A New Profiling Float for Coastal and Upper Water Column Applications

Gene Massion, Kenneth S Johnson, Eric J Martin, Ed Mellinger, Paul McGill and Paul Coenen

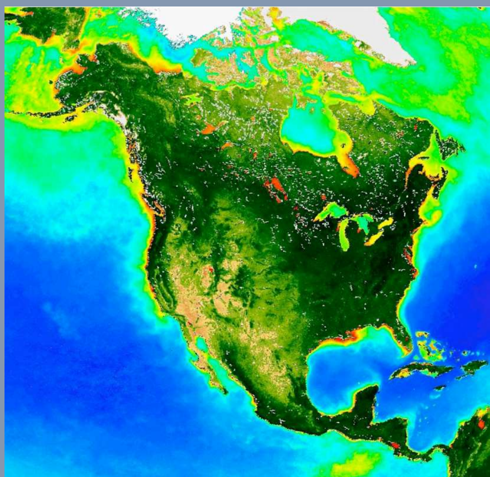
Monterey Bay Aquarium Research Institute, Moss Landing, CA, United States

Ocean Sciences Meeting, 20 February 2020

The Initial Motivation

"the widespread pattern of low returns along the West Coast for two species of salmon indicates an environmental anomaly [low nutrient production] occurred in the California Current in 2005."

More Motivation



"Further development of event-scale observing capacity (e.g., novel autonomous platforms) in all continental margin systems to better quantify impacts of episodic events on coastal carbon budgets"

A Science Plan for Carbon Cycle Research in North American Coastal Waters 2016, Ocean Carbon and Bio. Program and NA Carbon Program

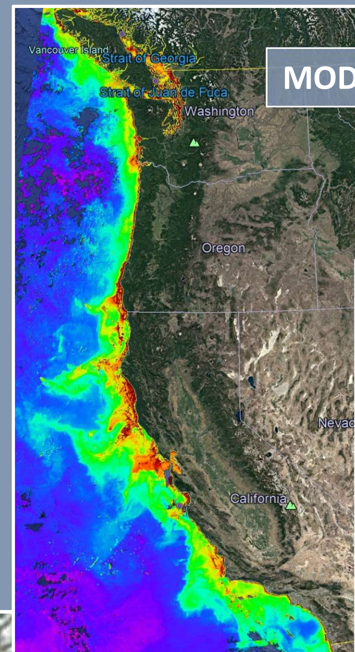
NSF'S 10 BIG IDEAS

Navigating the New Arctic

"Current Arctic observations are sparse and inadequate for enabling discovery or simulation … to assess their impacts on the broader Earth system"

Science Requirements

- A cost-effective, coastal ecosystem size observing system
- Sensor suite: CTD, O_2, pH, Nitrate, FL/BB and Optical Radiation
- Spatial Scale: coastal ecosystem, e.g., the west coast of North America
- Time Scale: up to 4 profiles/day (or more)
- 100s of profiles spread over several years
- Science targets: Fisheries, HABs, Oxygen Dead Zones, …



MODIS Chlorophyll July 2019

Devastating toxic algae bloom plagues Florida's Gulf Coast
By TAMARA LUSH (AP), August 10, 2018

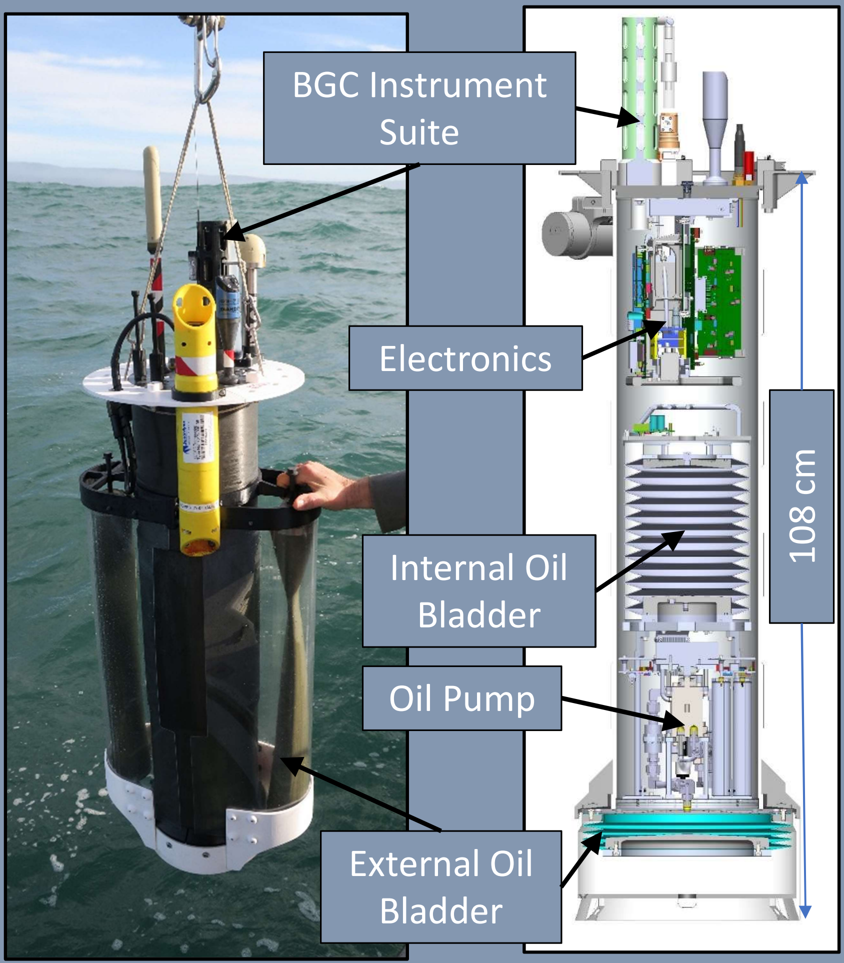
Declining oxygen in the global ocean and coastal waters
Denise Breitburg,et. al., *Science* 05 Jan 2018: Vol. 359, Issue 6371

Risks and Relevant Examples

- Risks:
  - Working in shallow, coastal water
    - Can't drift on or off-shore
    - Need accurate velocity and depth control
  - Biofouling
- Relevant Examples:
  - Profiling Floats have proven to be very effective in deep water and open ocean applications, e.g. Argo and SOCCOM
  - Coastal Floats: Univ of SF BSOP, NKE Arvor-C, MRV Alamo, etc.

