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# CalCOFI – A 63-Year-Old Ocean Observing System

*by Ralf Goericke and Tony Koslow (UCSD, Scripps Institution of Oceanography)*

In response to a collapse of the California Sardine fishery in the latter half of the 1940s, fisheries managers and stakeholders implicated either environmental degradation or overfishing. Although they did not reach consensus on the primary driver of this collapse, they did employ a typical political solution: "to study the problem," hence the birth of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program, a partnership of the Scripps Institution of Oceanography (SIO), the NOAA National Marine Fisheries Service (NMFS), and the California Department of Fish & Game. Thus far, nothing unusual had happened; in response to an environmental crisis, a political solution had been implemented. This, however, changed once scientists were charged with planning the program. At a meeting at Stanford University in 1947, the objective of the program was defined as

*"...investigating the sardine in relation to its physical and chemical environment, its food supply, its predators and its competitors, in attempting to evaluate the findings in terms of the survival of the young, and in terms of the distribution and availability of the sardines when they reach commercial size."* (California Cooperative Sardine Research Program Progress Report, 1950).

This statement was drafted only 5 years after the publication of the classic paper *"The trophic-dynamic aspects of ecology"* (Lindeman, 1942), the birth of ecosystem ecology. It predates the concept of ecosystem-based management of fisheries by 4 to 5 decades. This partnership between fishery agencies and an oceanographic institution established a program to meet the ongoing needs for stock assessment and fishery management within an ecosystem and ocean observation context. Underlying the CalCOFI program today remains a community of scientists who hold an annual symposium, publish a journal (*CalCOFI Reports*), and collaborate on a wide range of topics of relevance to understanding the California Current ecosystem. Today CalCOFI data, publications, information about the CalCOFI cruises and the

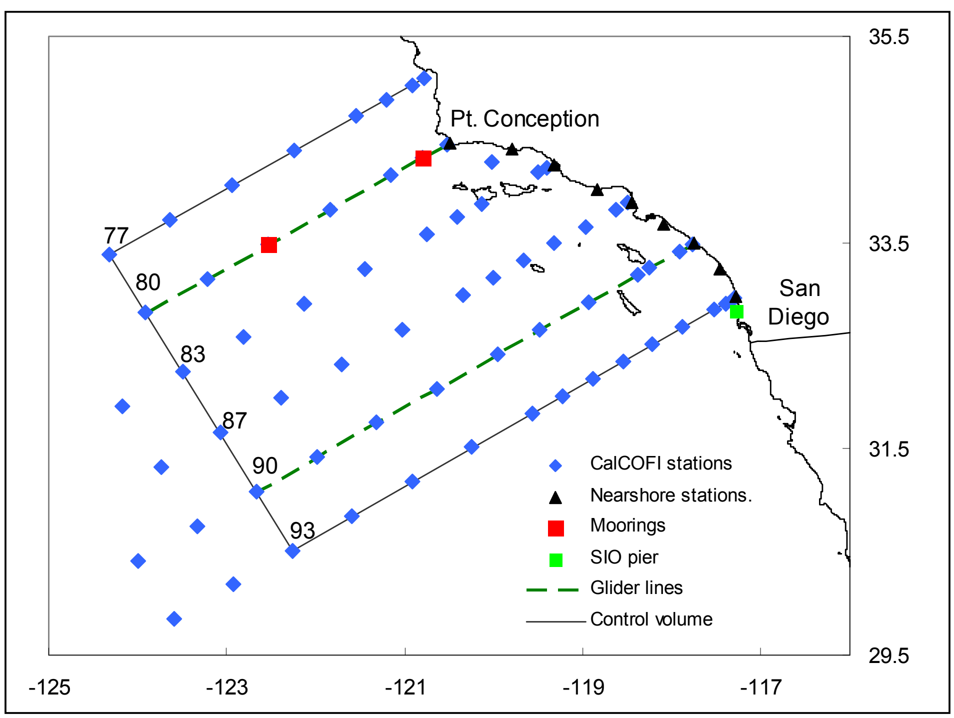



**Figure 1.** Map of current CalCOFI stations. The 66 standard stations have been occupied quarterly since 1984. A set of nearshore stations was established in 2004, providing the opportunity to characterize nearshore processes in the context of larger-scale dynamics. The CCE-LTER program carries out basic sampling at all 66 stations, with more focused sampling at stations on lines 80 and 90. Gliders operate continuously on these two lines. The CCE-LTER program and others operate two moorings at stations on line 80.

larger CalCOFI program are publicly available at www.calcofi.org.

For its time, the CalCOFI Program was implemented on unprecedented temporal and spatial scales, with monthly surveys involving 2 to 5 ships sampling the ocean from northern California to mid-Baja, California. Over time, funding cuts gradually reduced the spatial and temporal frequency of these cruises, and by the second half of the 1960s, systematic surveys were undertaken at times only every third year. In the early 1980s, the program was reconceived as a time-series program, and the current format of quarterly cruises covering 66 stations off Southern California was adopted (Fig. 1). These early years resulted in significant achievements, including the identification of a ~60-year natural cycle in the abundance of sardines and anchovies (Soutar and Issacs, 1974), understanding the impacts of El Niño on marine invertebrates, fishes, and birds (Sette et al., 1960; Chelton et al., 1982), understanding the correspondence between biogeographic distributions of planktonic organisms and large-scale ocean circulation (Fager and Mcgowan, 1963), and much more. Today, scientists from around the world continue to draw on CalCOFI data, primarily to elucidate the response of the ocean to climate change. Over the last year alone, more than 50 publications have drawn upon CalCOFI data.

Although the spatial scale and frequency of CalCOFI sampling have been reduced since its inception, the intensity of sampling has steadily increased. With the exception of dissolved oxygen, CalCOFI investigators did not initially focus much attention on the biogeochemistry of the California Current system. This changed in 1984 when measurements of inorganic nutrients and primary production were added to the core measurements, and in particular, in 2004 when the California Current Ecosystem Long-Term Ecological Research site was established. The current list of measurements carried out on CalCOFI cruises is shown in Table 1. The CCE-LTER program focuses on three main tasks:

- enhance the CalCOFI program with additional measurements to further elucidate plankton community structure and the biogeochemistry of the system;
- carry out process studies that probe the mechanisms that drive the system; and
- perform modelling studies designed to synthesize the CalCOFI and CCE-LTER data and provide new hypotheses for further field studies.

| Observed Variable | Observer |
|---|---|
| Temperature, salinity (CTD system) | CalCOFI |
| Oxygen*, Salinity*, Temp.* (bottle samples) | CalCOFI |
| Nutrients (N, P, Si) | CalCOFI |
| Upper ocean currents (ADCP) | CCE LTER & others |
| Underway $pCO_2$ | others |
| Underway pH | CalCOFI, others |
| $TCO_2$, TAlk | CalCOFI, others |
| Particulate C & N | CCE LTER |
| Dissolved C & N | CCE LTER |
| Bio-optical properties | CCE LTER |
| Phytoplankton biomass | CalCOFI |
| Primary production | CalCOFI |
| Phytoplankton Community Structure (HPLC, microscopy) | CCE LTER |
| Bacteria & picoautotrophs (flow-cytometry) | CCE LTER |
| Nano- & microheterotrophs (microscopy) | CCE LTER |
| Zooplankton*, ichythyoplankton* | CalCOFI |
| Mesozooplankton, size classes, species, species groups (microscopy, zooscan) | CCE LTER |
| Krill, micronekton, small pelagic fish (microscopy) | NMFS, others |
| Seabirds, Marine mammals | CCE LTER, others |

**Table 1.** List of measurements currently made on CalCOFI cruises, including the observing group(s). "Others" indicates efforts by CalCOFI-affiliated scientists. A '*' designates a measurement that has been made since the beginning of the CalCOFI program. Many other measurements have been made on CalCOFI cruises, but not consistently over time.

The long-term goal of the CalCOFI and CCE-LTER collaboration is to understand the ecosystem sufficiently that we can predict its response to climate change. With these changes, the CalCOFI program is now one of the only true ‘end-to-end’ ocean observation programs in the world.

