

Project Number: 901112

Project Start: Jan. 1, 2011

Project Duration (in years): 5

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

☐	☐	☐	☐	☐
Feasibility/Scoping [Less than 100 days effort]	Development¹	Research	Infrastructure¹	Education
	☒	☐		
	Time Series	Institute Initiative		

Project Manager²: Tim Pennington

Principal Investigator: Francisco Chavez

Project Title:
Monterey Bay Time Series

¹ Development and infrastructure projects must complete the risk matrix (see item #5 at the 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.

1. Overview and summary

For 2013 we request continuing support for our time series proposal, ‘The Monterey Bay Time Series’, a 5 year project begun 1Jan 2011 (901112).

The MBTS investigates fundamental oceanographic phenomena. Over its 23 year run, it has

- Defined the roles of the California Current, the California Undercurrent, and coastal upwelling in our Monterey Bay oceanographic system
- Determined the nutrient and phytoplankton dynamics that support fish and mammal production off California
- Documented the impacts of El Niño and La Niña in the coastal California ocean
- Elucidated the longer-term, decade scale climate fluctuations responsible for the sardine/anchovy fluctuations
- Placed these phenomena in a global context of changing oceans and climate

These results are directly in line with the MBARI Strategic Plan and Packard Foundation goals. They have been presented as over 189 publications (web link; this number is underestimated significantly because of papers that use our data and do not report to us) and literally hundreds of talks around the world. To date, these publications have been cited over 13,000 times by our global audience (Google citation index), attesting to their impact and prominence. MBTS contributions are fundamental, will retain value, and will continue in future --- added years have enlarged the scope, application and leverage of the effort.

In addition to its scientific value, as a multidisciplinary program the MBTS (1) supports technological development of platforms that augment ship-based sampling (moorings, drifters, gliders, wavegliders, sensors, satellites and mathematical models), and (2) provides foundation and cohesion for other MBARI (i.e., CANON) and externally funded projects (\$1.2M/yr currently funded). With a flat MBARI budget we also note that the MBTS is extremely economical, running on ~\$100K/yr and 3.5 FTE,. The ratio of MBTS *science out/support in* is very, very high. This level of production will continue.

2. Current status

Nevertheless, the MBTS struggled in 2012 and has been compromised by inadequate ship availability. In 2012 by the end of May, we had completed only three MBTS cruises (with six cancelled), all on the small John Martin which suffers from a severely restricted weather window and no laboratory space. Our seagoing people have done heroic laboratory work on a lurching open deck, but data quality inevitably suffers and we are losing stations and cruises. We feel strongly that our 23 year investment in the time series must remain viable. In June we ran an MBTS cruise on the Sanctuary’s Fulmar and found this larger boat a much better platform (indoor lab space, superior stability, speed and communications). The Martin and Fulmar (\$2.43K and \$3.8K/d, resp) are both cheap relative to the Lobos or Carson (\$7K and \$12K/d, resp) but it has become clear the Martin is not large enough to effectively support the MBTS.

In this age of robots, we feel compelled to point out that ship-based sampling is not and will not become *passé*. Ships enable many of MBARI's sampling efforts, and CTD rosette sampling provides gold standard data. It is absolutely critical that the gold standard be maintained. The focus, however, is shifting to automation of routine measurements (note examples below). Increasingly, ship-based sampling will focus on gold standard data collection and process-oriented experimentation.

3. Results for the past year, 2011-2012

Below we provide brief summaries of our efforts over the past year. Some of the work is supported by additional proposals, but all is founded on MBTS core data. The MBTS 'glues' this work together.

Oceanographic state of Monterey Bay --- The MBTS. After weakening in summer 2011, cold La Niña conditions redeveloped for a second year, both on the equator and in Monterey Bay (Figure 1). Consistent with La Niña, in 2011 Monterey Bay upwelling was strong and temperature low, and nitrate, primary production, chlorophyll and centric diatom abundance all high (Figure 2). Picophytoplankton counts fell but were not negative in 2011, after unexpected abundance in 2010. This 'cool constellation of parameters' is also that predicted for the post-1998 shift to the cool eastern Pacific phase of the PDO or NPGO, which has been a major topic of interest. Interestingly, El Niño now appears to be developing on the equator; we shall be carefully monitoring MB conditions over the next weeks and months.

Oceanographic state of the California Current --- CalCOFI Line 67. BOG personnel occupied L67 three times by ship in 2011, twice with NOAA and in September on the Western Flyer (see CANON11, below). As a major accomplishment, the LRAUV Tethys successfully accompanied the Flyer to produce high-resolution sections of L67 properties. Spray gliders have also occupied L67 near-continuously over 2011-2012 (Figure 3). These multiple occupations of L67 are proud examples of constructive synergies between manned and autonomous vehicles (Figure 4 shows sections by the WF, Tethys and Spray).