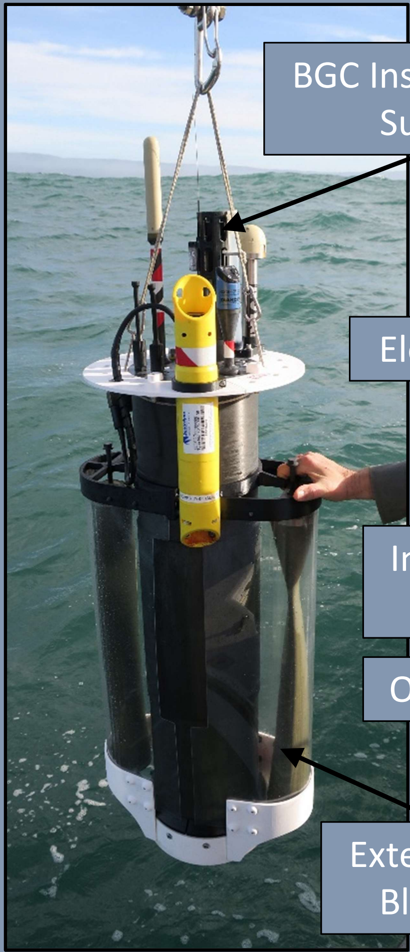
Current CPF Version 2.1 and 2.2

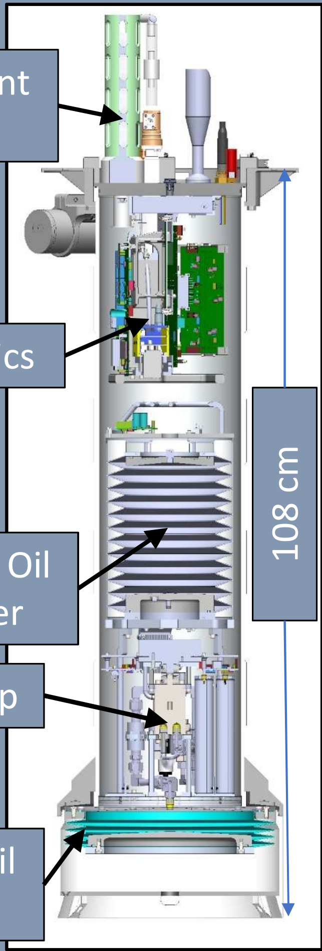
- **Depth range = 0 to 500 meters**



Current CPF Version 2.1 and 2.2

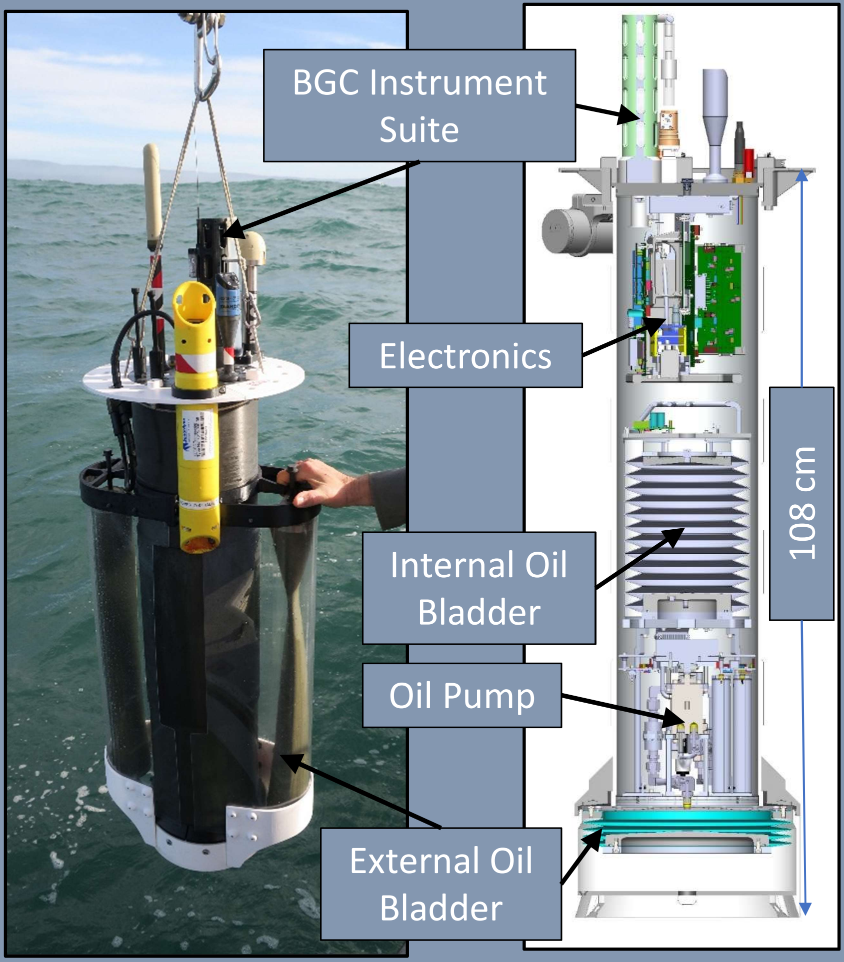
- Depth range = 0 to 500 meters
- **Buoyancy engine ΔV/V = 3.5 liters / 40 liters = 9%**
  - **Working density gradient = 1000 kg/m³ / 1025 kg/m³ = 2.5%**
  - **Vertical velocity = zero to ~50 cm/sec**
  - **Ability to anchor/deanchor**
  - **Reserve buoyancy to offset biofouling**