The history of the CalCOFI program is rich in innovation, be it the development of new sampling techniques or the addition of new measurements that provide valuable new insights into the system we are studying. The product of these efforts is a comprehensive 60+-year ocean time-series that is unprecedented. However, maintaining continuity in a time-series of this length can also present problems as associated sampling methodologies and analytical techniques continue to evolve. For example, zooplankton sampling has undergone two changes, the first in 1969 when the depth of the tow was changed, and the second in 1977 when the zooplankton net was changed from a 1-m diameter net to a twin 0.71-m BONGO net. Extraordinary effort went into documenting the effects of these changes on zooplankton biomass estimates, but to this day, any study using zooplankton data spanning the two time periods has a virtual asterisk attached. Similarly, the method used by CalCOFI since 1984 to measure primary production — half-day incubations starting at noon — could today be changed to obtain more accurate measurements. However, this begs the question: Is a shorter time-series employing a superior proxy measurement preferable to a longer time-series based on an older method?

The long CalCOFI time-series has helped scientists characterize the influence of decadal-scale climate variability, particularly the Pacific Decadal Oscillation and North Pacific Gyre Oscillation, on the California Current ecosystem (Brinton and Townsend, 2003, Di Lorenzo et al., 2008). Data sets from this time-series are now yielding insight into potential effects of climate change on the ocean, such as acidification and deoxygenation. Over the last decade, we have observed declining oxygen concentrations in the North Pacific Ocean and other basins. This decline is thought to be due to increases in surface warming, leading to enhanced stratification, reduced ventilation of deeper waters, and thus lower concentrations of oxygen. Such changes in oxygen bring about a corresponding pH change. Using the 1984-2007 CalCOFI time-series, Bograd et al. (2008) showed that oxygen had been declining in the California Current System since the early 1980s, a trend similar to the basin-wide trend. The immediate question for ecologists and fisheries scientists was what effect this trend might have on fish habitat and if such low oxygen concentrations were unprecedented. McClatchie et al. (2010) used the full CalCOFI time-series (1950- 2009) to determine the variability of oxygen concentrations in essential fish habitats of the Southern California Bight. The surprising conclusion was that the low concentrations of oxygen recently observed in this region were not unprecedented (Fig. 2). Similarly low oxygen concentrations were observed during the late 1950s and early 1960s. Although the authors were unable to identify the mechanism(s) responsible for the reduced oxygen concentrations, they did conclude that recently observed declines of long-term oxygen concentrations in this region are within the range of variability experienced by fish populations over the last 5 decades.

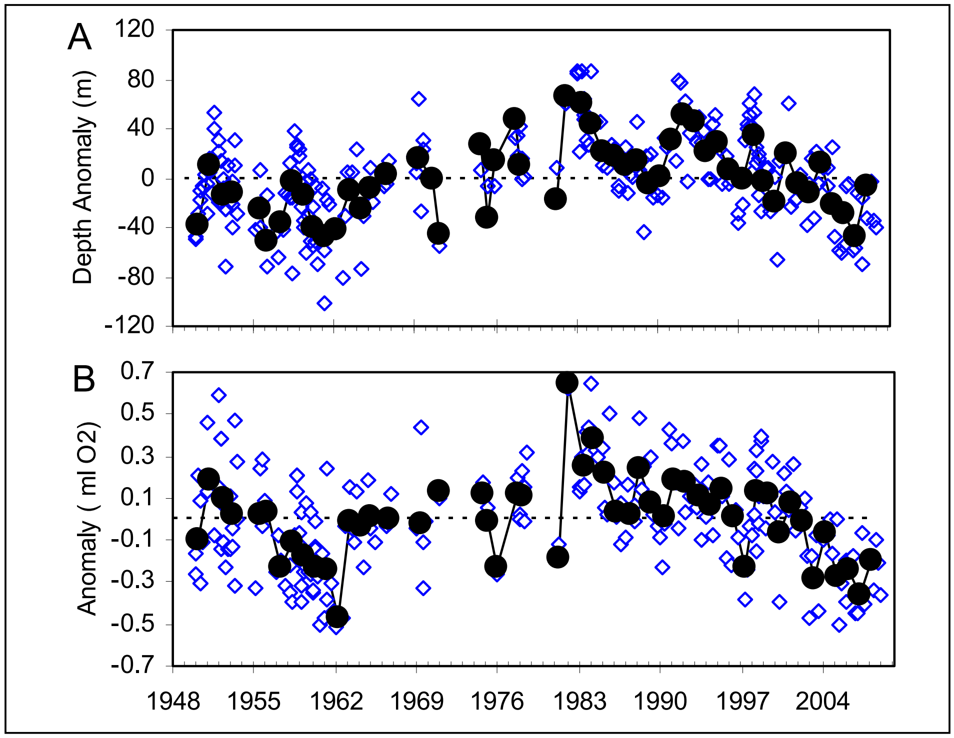
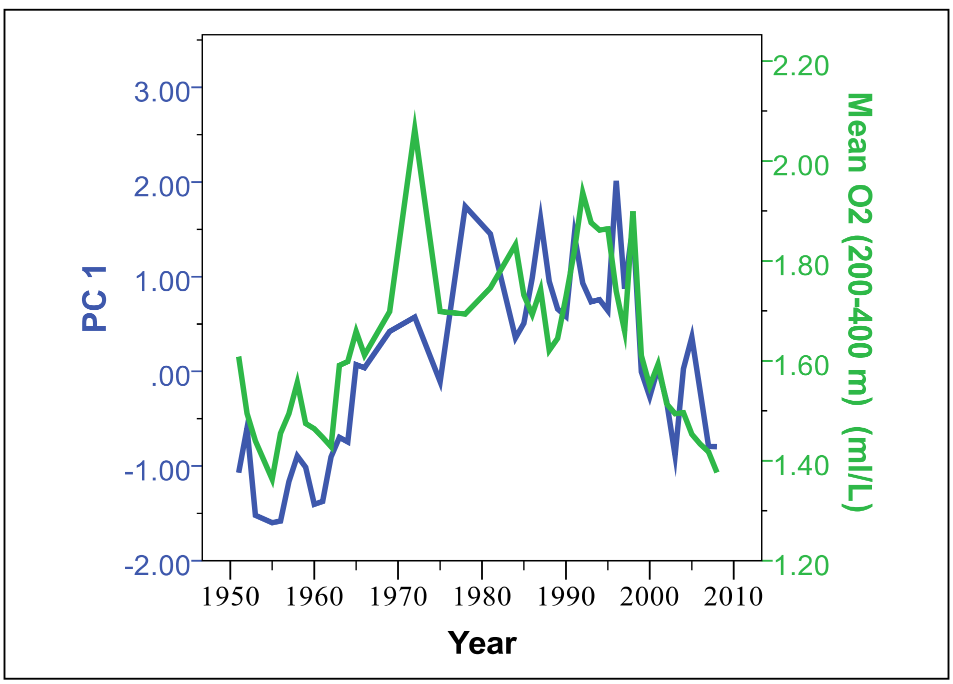



**Figure 2.** Time-series of anomalies at the (A) depth of the 1.5-ml L$^{-1}$ $O_2$ concentration isoline in the Cowcod Conservation Area of the Southern California Bight from 1950-2007; and (B) corresponding $O_2$ concentration anomalies at the $\sigma_\theta$ = 26.6 isopycnal. Shown are cruise averages of station anomalies (blue symbols) and annual averages (solid symbols). Modified from McClatchie et al. (2010).

Efforts are currently underway to hindcast carbonate system parameters in the California Current System. Using multiple linear regression, Alin et al. (2012) developed empirical relationships between hydrographic variables ($O_2$, temperature, salinity, etc.) and carbonate system parameters such as pH and carbonate saturation state. These relationships were then applied to CalCOFI hydrographic data to hindcast pH and saturation state, showing large seasonal and interannual variability. In the future, this hindcast method will be applied to the entire CalCOFI time-series.

Koslow et al. (2011) used the oxygen time-series to explain the temporal variability of midwater fishes in the Southern California Bight. Principal component analysis of CalCOFI ichthyoplankton time-series showed that midwater fish experienced dramatic abundance changes over the last 5 decades, with distinct lows during the late 1950s-early 1960s and the last decade. These changes were significantly correlated to changing oxygen concentrations at depth (Fig. 3). Koslow et al. (2011) suggested that the shoaling of the hypoxic boundary layer during periods of reduced oxygen forced diurnally migrating fish to spend their daytime hours at depths that were exposed to higher irradiance, i.e. under conditions of increase predation pressure by visually-orienting predators for capturing their prey. This is yet one more demonstration of the strong linkages between chemistry and biology in the ocean.