GOC southbound transit 2012. In February the BOG group spent 10d on the Western Flyer, occupying CTD stations each 1° of latitude from Monterey Bay to the tip of Baja California at 20°N. The cruise was a delightful transition from subarctic to subtropical, complete with afternoon seminars offered by our distinguished participants. The main purpose was to construct an along-coast section of the Oxygen Minimum Zone to compare with our 2003 occupation of the same section. Notable declines in oxygen and increases in carbon observed in the ~100m depth range have been reported at Board meetings (Figure 5). When it reaches Monterey Bay this California Undercurrent water is typically upwelled to the surface in the spring and summer, and during 2012 resulted in the highest levels of carbon dioxide ever observed at the surface of MB (see below, CANON and wave glider). These increases in carbon dioxide are driven primarily by increased oxygen respiration (either through greater vertical fluxes or slower circulation) rather than the slow absorption of atmospheric fossil fuel carbon, and open a new paradigm for studies of ocean acidification.

2013 Proposal Process – Internal-Only Projects
Submission Deadlines: Phase I – August 2nd, Phase II – September 6th

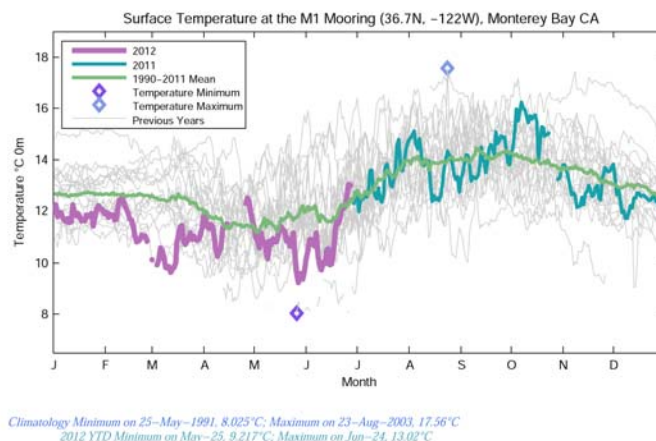


Figure 1. Sea surface temperature in central Monterey Bay, latter 2011 (teal color) and first half 2012 (purple) compared to climatology (green). 2012 has so far been a cold year, often 2°C below normal consistent with La Niña as observed over the past two years. But stay tuned --- El Niño appears to be rapidly developing on the equator.

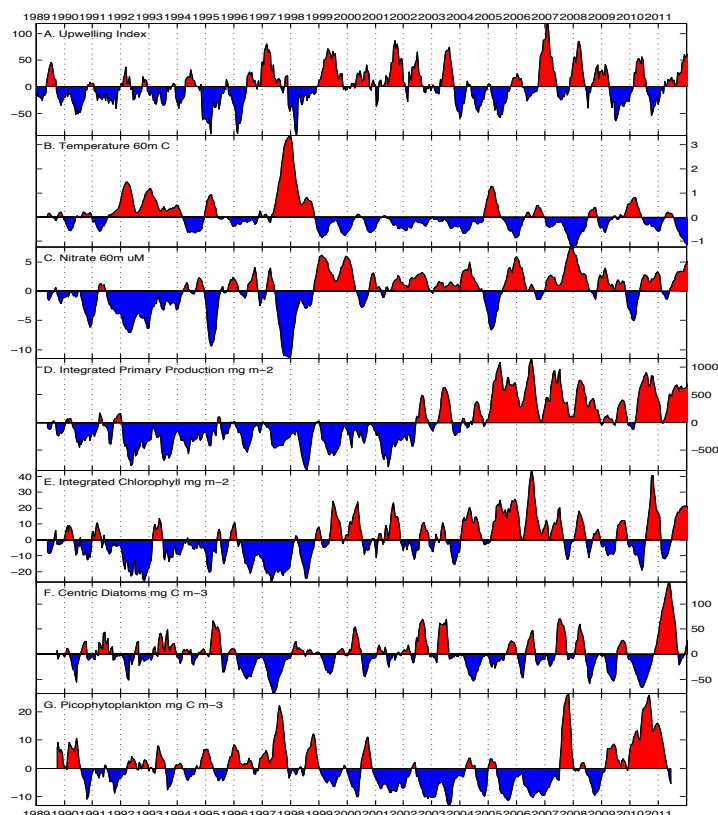


Figure 2. Anomaly plots for Monterey Bay. Consistent with La Niña, in 2011 upwelling was strong while temperature was low and nitrate, primary production, chlorophyll and centric diatoms were all high. Picophytoplankton counts fell in 2011 (unexpectedly high in 2010). The results also remain consistent with our proposed decadal shift to cold conditions after 1998.

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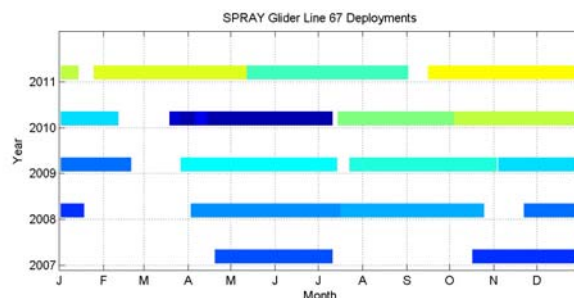


Figure 3. Spray glider deployment periods, 2007-2011. Over the last 3 years gliders have been patrolling L67 almost continuously.