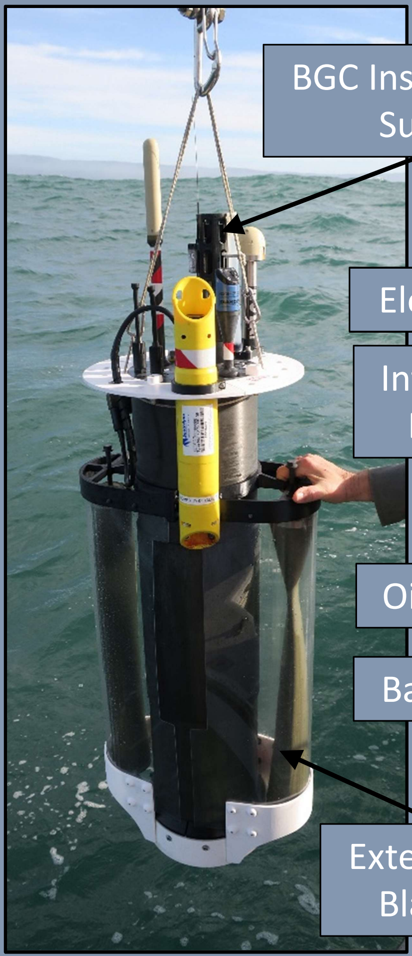
Current CPF Version 2.1 and 2.2

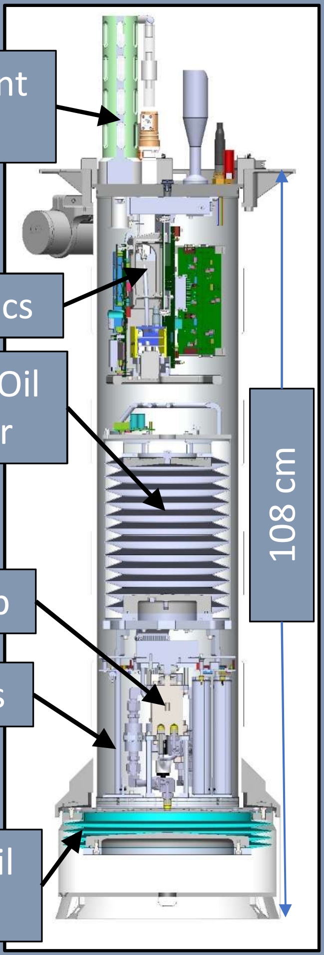
- Depth range = 0 to 500 meters
- Buoyancy engine ΔV/V = 3.5 liters / 40 liters = 9%
- **Science Payload = 9 sensor ports: 6 BGC sensors plus 3 more**



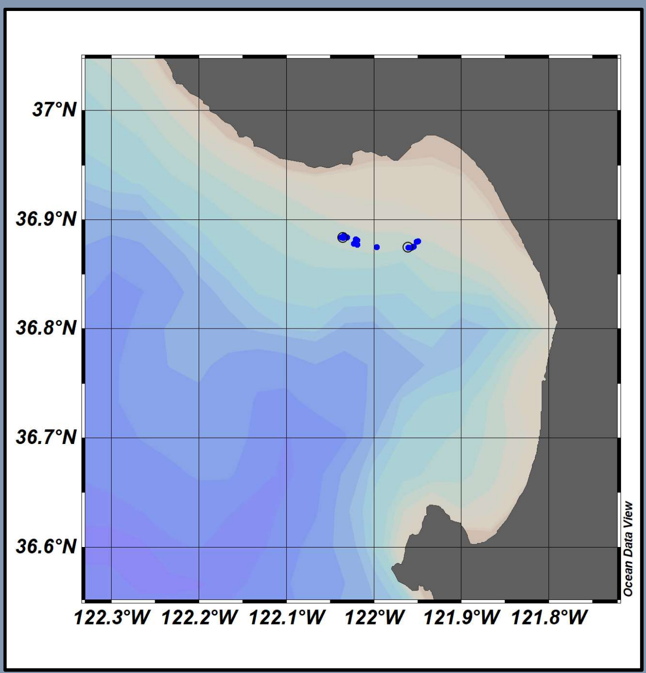
Current CPF Version 2.1 and 2.2

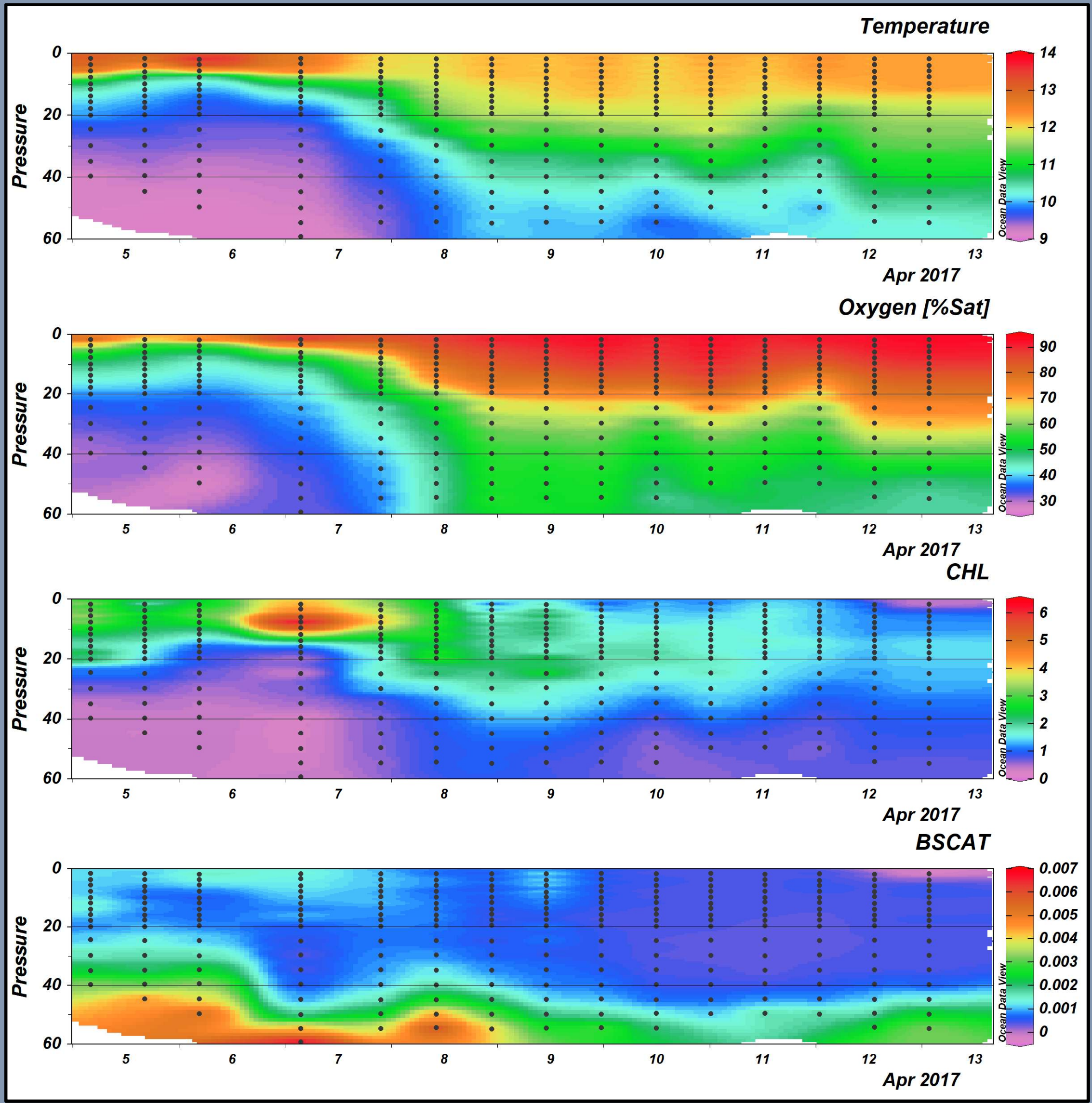
- Depth range = 0 to 500 meters
- Buoyancy engine ΔV/V = 3.5 liters / 40 liters = 9%
- Science Payload: 9 sensor ports: 6 BGC sensors plus 3 available ports
- **Iridium SBD and RUDICS communications**