**Figure 3.** Time-series of the first principal component (PC 1) derived from an analysis of the CalCOFI ichthyoplankton time-series (blue), representing primarily midwater fish, compared with mean $O_2$ concentration at 200–400 m depth in the CalCOFI survey area (green) from 1951–2008. Using differenced time-series, Koslow et al. (2011) showed that the two time-series are significantly correlated.




The CalCOFI time-series not only consists of data, but also of >65,000 zooplankton samples held in the SIO Pelagic Invertebrate Collections. Recently, Ohman et al. (2009) drew on this collection to address the question of whether recent acidification of the surface ocean caused a decline in calcareous zooplankton groups in the California Current. No such decline was noted in groups potentially most affected by ocean acidification, i.e. foraminifera, thecosomata, and heteropoda. Rather, some groups showed increasing trends in abundance, perhaps related to increasing phytoplankton biomass or changing circulation patterns (e.g., upwelling).

The examples described here represent only a small handful of the many recent studies of climate and biogeochemistry that have relied on CalCOFI data. The mining of the 60+-year CalCOFI time-series will continue, and the analysis of the 8-year CCE-LTER time-series is just beginning. It is unlikely that the scientists who launched CalCOFI in the 1940s with little more than simple plankton nets, Nansen bottles, and reversing thermometers could have foreseen the scope of the program today and what it has revealed about the oceans. However, we stand in awe of their vision of ecosystem-based ocean science and management, which we continue to strive toward today. If we see farther than they did, it is because, truly, we stand on the shoulders of giants.

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# Exploring the Future Evolution of Multiple Stressors in Eastern Boundary Upwelling Systems

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The anthropogenic emission of carbon dioxide into the atmosphere is causing a cascade of interacting chemical and physical changes in the oceans. On the one hand, global warming induced by the accumulation of $CO_2$ in the atmosphere warms the ocean and enhances water column stability, causing, among other effects, the loss of oxygen from the ocean, or "deoxygenation" (Keeling et al., 2010). On the other hand, rising atmospheric $CO_2$ drives a flux of $CO_2$ into the ocean, increasing the concentration of carbonic acid in the ocean while decreasing pH and carbonate ion concentration, collectively driving a phenomenon known as "ocean acidification" (Caldeira and Wickett, 2003).

These concurrent anthropogenic environmental changes are exerting increasingly intense and pervasive stresses on marine ecosystems, thereby jeopardizing the various services these ecosystems provide to human societies (Doney et al., 2012). Furthermore, the concomitant occurrence of these stressors may have synergistic effects that lead to impacts far greater than the ones predicted on the basis of individual perturbations taken in isolation (Gruber, 2011).

The highly productive marine ecosystems in Eastern Boundary Upwelling Systems (EBUS) such as the California Current System (California CS) and the Canary Current System (Canary CS) are examples of ecosystems undergoing increasing stress levels driven by these changes in ocean chemistry. These systems naturally experience low pH and $CaCO_3$ saturation states (Ω) due to upwelling of deeper waters enriched in dissolved inorganic carbon (DIC) from the remineralization of organic matter that sank from the upper ocean (Feely et al., 2008). Since this process consumes oxygen, it also generates naturally occurring hypoxia ($O_2$ < 60 µmol kg$^{-1}$) in the thermocline of many EBUS. The combined global anthropogenic stressors: warming, ocean acidification, and deoxygenation will likely accentuate these low-pH and low-$O_2$ conditions in EBUS, making them particularly vulnerable. This makes EBUS ideal test beds for exploring the impacts of multiple stressors on marine biogeochemistry, organisms, and ecosystems.

Important changes have already been observed in EBUS. For example, ocean acidification has caused a measurable decrease in pH and saturation state of upwelling waters since pre-industrial times, making the upwelling of undersaturated waters ($\Omega_{arag}$ < 1, i.e., saturation state with regard to the $CaCO_3$ mineral aragonite) more frequent along the coasts of California and Oregon (Feely et al., 2008, Hauri et al., 2009). Furthermore, Bograd et al. (2008) reported a long-term shoaling of the hypoxic boundary in the southern part of the California CS, possibly related to large-scale ocean deoxygenation (Stramma et al., 2010).

More changes are likely in store for the future. With atmospheric $CO_2$ bound to increase in the coming decades, ocean acidification will continue, pushing some EBUS across some potentially important thresholds, such as the widespread occurrence of undersaturated conditions. Using high-resolution model simulations, Gruber et al. (in press) indicate that within the next 30 years, the nearshore areas of the California CS will likely develop summer-long undersaturation in the upper 60 m. By the year 2050, waters with $\Omega_{arag}$ > 1.5 will have largely disappeared, and more than half of the waters will experience year-round undersaturation. In addition, they demonstrated that seafloor ecosystems will experience year-round undersaturation in the next 20-30 years. These results were obtained under the assumption of constant climate, so the likely changes associated with global climate change are not yet considered. For example, ocean warming is bound to continue for several decades (IPCC, 2007). There is also good reason to assume that the observed increase in upwelling-favorable winds over recent decades in several EBUS (e.g., McGregor et al. 2007) will continue into the future (Snyder et al, 2003) due to increasing land-sea thermal gradients driven by global warming (Bakun 1990). This will not only have direct effects on marine organisms and ecosystems, but it will also likely change circulation and mixing patterns and enhance stratification.

Here, we explore how potential changes in upwelling intensity and thermal stratification affect the vulnerability of EBUS to ocean acidification and deoxygenation. Of particular interest is how this response may vary from one EBUS to another, as previous results show substantial regional differences in the sensitivity to perturbations, e.g., the response of biological productivity to changes in upwelling (Lachkar and Gruber, 2012).

Regional modeling is a powerful tool to address such questions, to test different hypotheses, and to identify the key mechanisms at play. Global general circulation models (e.g., NCAR CCSM (Doney et al., 2009)) generally lack the resolution needed to resolve the high spatial and temporal variability associated with EBUS (Fig. 1a). Regional models such as the Regional Oceanic Modeling System (ROMS) overcome this limitation due to their higher (i.e. eddy-resolving) resolution. Simulations with progressively finer resolutions show that while a grid spacing of ~15 km is sufficient to generate the strong onshore-offshore gradient in many key properties such as pH, only resolutions that are much finer than 10 km generate the strong eddy-driven variability and the sharp fronts shown by observations (Figs. 1b-d).

Here, we compare the responses of the California vs. Canary CSs to a set of idealized perturbations, including i) increased $CO_2$ (280, 380, and 540 ppm), ii) increased upwelling-favorable winds (1x, 1.5x, and 2x), and iii) increased temperatures (0°C, +2°C). The model we employ is the ETH-UCLA version of ROMS, to which we have coupled a simple nitrogen-based ecosystem model that includes a full ocean carbon system module (Gruber et al., 2006; Gruber et al., in

