety committee has a better set of safety guidelines for this kind of battery pack. Development of these guidelines is in progress but we don't anticipate restarting development of the CPF battery pack until after the initial pilot science experiment has been completed. At the beginning of this project, we identified floats drifting out of the desired measurement volume as a risk with a mitigation strategy using the ROMS ocean model as described earlier. We have done enough work on a second mitigation strategy for this risk that involves measuring actual float drift on the CPF using the latest generation of inertial measurement units (IMUs) that have the required accuracy, power consumption and form factor. Based on work by 2 of our summer interns, we are ready to start on a prototype and will work on this as a background task.

Robustification: We recognize the difficulty in developing a new system capable of running multi-year, autonomous missions and have been working on a test strategy to make sure we can comprehensively and effectively test the CPF. We have developed 2 tools that to enable this effort. First, Eric Martin has incorporated a formal test framework into our software development environment. This framework gives us the ability to run thoroughly instrumented (in software) tests when all systems are functional and just as importantly, inject errors and failures to make sure the unexpected is handled appropriately. Second, Pierre Baudin (summer 2017 intern) completed a hardware benchtop simulator which gives us the ability to simulate on the bench a set of profiles as if the CPF was in the water column by applying pressurized air at the CPF CTD pressure port. The simulator uses a closed loop dynamic model to ensure the simulated pressure matches the physics of the actual float profiling in the ocean. This gives us the ability to run missions that simulate real world anomalies e.g., hitting a pile of kelp during a profile or large density gradients like those off the Columbia River. In addition, the simulator allows us to run long term tests on shore with the software test framework running to help uncover bugs that may not show up until months into a mission.

Completion of the high energy density battery pack: We still have money committed for purchase of these packs but based on the initial progress of the battery safety committee; it is highly likely we will have to design and build a new controller circuit.

Digital I/O circuit card assembly (CCA): Brent Jones developed a simple prototype of this board for his work that we've been using until we could design one specifically for our needs. Unfortunately, we had to design a new battery pack and the associated CCA while we're developing high energy density pack safety guidelines and that's where the EE hours for this task went. We still need to do this in order to get a high reliability design with the required functionality and are proposing this work for 2019.

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

In 2019 we expect to run 2X 30 day experiments. We've talked to Mike Kelly and it seems reasonable to get support from the marine operations experts in DMO to help run these missions in order to keep the Chem Sensor lab staff focused on the long list of shore side operations. Running a mission consists of the following

Task	People	Days	Subtotal	
Loading the CPFs on the Paragon	1	0.5	0.5	
Deploying at the experiment site near the head of Soquel Canyon	2	0.5	1	
As a contingency we include recovering and re-deploying wayward floats	2	1	2	
Recover all the floats at the end of the experiment	2	0.5	1	
Given the uncertainty in the availability of a high energy density battery pack it may be necessary to recover, recharge and redeploy floats	2	1	2	
Per experiment total			6.5	
Total for 2 experiments			13	

We can of course provide Chem Sensor lab staff to fill in or handle whatever Paragon operations can't be handled by DMO staff.

Isotope Usage

None

Specific deliverables

1) Completion of 2 science experiments with our fleet of 3 CPFs with data publically available on the FloatVIZ website.
2) Science publication (or conference presentation) describing the tools, techniques, processes and results from this experiment.

Milestones and required personnel (see personnel classification list for staff classifications)

[Click here to enter text]

2019 Project Start Date: MM/DD/2019	**Milestone 1**	**Milestone 2**	**Milestone 3**	**Milestone 4**	**Milestone 5**	**Total Resources[4] (in hours)** for each resource category for all milestones listed here
Milestone Date	**10/1/2019**	**12/1/2019**	**12/30/2019**	**12/30/2019**	**6/1/2019**	
Milestone Description	**Completion of science experiments**	**CPF paper submitted or presentation**	**Robustification**	**Inertial current sensor**	**Digital I/O and Battery CCA**	
Electrical Engineer			**200**	**200**	**240**	**640**
Software Eng-Embedded						
Software Eng-Info Eng						
Mechanical Engineer						
Mechanical Eng-Division						
Mechanical Eng-Mfg						
Associate Engineer	**100**		**100**			**200**
Electrical Tech	**100**		**160**		**60**	**320**
Software Tech						
Mechanical Tech	**40**		**200**			**240**
Machinist	**120**		**120**			**240**
Divers						

Budget justification

We've talked to Scott Jensen about the Digital I/O CCA and would very much like to get him on this task if possible.