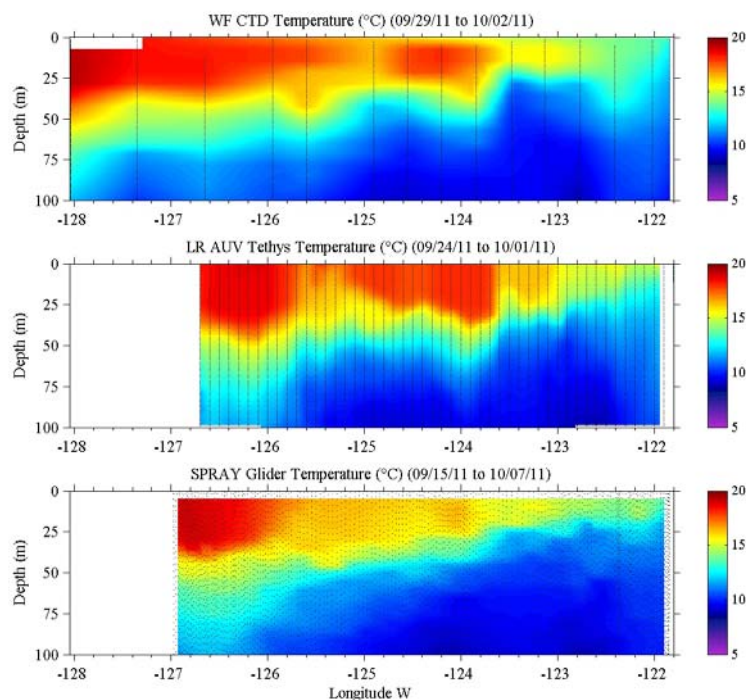


Figure 4. L67 temperature sections during California Current CANON 2011. The Western Flyer (top) produced a low resolution section to 128° W, whereas the autonomous vehicles produced higher resolution sections to ~127° W. These sections represent major advances for the autonomous vehicles. Scientists aboard the WF made many additional measurements and conducted experiments (below).

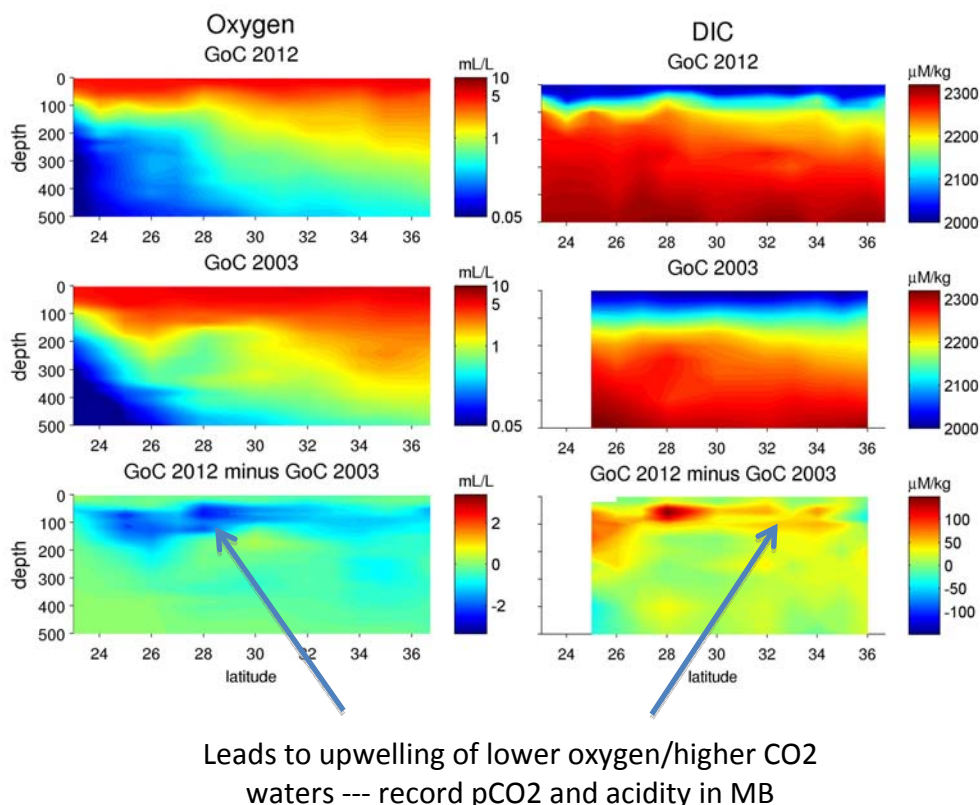


Figure 5. Gulf of California transit along-coast sections of oxygen (mL/L, north at right) in Feb 2003 (top) and 2012 (middle), and their difference (bottom). Oxygen levels were lower and carbon (DIC) levels higher in 2012 in approximate Redfield balance (~100m, bottom panels), suggesting a stronger biological pump. This shoaling of the oxygen minimum is consistent with decade scale change observed in Monterey Bay.