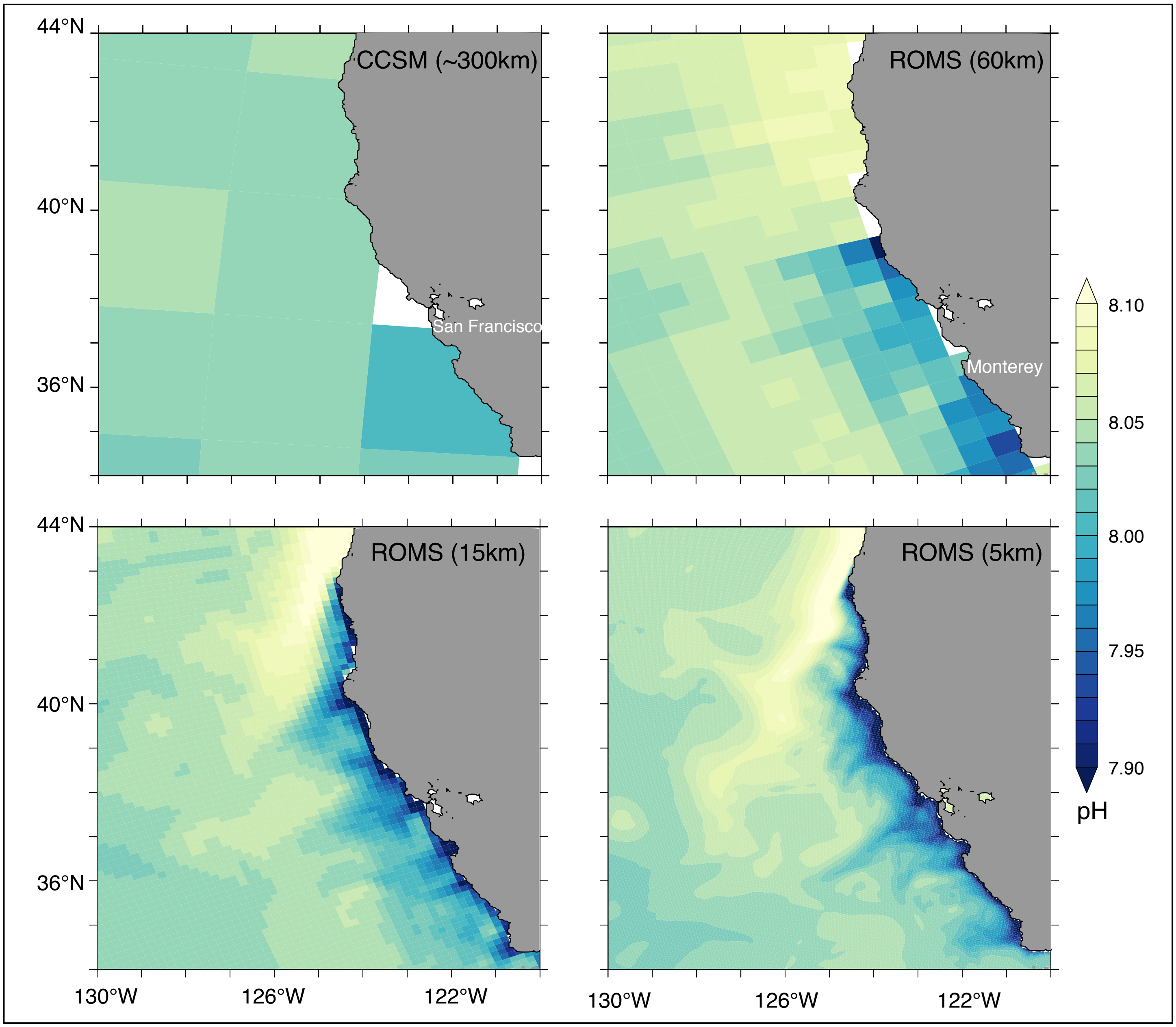


**Figure 1.** Surface pH in the California CS in June under modern conditions, as simulated by a global general circulation model (NCAR CCSM) at ~300-km horizontal resolution and 3 regional (ROMS) models at resolutions of 60 km, 15 km, and 5 km.

press). The idealized perturbations were undertaken at a resolution of 15 km, with each case having been run for 12 years with constant forcing. The comparison of different upwelling systems provides a framework for developing a more comprehensive view of the factors that influence ecosystem sensitivity to local and global environmental changes, and for a better understanding of the underlying dynamics of EBUS ecosystems in general (Lachkar and Gruber, 2011). Results from these regional comparisons illustrate how identical climate perturbations can lead to a wide range of ecosystem responses in different ocean settings. We first look at ocean acidification and then at ocean deoxygenation.

## Ocean acidification in EBUS

In response to increasing atmospheric $CO_2$, the volume of undersaturated waters ($\Omega_{arag} < 1$) in the nearshore (50 km) upper 200 m increases substantially in both the California and Canary CSs (Fig. 2a), but the California CS exhibits much greater sensitivity. Our simulations indicate that in preindustrial times, only a very small fraction of these waters were undersaturated in both regions. But this fraction increases to ~5% in the Canary CS and ~25% in the California CS under current atmospheric $CO_2$ levels. If atmospheric $CO_2$ levels increase to ~540 ppm, as suggested by IPCC's SRES A2 scenario for the year

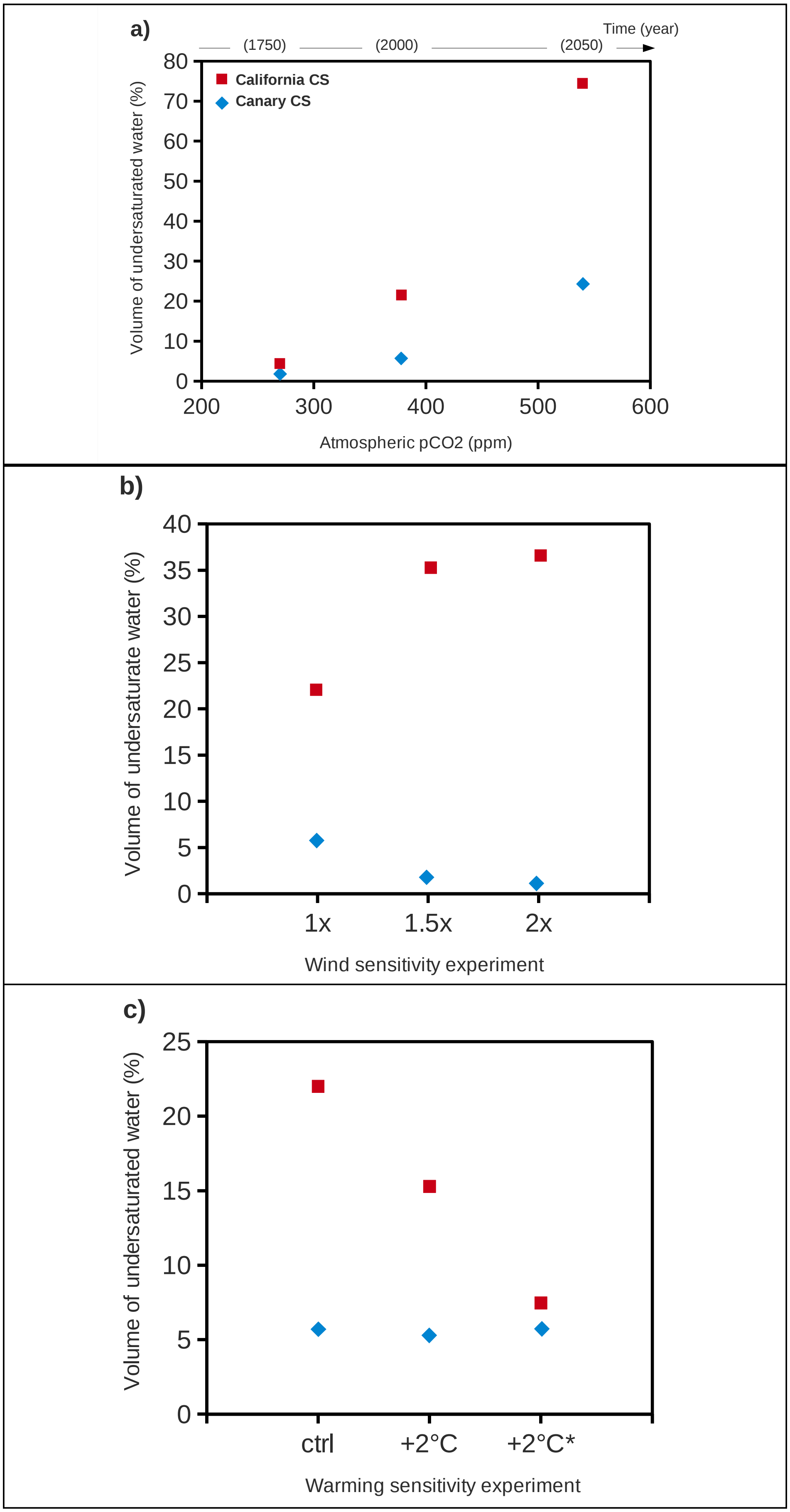


**Figure 2.** Volume fraction of waters undersaturated with regard to aragonite in the nearshore 50 km and upper 200 m under different (a) $CO_2$ levels (280, 380, and 540 ppm), (b) wind stress forcing (1x, 1.5x and 2x) and (c) increased surface temperature (0°C, +2°C, +2°C* with deeper penetration of the temperature anomaly), as simulated in the California CS (red squares) and Canary CS (blue diamonds).