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

Eric Martin has been a big part of the software engineering and will be working on the robustification and the inertial current sensor tasks.

We've described using the ROMS model to help navigate the floats elsewhere in this proposal. We've discussed this challenge with Yanwu Zhang and he has expressed an interest in the problem so we've included 2 weeks of his time to help up with automating the process of deriving park depths for wayward floats from the ROMS model output.

We're looking forward to the new hire for the ME tech position. It is looking likely that this hire will have reasonable SolidWorks skills. While our drawings are in pretty good shape, it would be great to make sure all the drawings and bill of materials are complete and consistent. This is a somewhat tedious task but would be a very good way for the new hire to build better SolidWorks skills.

While we aren't proposing any significant fabrication tasks, it is prudent to expect that modifications and minor tasks will come up. Paul Coenen is an integral part of the CPF team in multiple areas and we continue to request his time specifically in addition to some generic e-tech hours. Mike Parker's is an invaluable resource for many mechanical design/build tasks and we are requesting his time and some machine shop time.

Project team

The CPF project team includes Ken Johnson, Yui Takeshita, Andrea Fassbender, Gene Massion, Eric Martin, Ed Mellinger, Paul McGill, Mike Parker, Paul Coenen, Ray Thompson, Mark Tynan and Chemical Sensor Lab personnel.

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.

The workbench we've been using in the LRAUV lab by the test tank has proven incredibly useful in our testing process and we sincerely hope we can continue to use this space in addition to the Chemical Sensor Lab. During the proposed science experiments, space in the dock house would be exceptionally useful for storage and battery charging of our 3 floats during each mission. Probably space for one of our typical folding cargo boxes is all that would be needed.

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.

We described our plan for the Paragon and operators in the Field Programs section above. We're specifically trying of offload some of the tasks from Gene Massion's task list but he is available as an operator/crew when DMO staff aren't available and we have other Chem Sensor staff who can also help where needed.

Risk matrix (development and infrastructure projects only)

	Technical Risk	Organizational Risk	Tech Transfer Risk	Labor Estimate Risk
High				
Medium	X		X	
Low		X		X

d) Compliance Considerations

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

No

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.

No

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, to the best of our understanding, the proposed work is covered under our current permit.

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 https://sanctuarysimon.org/regional_sections/maps/mpaviewer/. If your work will be conducted in one of these areas, please indicate which area by number or name (zoom in to see names of MPAs).

None of the proposed experiments will be conducted in any of the MBNMS SESAs. However, it is possible that a wayward float could drift over or touch down in SESA #6 or #8 before we can recover it, e.g. in bad weather.

California Department of Fish & Wildlife
A Scientific Collecting Permit will be required for biological and geological sample collections offshore California (even in Federal waters and beyond), and for many activities in State Marine Protected Areas. Please see Mandy Allen for questions.

Will you be collecting samples that require a permit?

No

Will you be working in a State Marine Protected Area?

Yes, the Soquel Canyon SMCA

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.

No

Active Acoustics
We are keeping an inventory of acoustic instrumentation. The current list is posted here: https://mww.mbari.org/resources/2019_Proposal_Process/documents/mbari_acoustic_instruments_2018-05-29_ver_11.pdf. If you have or plan to use equipment that is not already on this list, please be sure to include that information here.

We are using a Sonardyne 7815 Coastal Acoustic Transponder on each float