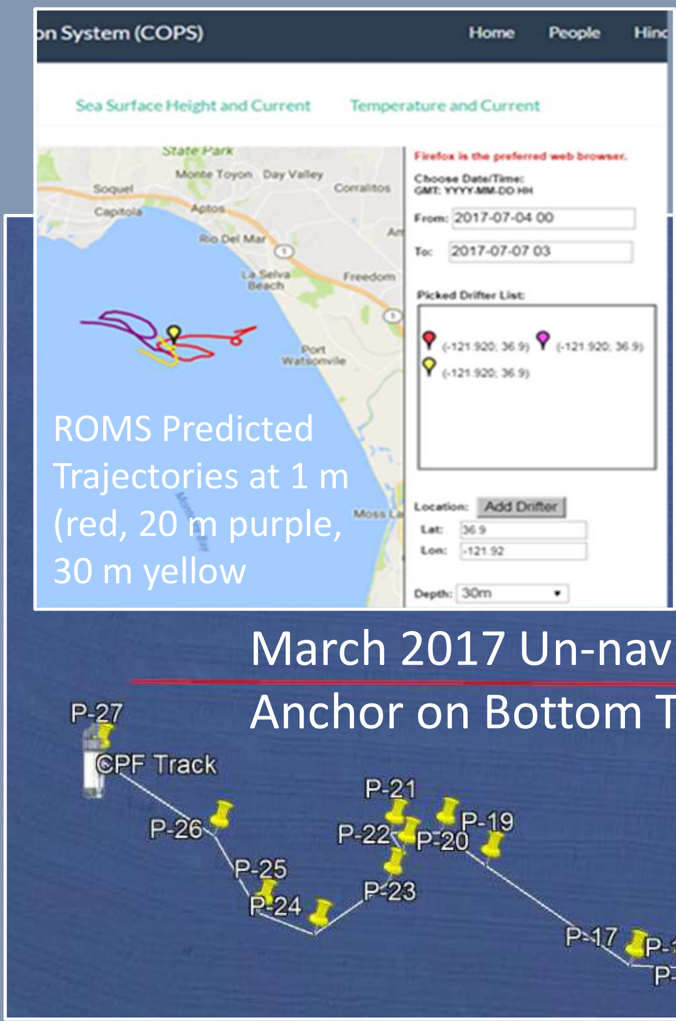
Science Data Products

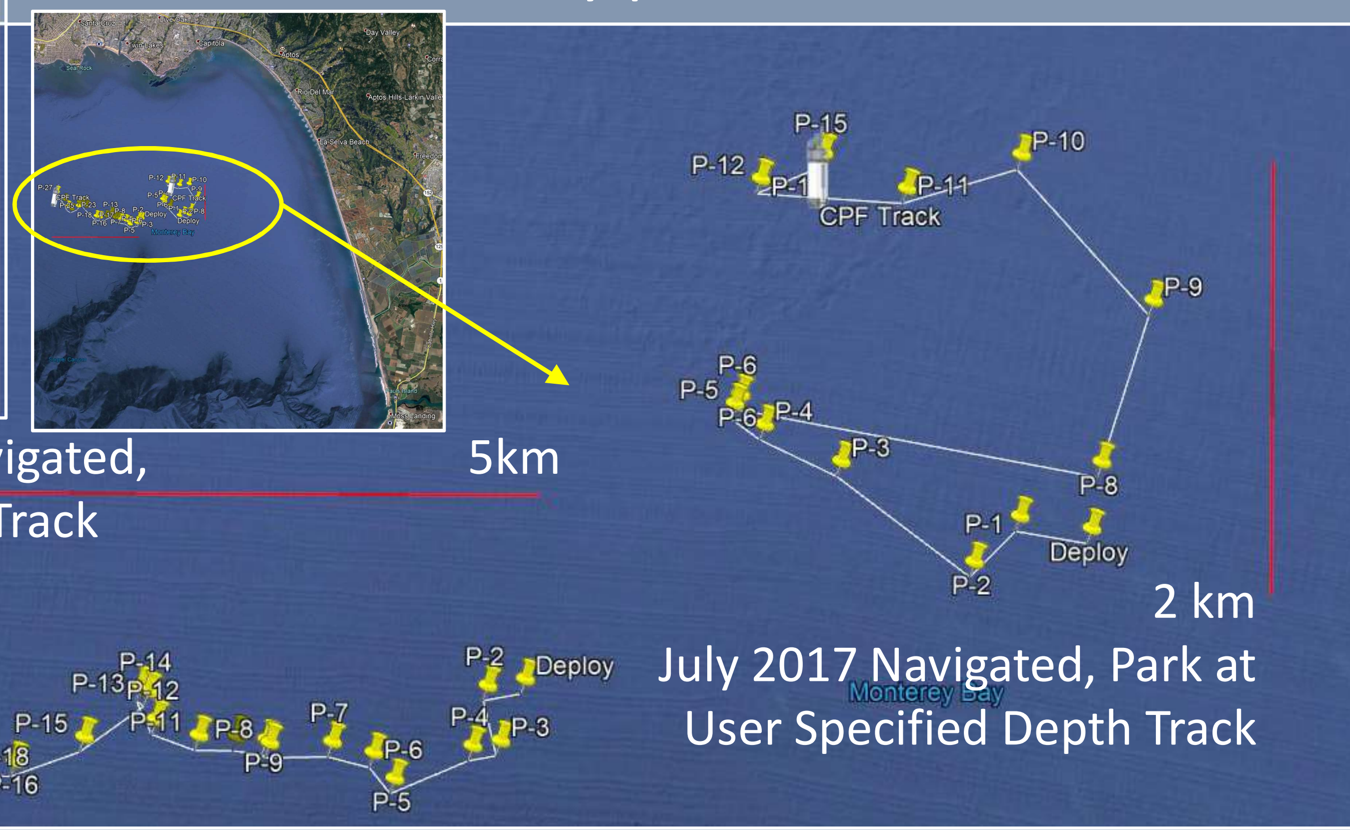




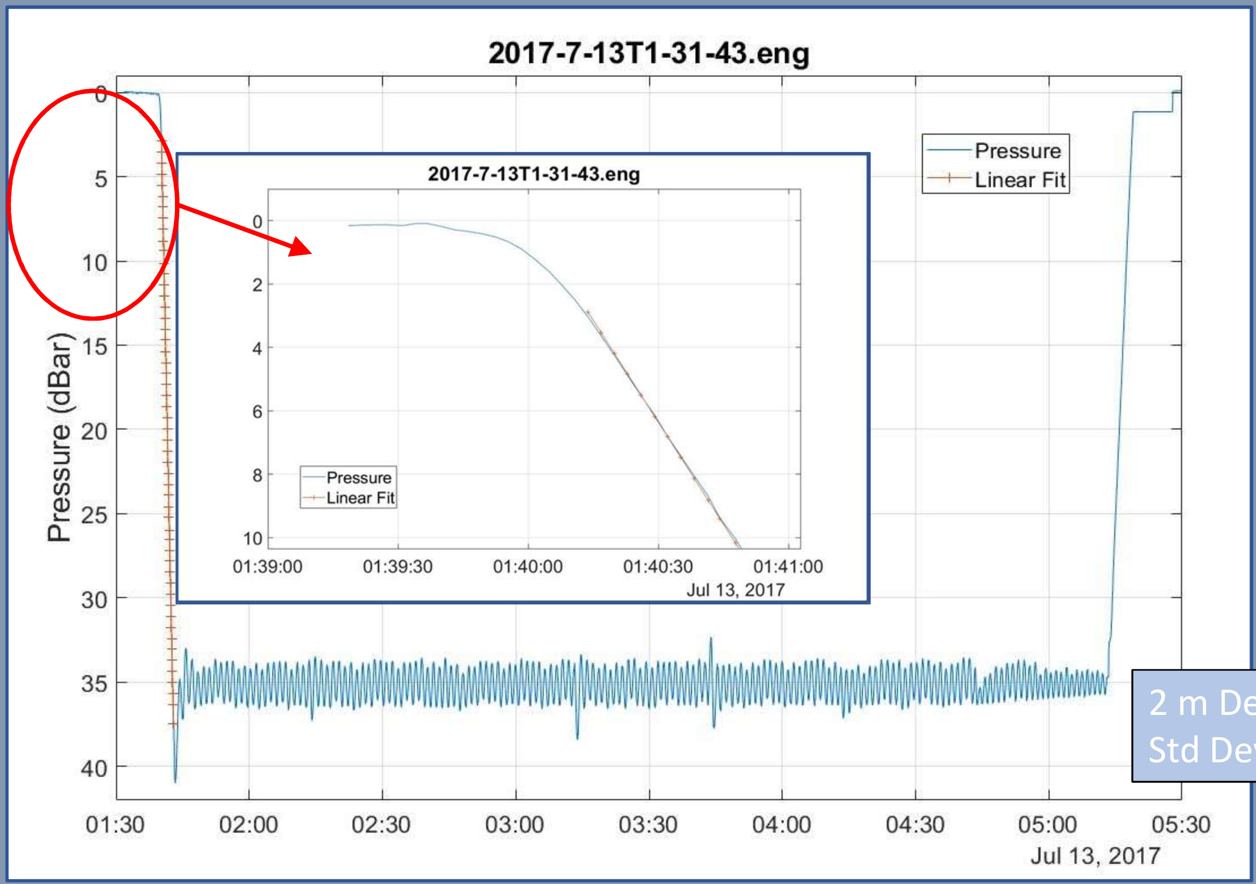
Float Navigation

- Experiment: Park the CPF at various depths and compare track to ROMS nowcast and previous missions that anchored on the bottom after every profile