Monterey Bay CANON 2012. Over two weeks in May/June 2012, the BOG group supported MB CANON with day cruises aboard the Fulmar. We focused on nitrogen (esp ammonia) cycling experiments in (i) upwelling plume, (ii) front, and (iii) wind shadow waters. This year the wind was strong and upwelling favorable --- contrasts were dramatic. These data are currently being processed. The spring experiment allowed for the deployment of a wave glider with our pCO₂, pH, oxygen, T, S ocean acidification package which gave exciting results (see below).

California Current CANON 2011. Last September BOG personnel participated in a Western Flyer cruise into the California Current led by the Worden group. We conducted two drift experiments and refined our ammonia measurements (Figure 6A-B), both now focuses of CC CANON 2012. In addition we melded C14 incubations and flow cytometry to produce taxon-specific estimates of primary production (Figure 6C).

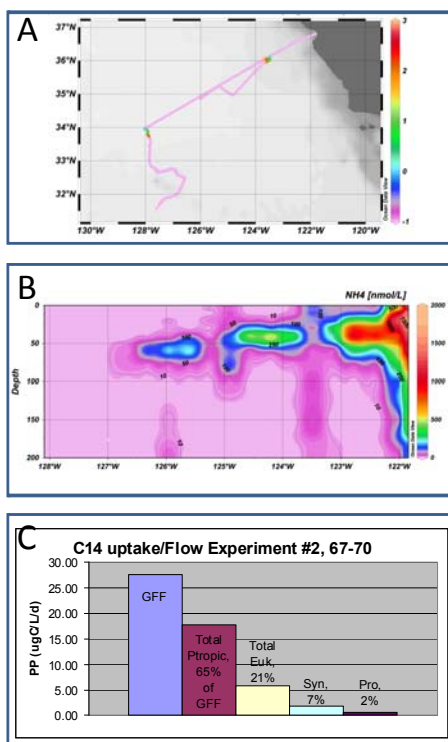


Figure 6. California Current CANON 2011: (A) Cruise track on CalCOFI L67 and the two drift experiments (green/orange segments); (B) Ammonia section on L67; and (C) C14 plus flow cytometry based estimates of primary production for phytoplankton taxa in mesotrophic waters at the inshore drift, 123.5°W.

Spray gliders. Our CalCOFI Line 67 cruises provide our inshore, Monterey Bay efforts with California Current and Pacific Basin context, and we’ve been occupying L67 by ship since 1997. The Spray gliders now collect L67 temperature and salt datasets --- at high spatial resolution --- autonomously --- almost year-round (Figure 3). During California Current CANON 2012, the Western Flyer, the LRAUV Tethys, and a Spray glider near simultaneously occupied L67 (Figure 4). The gliders and LRAUV represent a major robotic advance.

Waveglider. During MB CANON 2011, Liquid Robotics demonstrated a strange platform dubbed ‘Waveglider’. This vehicle uses wave energy to leverage a buoyant, instrumented surface platform against a weighted depressor --- the entire package is propelled forward with each passing wave while solar panels power the instrumentation (Figure 7A). We purchased a prototype command module and assembled an onboard pCO₂/CTD system (Figure 7B) that was deployed for the first time during the strong upwelling conditions of MB CANON 2012. The results are impressive. The platform punched through rough seas and maintained its programmed track while documenting the highest pCO₂ and most acidic surface water ever observed in Monterey Bay (Figure 8).

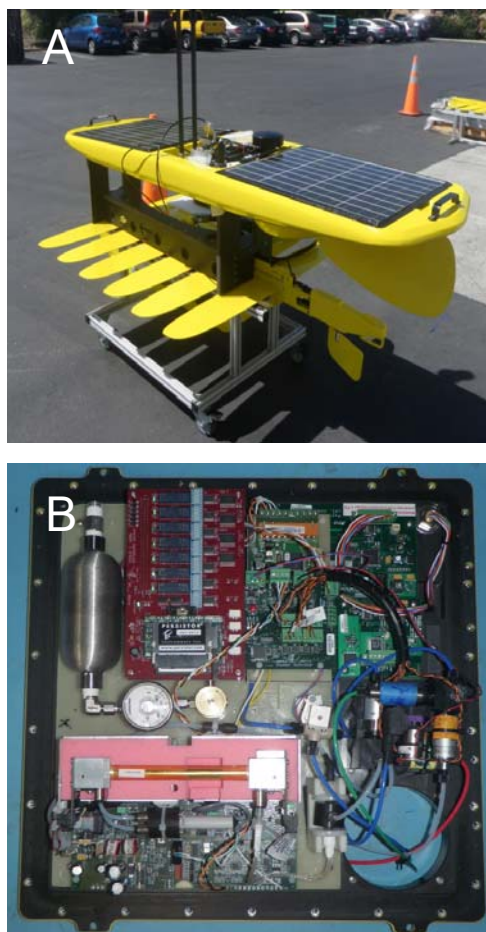


Figure 7. Waveglider: (A) Surface buoyant package with solar panels over weighted subsurface depressor plane. When deployed the depressor plane is cabled 10m beneath the platform; (B) pCO₂ sensor reconfigured from Ocean Acidification moorings to fit in the dry box aboard the Waveglider.