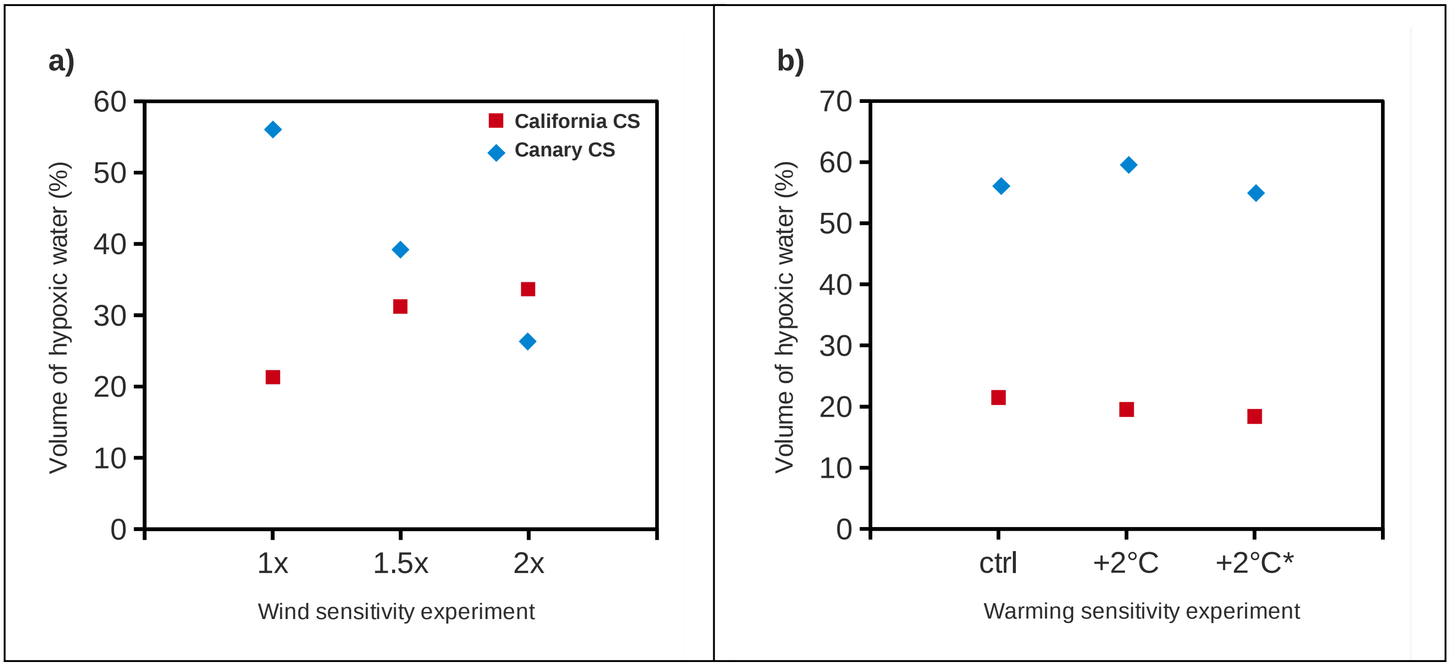


**Figure 3.** Volume fraction of hypoxic ($O_2$ < 60 µmol $kg^{-1}$) waters in the nearshore 50 km and upper 400 m under different (a) wind stress forcing (1x, 1.5x and 2x) and (b) increased surface temperature (0°C, +2°C, +2°C* with deeper penetration of the temperature anomaly), as simulated in the California CS (red squares) and Canary CS (blue diamonds).

2050, the fraction of undersaturated waters in these regions increases to 25% (Canary CS) and 75% (California CS). The difference in sensitivity between the two regions may in large part be due to different starting conditions. The waters of the California CS have today, on average, a substantially lower $\Omega_{arag}$ than those of the Canary CS due to the higher buffer capacity of the Atlantic relative to the Pacific. Despite the sensitivity differences between the two EBUS, the increased volumes of undersaturated waters will lead to substantial habitat compression for $CO_2$-sensitive species in both systems, particularly organisms that use $CaCO_3$ to build mineral structures (Gruber et al., in press).

The potential increase in upwelling-favorable winds will also alter the $CaCO_3$ saturation state in nearshore waters, thus affecting the volume of undersaturated waters. Our results from the wind stress perturbation experiments show contrasting results in the California vs. Canary CSs. While upwelling intensification leads to the expansion of undersaturated waters in the California CS, the same wind perturbations drive opposite changes in the Canary CS (Fig 2b). We observe similar contrasts in the responses of the two EBUS when applying an idealized 2°C surface warming. Specifically, the volume of undersaturated waters in the California CS decreases under increased surface temperature, particularly in the experiment in which we prescribe the temperature anomaly to penetrate deeper into the water column. Conversely, the volume of undersaturated waters in the Canary CS shows little sensitivity to the same warming perturbation (Fig 2c).

While these differential responses of ocean acidification to increases in wind and thermal stratification in the two EBUS appear puzzling at first, they actually reflect fundamental differences in the processes responsible for determining the $CaCO_3$ saturation state in the two systems. In the California CS, the undersaturation in the nearshore is primarily driven by the advection of undersaturated water from offshore at depth, while in the Canary CS, the undersaturation is primarily a consequence of local remineralization of organic matter on the continental shelf. We hypothesize that these differences in drivers are largely due to differences in topography and continental shelf width, with Atlantic-Pacific differences in large-scale stratification and thermocline depth potentially playing a role as well.

## Ocean deoxygenation in EBUS

The climate change-induced expansion of oxygen minimum zones (OMZs) in the eastern tropical Atlantic and the equatorial Pacific has the potential to enhance coastal hypoxia in EBUS and restrict the habitat of several local species. The magnitude of these changes may either be amplified or attenuated in response to local environmental changes, such as potential increases in upwelling-favorable winds and thermal stratification.

As was the case for ocean acidification, the results from the wind stress increase experiments show contrasting impacts on coastal hypoxia in the California vs. Canary CSs. In the California CS, upwelling intensification leads to a slight expansion of hypoxic waters, whereas in the Canary CS, the same wind perturbation results in a substantial reduction of hypoxia (Fig 3a), which likely reflects differences in the dominant processes that drive regional hypoxia. Nearshore hypoxia in the California CS is strongly conditioned by the advection of low-$O_2$ water from the Eastern North Pacific OMZ, which responds little to changes in upwelling and export production. In contrast, coastal hypoxia in the Canary CS is largely a function of organic matter remineralization on the continental shelf. Since export production changes relatively little in response to changes in wind stress, the reduction in hypoxia in the Canary CS is primarily due to reduced nearshore water residence times (Lachkar and Gruber, 2012).

Our model simulations suggest that surface warming and the associated increase in stratification have little impact on the volume of hypoxic water in either system (Fig 3b). This seems counterintuitive, as warming decreases $O_2$ solubility and the concomitant increase in stratification generally leads to an even stronger loss of $O_2$ from the ocean, since stratification hinders the ocean interior's replenishment of $O_2$ from the surface (Keeling et al., 2010). However, in the EBUS, these effects appear to be overwhelmed by a reduced oxygen demand stemming from the stratification-induced reduction in production and export of sinking organic matter. In addition, the stratification also appears to limit the onshore advection and upwelling of low-$O_2$ waters from intermediate-depth layers, further compensating the temperature-induced loss of $O_2$.

## Conclusions

The relatively low-pH and low-$O_2$ conditions characterizing EBUS make these systems natural hotspots for multiple stressors such as ocean warming, acidification and deoxygenation. Our idealized model simulations show that ocean acidification in EBUS is primarily driven by the rise of atmospheric $CO_2$, while warming, stratification, and local wind changes have a much smaller impact. In contrast, ocean deoxygenation is quite sensitive to increased thermal and wind stresses, but with large differences between the two investigated EBUS, which are likely a result of underlying differences in the processes that govern regional oxygen balance.

Our exploration of the potential future evolution of stressors in EBUS suggests that while the ocean acidification and ocean warming stressors will likely intensify, the future evolution of the deoxygenation stressor is more regionally variable and thus more difficult to predict. Even more uncertain is the prediction of the implications of these changes for organisms and marine ecosystems. What we can conclude based on our exploratory investigation, is that the investigated stressors will lead to considerable changes in the habitat size of $O_2$- and $CO_2$-sensitive species, with potentially serious consequences for local biodiversity in these rich ecosystems.