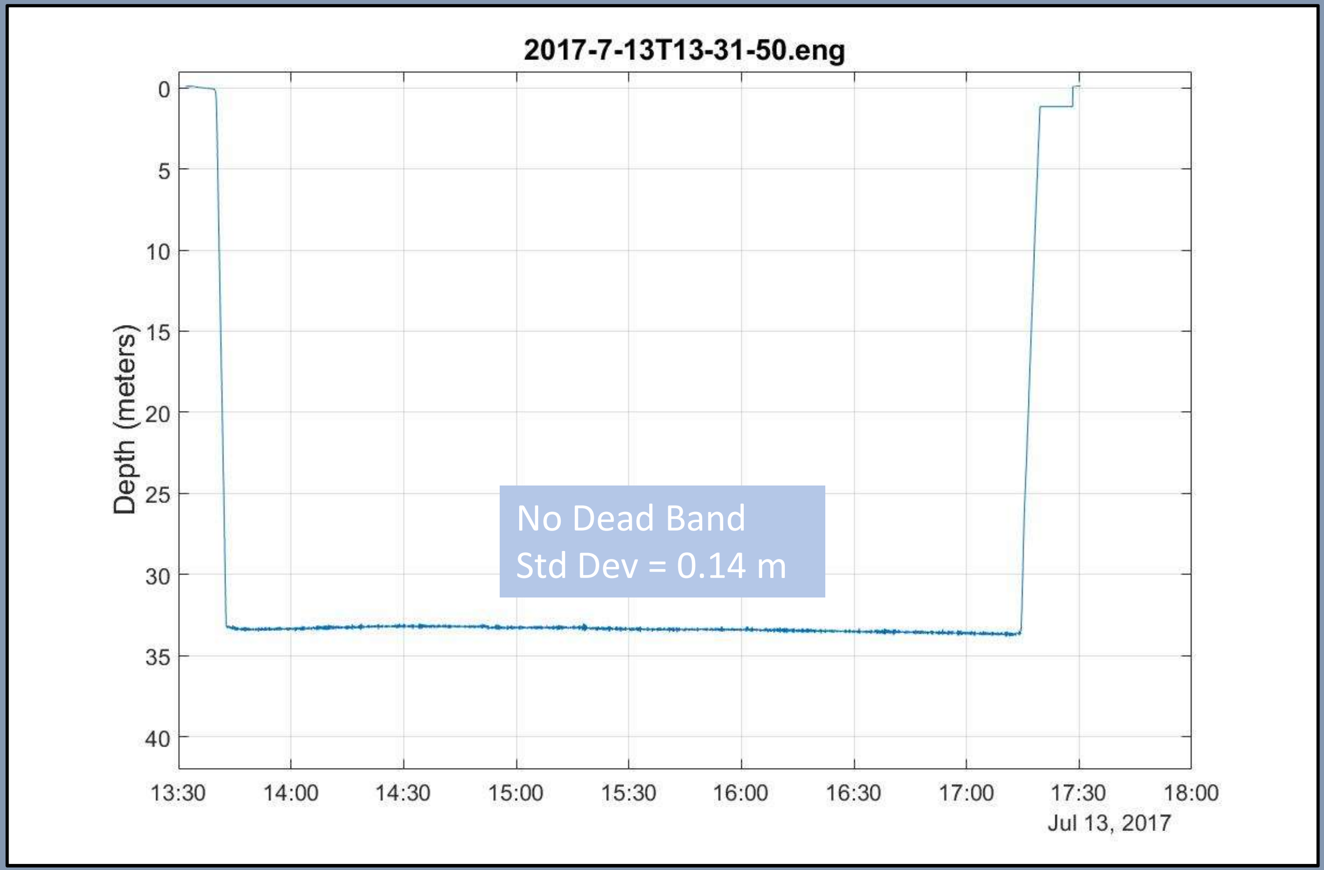


Engineering Results



2 m Dead Band
Std Dev = 0.90 m

More Engineering Results



One More Engineering Results

CPF V1.1 with sediment trap and acoustic modem

Next Steps

- Run science missions with all 6 sensors
  - The influence of lateral nutrient transfer from upwelling plumes versus canyon upwelling on the development of high chlorophyll levels in the Monterey Bay “upwelling shadow”

Next Steps

- Run science missions with all 6 sensors
- **Extend the mission duration**

Next Steps

- Run science missions with all 6 sensors
- Extend the mission duration
- **Continue enhancing reliability**

Next Steps

- Run science missions with all 6 sensors
- Extend the mission duration
- Continue enhancing reliability
- **Finish new rechargeable battery pack with 3X higher energy per cm^3**

Next Steps

- Run science missions with all 6 sensors
- Extend the mission duration
- Continue enhancing reliability
- Finish new rechargeable battery pack with 3X higher energy per cm^3
- **Supplement/replace ROMS current forecasts with small, low power current sensor based on new tactical grade moderately expensive Inertial Measurement Unit**

Next Steps

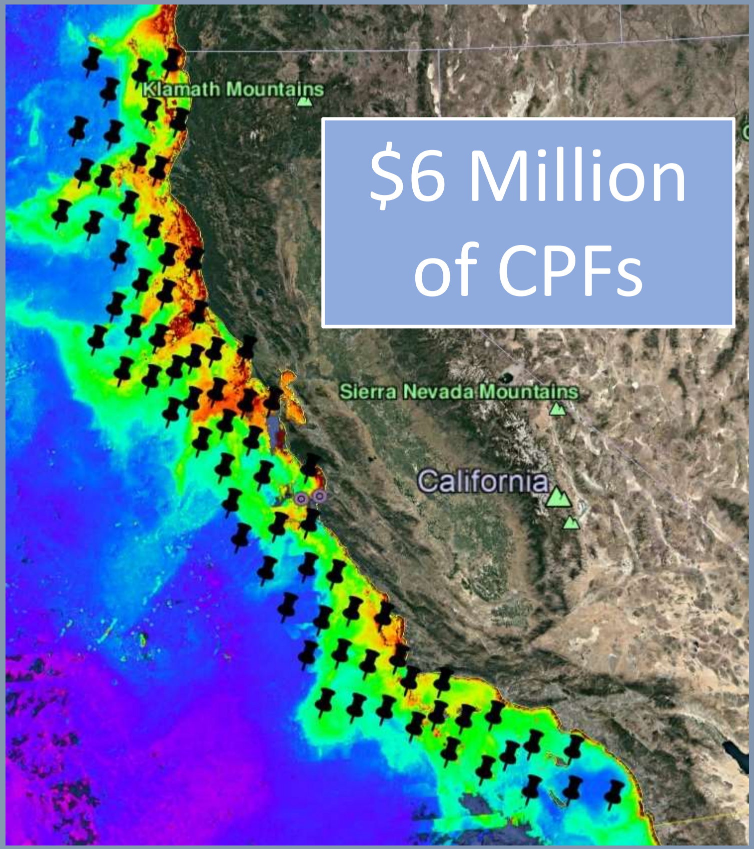
- Run science missions with all 6 sensors
- Extend the mission duration
- Continue enhancing reliability
- Finish new rechargeable battery pack with 3X higher energy per cm^3
- Supplement/replace ROMS current forecasts with small, low power current sensor based on new tactical grade moderately expensive Inertial Measurement Unit
- **Make our data freely available on MBARI FloatViz**