May 25-27 2012

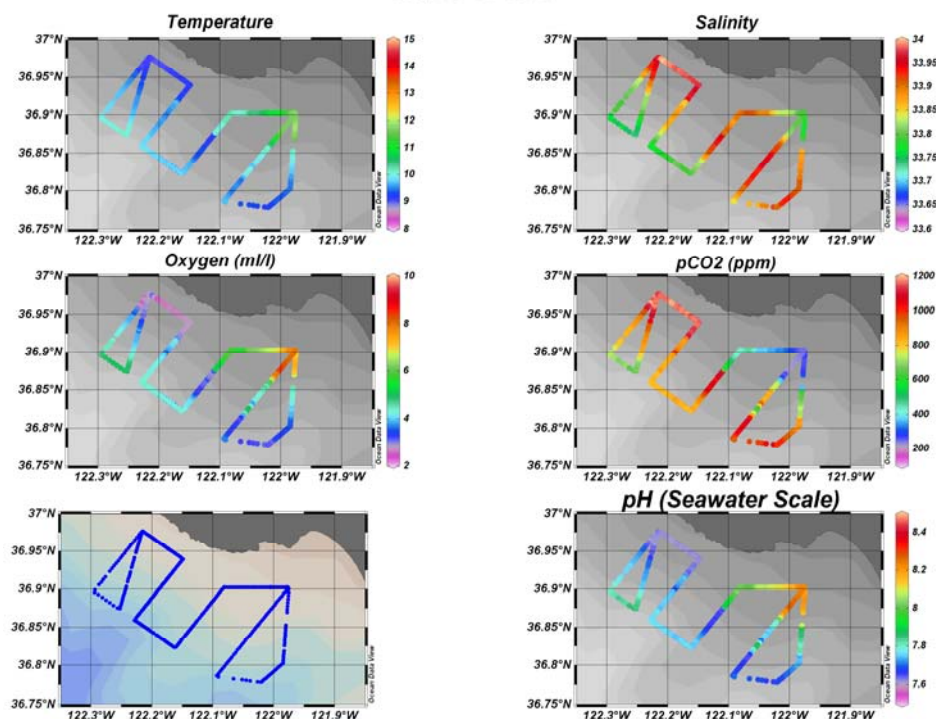


Figure 8. Waveglider track during MB CANON 2012 strong upwelling. The wave-propelled and solar-powered platform maintained its programmed course and documented the highest pCO₂ and acid conditions ever observed in Monterey Bay.

‘M’ moorings --- M1, M2H. The M1 mooring is core to our efforts (Figure 1). Mooring M2 monitors presence of California Current waters off Monterey Bay as well as providing an indicator of California Undercurrent (CU) dynamics. In collaboration with NDBC we deployed a subset of M1 instrumentation on an NDBC buoy at the M2 site as well as improving the measurement of in-water physics by NDBC. M1 and M2 temperature/salinity chain data in combination have permitted calculation of dynamic height differences between the moorings, providing valuable insight into speed and intensity of the CU. Maintenance of a minimum amount of instrumentation on M2H is of value to our program.

Ocean Acidification --- Key ecosystem components. We have leveraged funding from NSF to advance our capabilities to sense the coastal ocean in relation to ocean acidification (Figure 9). In addition to developing a pH sensor for intertidal applications we have developed a small coastal mooring system whose electronics were modified for the wave glider application described above.