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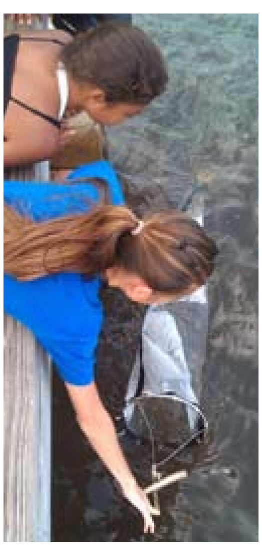
center for microbial oceanography: research and education

C-MORE *linking genomes to biomes*

# C-MORE's *Microscopes in Middle Schools Project*

As part of its wide-ranging education program, the Center for Microbial Oceanography: Research and Education (C-MORE), based at the University of Hawai'i at Mānoa, is partnering with the Hawaii State Department of Education (DOE) and the UH Fostering Inspiration and Relevance through Science and Technology (FIRST) Pre-Academy Initiative to distribute digital video microscopes and related supplies (valued at $1775) to Hawai'i's public middle schools statewide.

C-MORE hopes this new program will shed light on the hidden world of microorganisms. *"Every drop of sea water contains some of the most important organisms on the planet, and most people probably don't even realize it,"* said Jim Foley, a marine science educator with C-MORE. *"Microbes are the engines of the marine food web, and produce about half of the oxygen that we breathe."*



*"These lessons are blowing them away,"* one teacher commented after the students used the digital video microscope. *"They had no idea that there were microscopic things living in the ocean and they asked millions of questions along the lines of 'So when we swim at the beach, these things are touching us?' and if there were 'things' in our drinking water. It totally opened their eyes to the fact that there are microscopic creatures all around us."*

To receive the equipment, teachers must attend a C-MORE professional development workshop to learn how to safely collect plankton and how to operate and care for the microscope. Teachers who attend the workshop receive DOE professional development credit in the form of HOUSSE points, which count toward the federally designated Highly Qualified Teacher status.

To date, five workshops have been held on Oahu, Maui, Kauai, and the island of Hawaii. Over forty middle schools have already received the equipment. For more information, or to download the lessons, please visit C-MORE's website.

# OCB Hosts Three C-MORE Science Kits in Woods Hole

OCB hosts three C-MORE Science Kits: Ocean acidification, marine mystery, and ocean conveyor belt.

***Ocean acidification kit (grades 6-12)***

This two-lesson kit familiarizes students with the causes and consequences of ocean acidification: Lesson 1 includes a simple hands-on experiment, a short PowerPoint, and optional readings with worksheets. In Lesson 2, students conduct a more in-depth experiment with electronic probes to simulate the process of ocean acidification. Learn more about this kit.

***Ocean conveyor belt kit (grades 8-12)***

This four-lesson kit introduces students to some fundamental concepts in oceanography, including ocean circulation, nutrient cycling, and variations in the chemical, biological, and physical properties of seawater through hands-on and computer-based experiments. Learn more about this kit.

***Marine mystery kit (grades 3-8)***

Students learn about the causes of coral reef destruction by assuming various character roles in this marine murder-mystery. As they determine who killed Seymour Coral, students learn the basics of DNA testing. Suspects include global warming, sedimentation, and other threats facing coral reefs today. Learn more about this kit.

***To Request a Kit***

Teachers along the eastern seaboard may use these kits for free. To reserve a kit, please submit a request at: http://cmore.soest.hawaii.edu/education/teachers/science_kits/requestform.htm

## Refreshing the Frequently Asked Questions on Ocean Acidification

It is time to update the Frequently Asked Questions (FAQs) on ocean acidification. Since OCB led the document's assembly in 2010, ocean acidification science has advanced considerably. We would like your help!

The first step of the FAQ update project is to collect new and revised questions. Please visit the FAQ update project website to view the existing questions and submit your suggestions. This site will be active until **June 25, 2012.**

After we receive new questions, the OCB-OA subcommittee will edit the list of questions and seek volunteers from the scientific community to answer them using the latest OA knowledge. In late June, we will call on the authors who contributed to the last version of the FAQs, as well as the OA research community at large. If you would like to be added to the list of potential contributors now, please email Sarah Cooley.

Once the subcommittee collects the responses, they will review and edit them using an open peer-review process. The completed document will be available in September 2012.

## EPOCA Project Ends

The four-year European Project on Ocean Acidification, or EPOCA, ended this spring. Since 2008, OCB and EPOCA scientists collaborated on a number of research projects and organizational activities, including (but not limited to!) the OA FAQs, the Oceanography Magazine special issue on ocean acidification (2010), the OCB Short Course on ocean acidification (2009), the Kiel short course on ocean acidification (2010), and the OA guide to best practices (2010). Congratulations to EPOCA on an extremely successful project! We at OCB have enjoyed collaborating with you.

## OCB's Ocean Acidification Subcommittee Membership And Co-Chair Change

We welcome the following new members to the OCB ocean acidification subcommittee:

**Simone Alin** (NOAA/PMEL) – ocean acidification, coastal carbon chemistry

**Cathy Pfister** (Univ. of Chicago) – marine ecology, population modeling, marine biogeochemistry, microbial metagenomics, and historical reconstruction of past ocean conditions

**Joe Salisbury** (Univ. of New Hampshire) – ocean acidification observing, modeling, and fisheries impacts

**Kim Yates** (USGS) – coral reef communities, inorganic carbon chemistry measurements

We also congratulate **Jeremy Mathis** (U. Alaska, Fairbanks), whom the subcommittee recently selected as a co-chair.

**Richard Feely**, former co-chair, will stay on the committee in an *ex-officio* capacity. Leaving the subcommittee after more than three years of service are: **Scott Doney** (WHOI), **Victoria Fabry** (CSU San Marco), and **Lisa Robbins** (USGS). On behalf of the ocean acidification research community, we sincerely thank them for their leadership and contribution to ocean acidification research and outreach. During their tenure on the subcommittee, ocean acidification became a vital piece of Earth system research that continues to grow rapidly.

More information on the OCB OA subcommittee, including its terms of reference, can be found on the OCB website.

# A Report from the Ocean Acidification Data Management Workshop (March 13-15, 2012, Seattle, WA)

*by Jan Newton (University of Washington)*

The NOAA Ocean Acidification Program, in partnership with the University of Washington and the Integrated Ocean Observing System (IOOS) Regional Association Northwest Association of Networked Ocean Observing Systems (NANOOS) hosted an invitational workshop on integrating ocean acidification (OA) data management for the U.S. March 13-15, 2012 in Seattle, Washington. The workshop convened representatives from NOAA National Oceanographic Data Center, NOAA Fisheries, NOAA Oceans and Atmospheric Research division, U.S. Integrated Ocean Observing System, NSF Biological and Chemical Oceanography Data Management Office (BCO-DMO), NSF Ocean Observatories Initiative (OOI), NASA, Ocean Biogeographic Information System (OBIS)-USA, U.S. Geological Survey, Carbon Dioxide Information Analysis Center (CDIAC)/DOE, OceanSITES, and various investigators involved in observations, experiments, modeling, and satellite research, including international participants. The goal of the workshop was to establish a framework for the handling of ocean acidification data that makes it possible for users to locate, understand, and utilize relevant data in support of scientific research and resource management. Outcomes included a shared vision for integrated OA data management and an initial OA Integrated Data Management Plan with an emphasis on near-term (2-year) goals.

Dr. Libby Jewett, NOAA OA Program Director, introduced the workshop, noting the national mandate establishing an OA Program for the United States, which NOAA leads, and including this statement:

*"The success of the National OA Program will depend critically on effective data management and integration. Data must be shared and integrated across disciplinary boundaries, drawing marine biological data together with oceanographic data, and providing intelligible information to social scientists, planners, educators, and the general public."*

The workshop brought together information on the current status of programs collecting OA data, including the program's mandate, data streams, variables, QA/QC, data archival, and data services. This highlighted the substantial challenge of various organizations contributing diverse types of data that need to be integrated across agencies with minor financial support and attention. Solving this requires a cooperative approach between scientists and data managers. The thirty participants of the workshop articulated a common vision to address this challenge that was codified in a "Declaration of Interdependence" that can be found on the NODC ocean acidification website. The document highlights a requirement for "an easily accessible and sustainable data management framework that: i) provides unified access to OA data for humans and machines; ii) ensures data are version-controlled and citable through globally unique identifiers; iii) documents and communicates understood measures of data and metadata quality; and iv) is easy to use for submission, discovery, retrieval, and access to the data through a small number of standardized programming interfaces."