Next Steps

- Run science missions with all 6 sensors
- Extend the mission duration
- Continue enhancing reliability
- Finish new rechargeable battery pack with 3X higher energy per cm^3
- Replace/supplement ROMS model current forecasts with small, low power current sensor e.g. tactical grade MEMS Inertial Measurement Unit
- Make our data freely available on MBARI FloatViz
- **Make the CPF tech. available to the community**

Acknowledgements

- The CPF Village also includes: Jerry Allen, Larry Bird, Luke Coletti, Jared Figurski, Tom Marion, Jim Montgomery, Mike Parker, Josh Plant, Erich Rienecker, Jose Rosal, Aaron Schnittger, Ray Thompson and Mark Tynes
- This work has been generously supported by the David and Lucille Packard Foundation



Thank you

magene@mbari.org

NOAA scientists are reviewing unusual environmental conditions in the Pacific Ocean as the likely culprit for the dramatically low returns of Chinook and coho salmon to rivers and streams along the West Coast of the United States in 2007.
Researchers from NOAA's Northwest and Southwest Fisheries Science Centers are comparing data on the low food production of the California Current in 2005 that occurred when this year's returning salmon would have been entering the ocean from their natal streams to feed and grow.
The cold waters of the California Current flow southward from the northern Pacific along the West Coast and are associated with upwelling, an ocean condition caused by winds that bring nutrients to the ocean's surface and is the main source of nourishment for the ocean's food web.
In 2005 a southward shift in the jet stream, delayed favorable winds and upwelling for the California Current, which normally begins in spring. The winds instead arrived in mid-July, causing high surface water temperatures and very low nutrient production within the near-shore marine ecosystem.
"We are not dismissing other potential causes for this year's low salmon returns," said Usha Varanasi, NOAA Fisheries Service Science Center Director for the Northwest Region. "But the widespread pattern of low returns along the West Coast for two species of salmon indicates an environmental anomaly occurred in the California Current in 2005."
New data released by the Pacific Fisheries Management Council indicate the 2007 returns of fall Chinook salmon to the Sacramento River in California's Central Valley were approximately 33 percent of what fishery biologists expected. Projections for 2008 are substantially lower than last year's estimate.
Coho salmon returning to spawning streams in California and Oregon are also considerably lower than predicted. A preliminary analysis found an average 27 percent of the parental stock returning in 12 streams monitored in California. Even though coho returns appear to improve along the coast from south to north, Oregon Coast coho salmon had less than 30 percent of their parental stock return.
Coho salmon are listed as either endangered or threatened under the Endangered Species Act in the Central/Northern California and Southern Oregon watersheds.

Here's a first pass at the energy in Joules from one profile from the March 20-24 deployment (3.5 hour profile period) and a wild guess at what might be achievable in the future. I made my guesses and didn't change them even after I saw the pretty unrealistic total just for fun.

	Actual	Wild guess for future
Surface Ops	216	216
Retract Fast	2684	100
Retract Slow	734	500
Descend	1972	1500
Park	0	0
Anchor	49771	500
Start CP Mode	133	133
DeAnchor	1747	2500
Ascend	4737	1500
Init Profile	2	2
Surface Ops Set Bellows	5648	1500
Dump CP Data	193	193
Total	67837	8644

Our current packs have about 3000 kJoules which would suggest we should get 3000/67.8 = 44 profiles. We stopped the mission after 26 profiles with a battery voltage of 29.75. That's about half the energy available so we might have been able to get 52 profiles which is at least in the same order of magnitude as 44.

Without any derating, the new battery pack should have about 4600 KJoules. 4600 / 8.6 = 535 or so 50 meter-ish profiles. Which would be an optimistic upper limit if you believe any of these numbers.

Here's Dana's data which includes 3 kJ of energy for the ISUS

Subsystem:	percent	mean	stdDev	min	max
(257 profiles)	%	kJ	kJ	kJ	kJ
Apex(260ml):	26.5	4.02	0	4.02	4.02
Apf9i:	13.7	2.08	0	2.08	2.08
Iridium/GPS:	14.1	2.14	0.054	2.06	2.24
Isus:	19.6	2.97	0	2.97	2.97
Optode:	0.6	0.09	0	0.09	0.09
Sbe41cp:	18.9	2.86	0	2.86	2.86
Self-Discharge:	6.6	1.01	0.597	0	2.06
Total:	100	15.16	0.6	14.1	16.22

Title
Good afternoon, I appreciate this opportunity to talk about our Coastal Profiling Float project

Initial Motivation
This project started during a conversation I had with Ken Johnson. Ken runs the chemical sensor lab at MBARI and we had just finished a couple of projects that went pretty well. I asked Ken what else he had on his list of future projects and he showed me this press release from NOAA Marine Fisheries. It was released in 2008 and it attributes the low return of Salmon along the West Coast in 2007 to a lack of nutrients in 2005. You don't have to read very far between the lines to realize that fisheries managers have an exceptionally difficult job to do and very little data, virtually none in real time, to do it with.

More Motivation
Along the way there was more motivation for this project. The US Ocean Carbon and Biogeochemisty Program and the North American Carbon Program held a series of community workshops and released "A Science Plan for Carbon Cycle Research in North American Coastal Waters" A key recommendation of this plan is further development of autonomous platforms for use in continental margins. This is the target for the CPF.

NSF also released their 10 Big Ideas: 10 research topics that will be a focus of their efforts for the near future. One of the Big Ideas is "Navigating the New Arctic" where they point out that observations are "sparse and inadequate". While the arctic is not an immediate target for our work, it does seem within the capabilities of the CPF.

Science Requirements
We started the project with the usual process of defining the specific science requirements, identifying risks and developing initial concepts. It is a fairly detailed document but I can summarize the important points here …

Risks and relevant examples
The most important risks we identified were first "Working in Shallow Water'. There are a couple of issues here. Most obvious is winding up on the beach or way off shore. So we need a way to "navigate" the floats that doesn't take any power, doesn't take up much volume and will continue working without failure for several years. Next, biofouling is always a problem when working in shallow water and I'll talk about our mitigation strategies for both these issues in a minute.