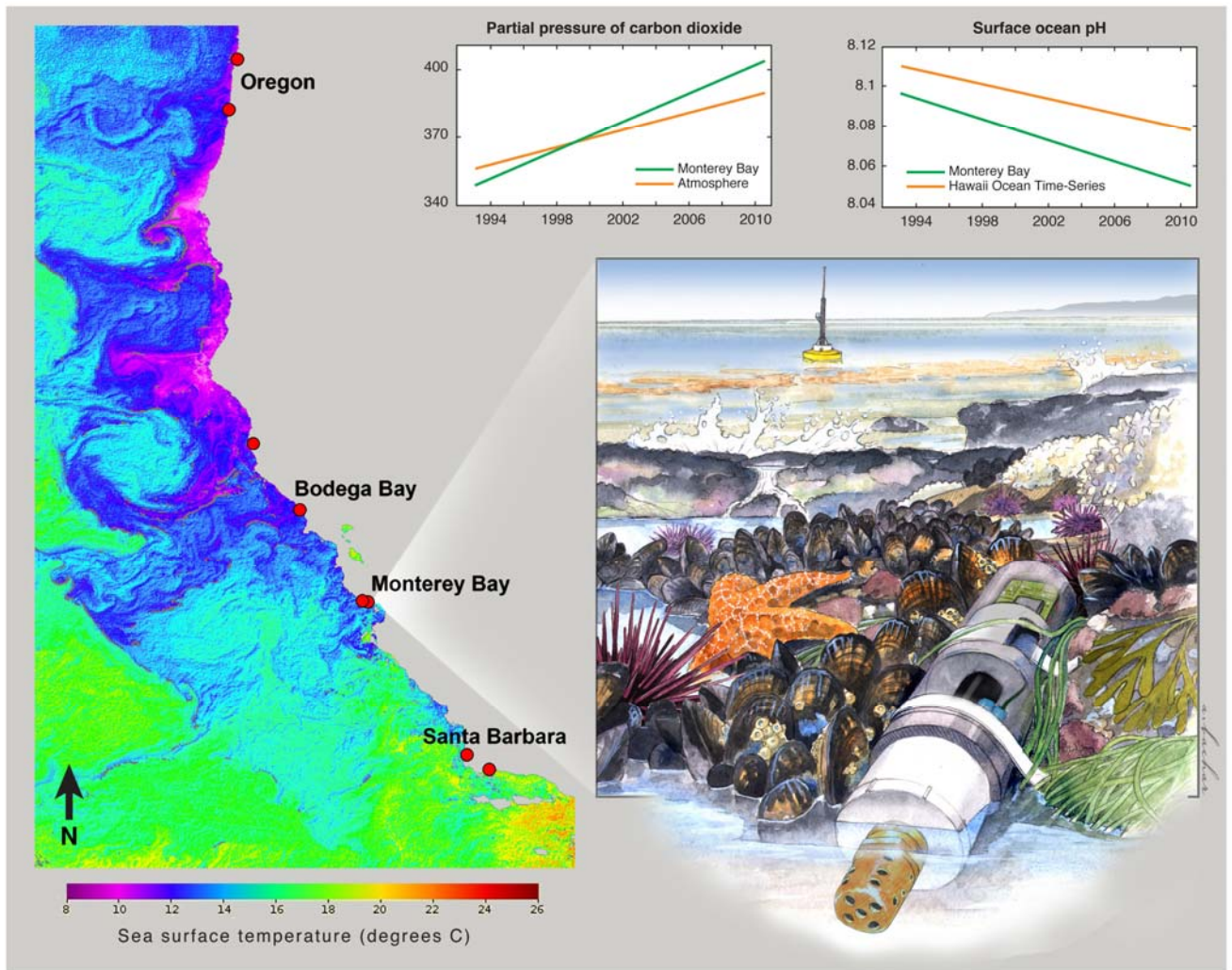


Figure 9. Ocean acidification moorings. With NSF funding we are monitoring ocean pH both with moorings and in the intertidal along the west coast. Near surface acidification is increasing as CO₂ levels rise, due apparently to a stronger biological pump as suggested by our GOC and other results.

Utilizing ecosystem information for management of central California salmon. We have also leveraged funding from NASA to gain access to state-of-the-art coupled physical-biogeochemical models (validated with data collected by our team) to improve a decision support system for management of central California salmon. One of the surprises has been the accuracy with which large zooplankton appear to be simulated (Figure 10). These model results have in turn stimulated the Fall 2012 CANON experiment, focused on ammonia produced by zooplankton.

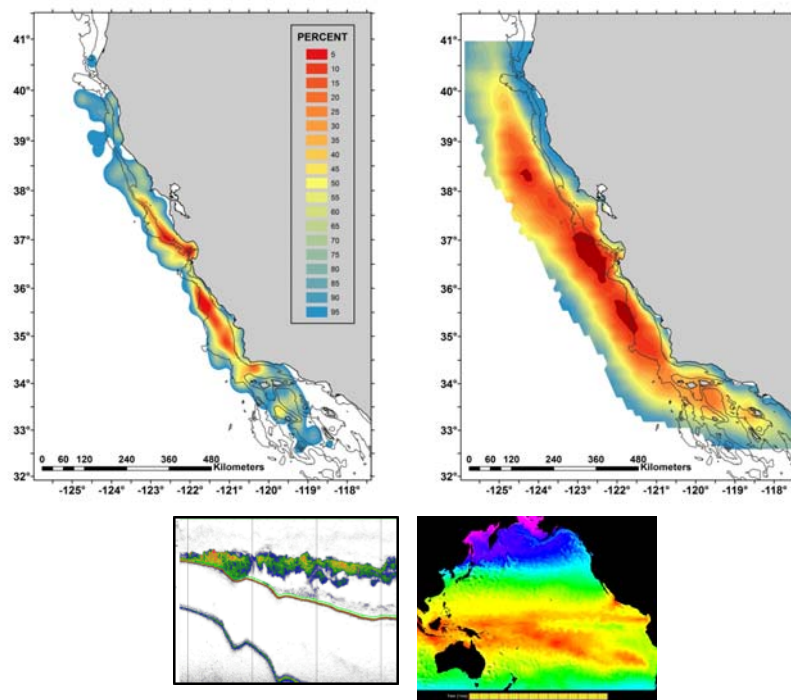


Figure 10. Abundance of large zooplankton in the California Current System. The upper left panel is based on empirical sections of acoustic data (lower left panel), whereas upper right panel are model results (lower right panel is model domain).