Further, the workshop participants established themselves as the Consortium for the Integrated Management of Ocean Acidification Data (CIMOAD) and identified three necessary steps forward to achieve the vision:

*"1. The endorsement of agency program directors and managers for collective use of machine-to-machine cataloging and data retrieval protocols (including THREDDS/OPeNDAP) by each agency data center to provide synergistic, consolidated mechanisms for scientists to locate and acquire oceanographic data;*

*2. The commitment of the scientific community to establish best practices for OA data collection and metadata production, and the leadership to provide a means of gaining this consensus; and*

*3. The endorsement of agency program directors and managers to direct data managers to collaborate to develop the system articulated above and contribute to a single national web portal to provide an access point and visualization products for OA."*

The workshop also identified concrete plans deserving of funding (tailored to individual agencies), including short-term opportunities for progress arising from existing projects, priorities, and funding. These, with the summaries of the current status, need, and vision are being consolidated into an OA Integrated Data Management Plan. The Plan will be posted on the NODC ocean acidification website. Be sure to check out this new website. Not only will it be used for hosting the workshop data management plan, but it has a lot of other useful and relevant information.

## Requesting OA Researcher Input on Ocean Acidification Observing Network

To document the status and progress of ocean acidification in open-ocean and coastal environments and to understand its drivers and impacts on marine ecosystems, it will be necessary to develop a coordinated multidisciplinary multinational approach for observations. In partnership with the NOAA Ocean Acidification Program, the International Ocean Carbon Coordination Project, and the Global Ocean Observing System, the University of Washington is hosting a **workshop on June 26-28th to take steps to develop a global ocean acidification monitoring network.**

The primary goals are to identify:

- the locations and components of the observing networks including repeat hydrographic surveys, underway measurements on volunteer observing ships, moorings, floats and gliders
- a minimum suite of measurements and performance metrics for physical, chemical, and biological parameters and
- a strategic approach to data quality assurance and data integration and distribution.

We ask that any researchers actively or planning on measuring ocean acidification parameters send the following information to cathy.cosca@noaa.gov in order to create an interactive map for all current and planned Ocean Acidification platforms. This information will allow for a productive workshop and an effective international carbon ocean acidification observing network.

**Participant/Investigator information**

- Name
- Organization/Affiliation
- Project Website
- Funding Agency
- Contact e-mail address

**For each Ocean Acidification Platform**

- Type of Platform (examples include but are not limited to: mooring, profiling glider, ship of opportunity, pier, float)
- For stationary platforms, Latitude and Longitude of deployment
- For cruises, gliders, floats, and other non-stationary platforms: Coordinates of completed and/or anticipated track line. Please provide coordinates with at least 5° resolution of latitude and longitude so the track line can be drawn on a Google world map. An attached file with the coordinates is acceptable.
- Date of deployment
- Duration of deployment
- Sensors planned, including name and approximate depth of each parameter being measured

Sincere thanks,
Dr. Jan Newton
*Director, Northwest Association of Networked Ocean Observing Systems (NANOOS)*

## Ocean Acidification at Rio+20 Preparatory Negotiations

Scott Doney and Sarah Cooley, both OCB scientists and Project Office staff members at WHOI, recently spoke at the United Nations as part of the informal-informal negotiations on the zero draft of the outcome document for the Rio+20 Earth Summit, to be held in Rio de Janeiro on June 20-22, 2012.

Doney spoke at a side event organized by the Global Ocean Forum, IOC-UNESCO, and the Permanent UN Missions of Seychelles and Fiji, emphasizing the role of science in considering ocean acidification. He underscored the importance of increased coastal monitoring for ocean acidification-related parameters, data synthesis, and development of adaptation strategies for coastally dependent human communities. A summary of this event can be found here.

Cooley spoke at a side event organized by the Natural Resources Defense Council and the Permanent UN Mission of the Principality of Monaco, describing how the effects of ocean acidification on marine life could have profound follow-on effects for marine ecosystems and the human communities that depend on them. These effects could be especially severe for island nations, which have fewer resources for harvesting high-quality protein, and both island and developing nations, which often derive significant economic benefits from exporting marine products. An article was published in Grist magazine about this event.

# OCB Updates

## Important Dates

- **July 16-19, 2012:** OCB Summer Workshop (Woods Hole Oceanographic Institution, Woods Hole, MA)
- **Fall 2012 (Details TBA):** OCB and IOCCP (with funding from the IOC-UNESCO) will co-sponsor **an international workshop (by invitation) on time-series methodologies and data intercomparison**

## Ocean Time-Series Advisory Committee (OTSAC) Membership Changes

The OCB Ocean Time-Series Advisory Committee (OTSAC) was established by the OCB SSC to seed the development of future ocean observing activities and initiatives, and ensure that existing ocean time-series and observing systems are meeting community needs. OTSAC also helps keep the OCB community connected to international ocean observing programs and activities. We would like to thank the OCB community for submitting so many fantastic nominations. We are pleased to welcome five new members to the Committee:

**John Dunne** (NOAA/GFDL) — physical and biogeochemical modeling

**Ricardo Letelier** (OSU) — marine bio-optics, phytoplankton ecology, satellite remote sensing

**Susanne Neuer** (ASU) — ocean biogeochemistry, biological carbon pump

**Mary Jane Perry** (UMaine) — primary production, photosynthetic physiology, bio-optics, remote sensing

**Paul Quay** (UW) — Application of stable and radioisotope measurements to biogeochemical cycles, large-scale ocean circulation rates using anthropogenic tracers

## Reports

Najjar, R.G., Friedrichs, M.A.M., Cai, W.-J. (Editors) (2012) Report of The U.S. East Coast Carbon Cycle Synthesis Workshop, January 19-20, 2012, Ocean Carbon and Biogeochemistry Program and North American Carbon Program, 34 pp.

## Partner Activities and Co-Sponsorships

- **Joint Scientific Working Groups with U.S. CLIVAR (2012-2015)** – Outcome of joint US CLIVAR/OCB science session at 2011 Summer OCB workshop
  - » Oceanic carbon uptake in the CMIP5 models (Co-Chairs: Annalisa Bracco, Curtis Deutsch, Taka Ito)
  - » Heat and carbon uptake by the Southern Ocean (Co-Chairs: Joellen Russell, Igor Kamenkovich)
- **Coastal Synthesis Activities with the North American Carbon Program**
  - » East Coast Regional Team Meeting (January 19-20, 2012, Gloucester Point, VA)
  - » Coastal Synthesis Wiki Site (updates on regional coastal synthesis activities)
  - » Articles on regional synthesis activities published in OCB newsletter (east coast, west coast, Gulf of Mexico, Arctic, Great Lakes)
- OCB providing **travel support for U.S. students to participate in IMBER ClimECO3 summer school**

# Meeting Reports

## Report from a $N_2$ Fixation Methods Workshop *(February 2012, Kiel, Germany)*

*by Matthew Mills (Stanford Univ.) and Julie LaRoche (IFM-GEOMAR)*

In early February 2012, 23 scientists conducting research on marine nitrogen fixation gathered in Kiel, Germany for a 3-day workshop to discuss current methods for direct measurements of nitrogen fixation. The workshop was sponsored by the international SOLAS program, and OCB provided funding for five U.S. scientists to participate.

Over the past 15 years, the most widely applied method for direct measurement of $N_2$ fixation rates has involved the use of the stable isotope of nitrogen $^{15}N$, and consists of injecting a $^{15}N_2$ bubble into a bottle filled with seawater containing $N_2$ fixers. The bottle is mixed to dissolve the bubble, and rapid equilibration of the $^{15}N_2$ with the dissolved $N_2$ pool is assumed. However, recent research has shown that the dissolution of the gas bubble is actually quite slow, taking 6-12 hours to approach equilibrium. Subsequently, uptake rates of the $^{15}N_2$ label by the $N_2$ fixers are underestimated due to the gradually changing isotopic composition ($\delta^{15}N$) of the starting $N_2$ pool during the initial phase of the incubation.

The primary objective of the $N_2$ Fixation Methods Workshop was to design a working method for nitrogen fixation rate measurements that will be tested in the lab and field and agreed upon by the scientific community. Specific questions addressed included:

- Do we need to revise the commonly applied nitrogen isotope tracer addition method?
- What is the best approach for the revision?
- How will the consensus method be communicated to the rest of the scientific community?