My standard concept development process starts with looking around to see what good ideas I can beg, borrow or steal. There a plenty of very effective profiling floats to learn from. The Argo array and the SOCCOM project are great examples of using these profiling floats to provide a cost effective observing system at global and regional scales for deep water, open ocean applications. There are even several examples of profiling floats for coastal application but we thought there was an opportunity here to help advance this technology for coastal applications.

Current CPF
Here's what the CPF looks like today. It has the usual bits and pieces that any profiler has. An external expandable oil bladder. An oil pump, batteries, an internal oil reservoir, the electronics need to run the whole mess and the science sensor suite. We have 2 versions, one with the external bladder mounted concentrically with the pressure housing and a second version with the external bladder mounted coaxially underneath the pressure housing. Earlier, I mentioned the challenge of keeping the floats from winding up on the beach. One of our strategies for minimizing this risk is anchoring on the bottom between profiles. The concentric design minimizes the horizontal surface areas that could serve as places that might accumulate mud every time we anchor and interferes with the expansion and contraction of the external bladder. But this design is more awkward to deploy and recover. The coaxial design is pretty robust but has the potential of building up mud in the protective cover. Everything is identical in the 2 versions above the lower end cap and while we haven't done it, it is theoretically possible to swap between the versions. We will be fielding both versions to evaluate the relative pros and cons.

The depth range is down to 500 meters. One of the ways we've optimized the CPF for coastal applications is the buoyancy engine. We knew we wanted to anchor on the bottom with some modest negative buoyancy, we knew we wanted to descend fast to minimize drift while we were in the water column and we knew we weren't going to solve the biofouling issue on this project so we needed extra buoyancy to counteract the weight of the crud fouling the float, at least until the fouling made the sensors ineffective. On way to evaluate the capability of a buoyancy engine is to look at its ratio of delta V to V. Delta V is the amount the float can change it volume, basically the amount of oil we can pump from the internal bladder to the external bladder. V is the overall volume of the float. In our case, we have a deltaV / V of about 9%. For reference, if you want to work in an environment that has fresh water at the surface and typical density water at depth, you need a deltaV/V of 2.5% just to make up for the density gradient in the water column. For further reference, the profiling floats I'm aware of have deltaV/Vs of between 1 and 4%.

We knew we wanted to support the standard BGC sensor suite plus a few other, yet to be determined sensors. The current design supports the 6 BGC sensors and provides for at least 3 more. And we Iridium communications both the standard SBD, which is like 1900 byte text message, and RUDICS which is like a really slow, old school, dial up, 2400 baud internet connection.

Science Data Products

I used to work in the Engineering department at MBARI and now I work in the chemical sensor lab. One of the lessons I learned very soon after this move and continue to learn on a regular basis is that you could have the best engineered platform in the world but if you aren't generating high quality science data you're still failing. So we've been working on the tools we need to turn the files uploaded by the CPF into standard data products. Here's a few plots from one of our missions; temperature, oxygen, chlorophyll and backscatter. I'm going to play my engineer card and not try to explain the science here but even to my unscientific engineer's eye, you can see a blob of cold, low oxygen water. This data is from an early version of the CPF that didn't have the full suite of sensors. The CPFs we'll be fielding this year have the full suite of instruments and the science story should get more interesting.

Float Navigation

This slide is pretty dense, I'll try to unpack it for you. I talked about how we were going to keep the floats in the coastal zone and not in the beach without using any power on the platform. One strategy we have is to make use of the 3D current models that are run operationally, that is they get run every day and the data is available to the community. The idea is to find a current somewhere in the water column that is somewhat opposite to the overall drift of the float. UCLA and Remote Sensing Solutions run the Regional Ocean Modeling System, ROMS, which covers the California Coast. It runs every day and make a 3 day forecast. We ran an experiment where instead or our usual strategy of anchoring on the bottom between profiles, we parked at a couple of different depth and compared the track to another mission where we did anchor between profiles. You can see the big picture in the inset. Here's the northern part of the Monterey Bay, Santa Cruz to the north, MBARI is here in the middle of the Bay and here's where we have done most of our testing. Here's a blowup of the 2 missions. The un-navigated, anchoring mission has a pretty clear east west track. The so called navigated track has an overall south north trend but you can see 3 parts of the track with east/west and west/east movement which suggest the possibility of zigging west for a few profiles and then finding a depth that allows us to zig back east. This is the ROMS model output for the same time as the navigated mission. It has a very nice drop a drifter feature that is actually used in search and rescue missions where you can drop a drifter at a depth or your choosing and ROMS will predict the track based on its current forecast. There isn't an obvious correlation between the ROMS forecast and the observed track. This is very likely due to the fact that they're running the operational ROMS model with a 3 km spatial resolution for practical reasons which isn't accurate enough for our needs. The ROMS model can run at higher resolution and we've talked to Yi Chao about doing this. We are a long way from solving this problem but our initial experiment provides a slim glimmer of hope for the future.

Engineering Results
There are some engineering results that I hope are worth discussing. This is a typical depth profile. We start at the surface, descend at 20 cm/second hold depth in the water column and ascend at 20 cm/second. I mentioned the challenge of working in shallow water. One potential issue is if you're working in 20 meters of water you don't want to spend 15 of those meters trying to reach a stable profiling velocity. The inset is a zoom the first 10 meters and you can see that we acquire the desired profiling velocity in about the first 3 meters. You can also see a fair amount of oscillation while holding depth. Holding depth is expensive in terms of battery usage. Our depth control algorithm has a dead band that we can set where we don't run the buoyancy engine as a way to conserve energy. In this case we set the dead band to +/- 1 meter and, not surprisingly, the standard deviation while holding depth is about 0.9 meters.

I should point out that when you design a control system, you have to balance performance and stability. Both our depth and velocity control algorithms are designed to maximize stability and noise rejection but we're still getting pretty decent performance.

More engineering results
We also did a profile with no dead band, the buoyancy engine was running full time. In this case we were able to hold depth with a standard deviation of 14 cm.

Even more engineering results
There's a couple of points to be made here. First, MBARI's biological oceanography group built a couple of the earlier versions of the CPF for their CANON missions. Here you can see the BOG team deploying one with more stuff bolted the CPF then there is CPF. There's a sediment trap, an acoustic modem and room for a second sediment trap around the back. I think it's fair to say the CPF is much more of a pick-up truck of the sea and not so much a formula 1 race car.