4. MBTS-related publications (last five years – for publications since 1989 see <http://www.mbari.org/bog/publications/>)

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5. Plans for next year, 2013

a. Research activities

We will continue with time series activities described above (and below) with focus on autonomous systems reducing the dependency on ship occupations, greater efficiency of ship operations, integration with other time series efforts and analysis of physics to ecosystems optimal coastal observing units. These will be approached as follows:

- Work with our CANON collaborators to develop tools that will eventually subsume the critical elements of the time series.
- Work to make the Carson an effective multi-use platform in collaboration with other MBARI programs and the management team.
- Work with time series mid-water (Robison) and benthic (Smith) time series efforts to lower costs and develop integrated systems and conceptual models. Emphasis in 2013 will be on data integration.
- Work with external partners (locally, regionally and nationally) to develop a roadmap of how recent developments in autonomous vehicles, molecular techniques, and acoustics can be used in the design a coastal observatory that provides a mechanistic understanding of how changes in climate and ocean physics are linked to primary productivity, zooplankton, living marine resources and top predators.

b. Field programs

MBTS cruises. We remain committed to building consistent climate-quality datasets with occupations of stations C1, M1 and M2. In 2012 we attempted to use the John Martin but this boat is too small --- for 2013 we propose to develop the Carson's capabilities supplemented by the Fulmar. The MBTS provides foundation and cohesion for much of the work summarized above.

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Support is requested to continue the MBTS cruise series sixteen times annually. We request eight cruises aboard the Carson, one cruise each 3 weeks, to be scheduled with AUV-CTD deployment days and other compatible efforts. Funding is also requested for 4-12 cruises aboard the Fulmar to fill in the time series calendar.

CalCOFI Line 67. The L67 cruise series is expected to continue in 2013 with NOAA funding 2-3 times annually. California Current CANON relies heavily on our current and past L67 data collections. Inclusion of process-oriented/experimental studies adds value to our traditional L67 surveys; the ‘primary production of FCM-sorted taxa’ material above (Figure 6) was generated during the California Current CANON 2011 cruise. We also expect to continue the SIO Spray glider deployments on L67.

Southern California CANON 2013. Our lab will have minor involvement in the CANON ECOHAB Southern California experiment.

Monterey Bay/California Current CANON 2013. Our lab will be actively involved in the CANON ECOHAB Monterey experiment with an emphasis on nitrogen budgets. No additional funds are required.

Ocean acidification moorings --- Inorganic carbon cycle. For almost 20 years we have measured pCO₂ and DIC from moorings and ships, permitting calculation of ocean pH. pCO₂ has risen and pH fallen (more acid) at a faster rate in Monterey Bay than in the atmosphere and the central Pacific, respectively (Figure 9, upper right). These Monterey Bay changes are due to (i) upwelling of subsurface water that has been exposed to increased remineralization of sinking phytoplankton and (ii) ocean absorption of atmospheric CO₂. In 2011, in collaboration with PISCO and with support from NSF, we deployed two pH moorings, one off Long Marine Lab in Santa Cruz and the second off Hopkins in Pacific Grove.

We continue with our time series measurements of pCO₂, DIC and alkalinity which provide core long term information for the California coast.

Gliders. We will continue to support the L67 occupation with Spray gliders, work with Teledyne Webb and UCSC on Webb glider deployments and with Liquid Robotics on wave glider developments and deployments. Support for this activity comes from CeNCOOS, Scripps, UCSC and NPS.

c. Engineering/technology development

Waveglider. This platform brings the possibilities of continuous temporal and spatial coverage, communications, better bio-fouling control and increased payloads for samplers. We will continue to work with Liquid Robotics and external collaborators to improve on present payloads and add new capabilities. A small amount of SE time (Herlien, 50 hours) is requested.