Results from several of the participating laboratories have demonstrated the need for a standardized method that is easily implemented in both the lab and the field, and provides a stable and known isotopic enrichment of the $N_2$ pool. An initial protocol for enriching seawater with $^{15}N_2$ based on degassing seawater has been developed, and several participating laboratories agreed to test the protocol this spring. Workshop participants discussed plans for further method development, including testing the stability of $^{15}N_2$-enriched seawater in storage and assessing the impact of $^{15}N_2$-enriched seawater addition on the microbial community.

In addition to method development, discussions also focused on potential activities that would benefit the $N_2$ fixation research community, including an inter-calibration exercise and a training workshop. Finally, workshop participants set the goal of producing a *Best Practices Guide for Marine $N_2$ Fixation Research* within 3-4 years. For more information about this workshop, please contact Julie LaRoche or Wiebke Mohr.

## OCB Informational Resources

- OCB Policies and Procedures: A community guide on OCB's programmatic mission, objectives, and operating procedures
- OCB Ocean Acidification Website
- OCB Ocean Fertilization Website
- Subscribe or post to the OCB email list

## Did you know…?

An article in the OCB newsletter is a great way to highlight and share newly published results. Similarly, if you have news items (announcements, education and outreach products, etc.) you would like to share with the OCB community via our email list or website, please contact the OCB Project Office.

## Community Resources

### *Data and Research*

- Arabian Sea chemical and biological oceanographic data sets available
- Call to review SCOR Working Group proposals
- Version 1.0 of NODC netCDF templates available

### *Communication, Education, and Outreach*

- Euromarine Training Catalog – database of EU degree programs and training courses
- ICES Training Courses on communicating science and leading an effective technical meeting
- Updating the **Ocean Acidification Frequently Asked Questions** - view existing questions and answers and/or submit new questions

### *Reports*

- Partnership for Observation of the Global Oceans (POGO) releases final Honolulu Declaration

## Partner Program Updates

### IMBER

- IMBER International Project Office relocates to Bergen, Norway
- IMBER appoints **Dr. Bernard Avril** as new Executive Officer
- ClimECO3 summer school (July 23-28, 2012, Ankara, Turkey)
- IMBIZO III (January 28-31 in Goa, India) – abstract deadline **July 15**!

### IOCCP

- **New IOCCP Headquarters** at the Institute of Oceanology of the Polish Academy of Sciences (IO PAS) in Poland and the Joint Office for Science Support of the University Corporation for Atmospheric Research (UCAR/JOSS) in the United States
- IOCCP (with funding from the IOC-UNESCO) and OCB to co-sponsor **an international workshop (by invitation) on time-series methodologies and data intercomparison** in Fall 2012 (details TBA)

### U.S. CLIVAR

- 2012 CLIVAR Summit – July 18-20, 2012 (Newport Beach, CA)
- U.S. CLIVAR Project Office welcomes new staff member **Jennifer Mays**
- New websites for **joint U.S. CLIVAR/OCB working groups:**
    - » Oceanic carbon uptake in the CMIP5 models (Co-Chairs: Annalisa Bracco, Curtis Deutsch, Taka Ito)
    - » Heat and carbon uptake by the Southern Ocean (Co-Chairs: Joellen Russell, Igor Kamenkovich)

# OCB Calendar

| We maintain an up-to-date calendar on the OCB website. | |
|---|---|
| **2012** | |
| **June 17–July 7:** | BIOS Summer Course: Microbial Oceanography - The Biogeochemistry, Ecology and Genomics of Oceanic Microbial Ecosystems (Bermuda) |
| **June 20–22:** | Rio+20 United Nations Conference on Sustainable Development (UNCSD) (Rio de Janeiro, Brazil) |
| **June 20–22:** | NASA Workshop for Remote Sensing of Coastal and Inland Waters (Madison, WI) |
| **June 23–24:** | Gordon Research Seminar - Marine Microbes - Microbial Ecology in the Era of 'omics' (Lucca, Italy) |
| **June 24–29:** | 2012 Marine Microbes Gordon Research Conference (Lucca, Italy) |
| **June 24–29:** | Goldschmidt 2012 (Montreal, Canada) |
| **July 1–13:** | Darwin School on Biogeosciences 2012 (Utrecht and Texel, The Netherlands) |
| **July 2–14:** | IOCCG Summer lecture series 2012: Frontiers in ocean optics (Villefranche-Sur-Mer, France) |
| **July 8–13:** | 18th Conference on Air-Sea Interaction (Boston, MA) |
| **July 8–13:** | ASLO Aquatic Sciences Meeting (Lake Biwa, Japan) |
| **July 9–13:** | 21st International Radiocarbon Conference (Paris, France) |
| **July 9–13:** | 12th International Coral Reef Symposium (Cairns, Australia) |
| **July 13–25:** | XXXII SCAR Open Science Conference - Natural and anthropogenic forcing on the Antarctic and Southern Ocean climate system (Portland, OR) |
| **July 16–19:** | OCB Summer Workshop (Woods Hole, MA) |
| **July 18–20:** | 2012 CLIVAR Summit (Newport Beach, CA) |
| **July 23–28:** | IMBER ClimECO3 Summer School (Ankara, Turkey) |
| **August 20–31:** | Experimental Design & Data Analysis for Marine Biologists (Göteborg University, Strömstad, Sweden) – registration deadline: Jun 29 |
| **July 13–25:** | XXXII SCAR Open Science Conference - Natural and anthropogenic forcing on the Antarctic and Southern Ocean climate system (Portland, OR) |
| **Sept. 3–6:** | Bjerknes Centre open science conference: Climate change in high latitudes (Bergen, Norway) |
| **Sept. 3–6:** | 15th Biennial Challenger Conference for Marine Science on "Ocean challenges in the 21st century" (Norwich, UK) |
| **Sept. 10–13:** | 2012 LTER All Scientists Meeting - The unique role of the LTER network in the Anthropocene: Collaborative science across scales (Estes Park, CO) |
| **Sept. 17–21:** | Time-series analysis in marine science and applications for industry (Brittany, France) |
| **Sept. 23–28:** | Environmental Sensors 2012 (Anglet, France) |

# OCB Calendar (cont.)

| 2012 cont. | |
|---|---|
| **Sept. 24–27:** | Third Symposium on the Ocean in a High-$CO_2$ World (Monterey, CA) |
| **October 7–11:** | DISCO XXIII and PODS VII (Lihue, Kaua'i) |
| **October 8–12:** | Chapman Conference on The Agulhas System and its Role in Changing Ocean Circulation, Climate, and Marine Ecosystems (Spier Wine Estate, Stellenbosch, Western Cape, South Africa) |
| **October 13–20:** | DISCCRS VII Interdisciplinary Climate Change Research Symposium (Colorado Springs, CO) |
| **October 16–19:** | MESOAQUA International Symposium - Recent Achievements and Future Directions in Aquatic Mesocosm Research (Heraklion, Crete) |
| **October 21–23:** | XXXI$^{th}$ SCOR General Meeting (Nova Scotia, Canada) |
| **October 23–26:** | Joint ART-APECS Science Workshop "Overcoming challenges of observation to model integration in marine ecosystem response to sea ice transitions" (Sopot, Poland) |
| **November 5–9:** | Pan Oceanic Remote Sensing Conference (Kochi, Kerala, India) |
| **November 6–16:** | Satellite Monitoring of the Seas 2012 Africa (Morocco) |
| **December 3–7:** | 2012 AGU Fall Meeting (San Francisco, CA) |
| **2013** | |
| **January 21–23:** | Gulf of Mexico Oil Spill & Ecosystem Science Conference (New Orleans, LA) |
| **January 28–31:** | IMBER IMBIZO III: The future of marine biogeochemistry, ecosystems and societies (Goa, India) |
| **February 4–8:** | 2013 Ameriflux and NACP All Investigators Meeting (Venue TBD) |
| **February 11–16:** | 4$^{th}$ PAGES Open Science Meeting (Goa, India) (includes 2$^{nd}$ PAGES Young Scientists meeting Feb. 11–12) |

## OCB-RELEVANT FUNDING OPPORTUNITIES

- **August 15, 2012:** NSF Biological and Chemical Oceanography proposal targets
- **December 20, 2012:** Belmont Forum and G8 Research Councils Initiative on Multilateral Research Funding International Opportunities Fund **full proposal deadline** (**July 20:** preproposal deadline, **Sept. 20:** full proposal notification deadline)

## OCB News

is an electronic newsletter that is published by the OCB Project Office. Current and previous issues of OCB News can be downloaded from: www.us-ocb.org/publications/newsletters.html

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