Drifters. Our lab developed a robust low cost drifter that has been used repeatedly by our lab, CANON, Autonomy and several other MBARI projects. The drifter is based on a SPOT tracker and total hardware cost is about \$250. We propose to exploit the rapid development of commercial low-cost mobile computing and sensor platforms by taking a prototype instrument data logger (developed by O’Reilly and Risi) that runs on an Android device (e.g. phone or tablet) and deploying it as a test on the low cost drifter. The Android logger application developed by O’Reilly periodically retrieves data from

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one or more RS-232 instruments as well as onboard phone sensors (e.g. GPS, accelerometer, compass). The app then telemeters the retrieved data to shore via the cell phone network or a SPOT satellite modem. Such a data logger could have several applications including low-cost moorings, drifters, or pier-mounted deployments. Here we propose to refine this prototype on our drifter and deploy it in Monterey Bay with a pH sensor and telemeter the information together with location via the same SPOT device. The following tasks are required prior deployment:

- Refine app software; onboard data log, thermistor "driver", data summary for SPOT telemetry, improved interface to SPOT modem, Android OS power management - 2 weeks O'Reilly
- Power management; Power measurements, PIC microcontroller for power control of Android device and perhaps SPOT modem, instrument: 2 weeks Risi
- Evaluation of Android "BeagleBone" as lower-power lower-cost alternative to Android phone - 2 weeks O'Reilly

d. Budget justification

A detailed budget has been entered in the web-based form. Below we have grouped costs by subject.

General lab expenses

- \$5000 science lab supplies for general A285 laboratory supplies and maintenance.
- \$4000 computer software supplies for new or upgraded software and software contracts.

MBTS

- We request eight *Rachel Carson* days at regular intervals as can be scheduled. We propose to use these days in collaboration with AUV CTD days requested by others (Rajan, Vrijenhoek, etc.), with mooring maintenance or other activities that do not require full day use of the ship. We will rely on the management team and DMO to orchestrate these collaborations during Phase 1 review.
- Depending on how many days on Carson we can schedule with other projects, we also request 4-12 *Fulmar* days at (\$3000 per day + \$800 set up day before) to complete the MBTS calendar. As described above the *Fulmar* is a capable vessel. For time series integrity we require a minimum of 12 combined *Carson/Fulmar* days. The *Martin* can be used but it is a less desirable choice. We have entered 12 *Fulmar* days in the 2013 request.
- \$5000 supplies for general cruise equipment --- normal upkeep of pumps, manifolds, incubators, etc.
- \$2800 supplies for MBTS cruises --- 50 mCi C14 expendable radioactive isotopes.
- \$6400 supplies for MBTS cruises --- all other expendables (12d x 4sta/d x \$133/sta).
- \$10,000 outside subcontract for analysis of POC, N15, HPLC and flow cell cytometry samples collected on the MBTS and California Current/Line 67 cruises. These samples cannot be analyzed at MBARI and are exceedingly important parts of the MBTS and SECRET data collections.
- \$21,000 outside subcontract for analysis of EFS of phytoplankton by Sara Tanner, MLML (84 samples x 10 hrs/sample x \$25/hr; MBTS, L67).

CalCOFI Line 67 cruises

- \$2000 supplies for two cruises --- expendables (2 cruises x 10 sta x \$100/sta).

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- \$2000 outside subcontract for seagoing personnel to support 4 cruises aboard ships of opportunity. These are primarily grad students at UCSC or MLML or interns from CSUMB who assist at sea for \$50-100 daily.
- \$1000 domestic travel to cruises.
- \$600 domestic travel truck rental for cruises.

Inorganic carbon time series along Line 67

Sea surface pCO₂ mapping:

1. Infrared analyzer calibration and maintenance:	\$1000
2. Primary gas standard:	\$1000
3. Chemicals and supplies:	\$1500

Sea surface and water column TCO₂:

1. Infrared analyzer calibration and maintenance:	\$1000
2. Standard reference materials:	\$2000
3. Chemicals and supplies:	<u>\$1500</u>
Total:	\$8,000

Conference expenses

- \$5250 domestic travel for one conference each for Pennington, Michisaki, Friederich (3 people x \$1750 ea).
- \$2500 travel for Chavez

e. Project team

- Francisco Chavez (Sr. Sci.) is responsible for project direction, connection to other MBARI programs and the scientific community, data synthesis, publications --- 130 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).
- Gernot Friederich (Sr. Res. Spec.) Develops and deploys sensors and platforms and analyzes data from ship-, mooring- and drifter-deployed systems, with emphasis on pCO₂ and data 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).
- DMO-CTD Instrumentation technician Erich Rienecker will operate CTD and other systems on MBTS cruises --- 264hrs (12MBTS + 10GOC days x 12hr/day) We request at-sea and data-processing support from Erich on non-MBARI vessels as part of MBTS and CANON.
- Monique Messie' (Res. Ass.) develops and validates models --- externally supported.
- Marguerite Blum (Res. Tech.) processes and quality controls nutrient samples, analyzes O₂ and TCO₂ samples, organizes and participates in California Current cruises --- externally supported.
- Chris Wahl (Res. Tech.) assembles instrumentation and supports glider operations --- externally supported.

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- Jules Friederich (Res. Tech.) writes code and assembles wavegliders --- externally supported.

f. Project lab space

Our current lab space is excellent.

g. 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

In collaboration with Curt Collins and scientists in Peru and Ecuador we are discussing use of the Point Sur on its transit to and from the Southern Ocean. The only pieces of MBARI owned equipment would be underway pCO₂ and FRRF. This work would be supported by NSF.

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.