Ocean Carbon and Biogeochemistry
Studying marine biogeochemical cycles and associated ecosystems in the face of environmental change
News
Volume 6, Number 1 • Winter 2013

The next challenge: How do multiple environmental drivers influence ocean biota?

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Introduction

The summer OCB meeting in July 2012 featured for the first time a special session on "Multiple stressors in marine ecosystems" that was chaired by Cindy Lee (SUNY Stony Brook). The five speakers of this timely session - Jorge Sarmiento (Princeton Univ.), Lisa Levin (Scripps Inst. of Oceanography), Wei-Jun Cai (Univ. of Delaware), Nicolas Gruber (ETH Zurich), and Philip Boyd (NIWA New Zealand) - provided an illustrative range of approaches and viewpoints, in both their presentation and in a panel discussion, on this fledgling research field. In research fields such as ocean acidification, there has been a growing appreciation that restricting environmental perturbation experiments solely to manipulation of CO_2/pH can only fill in part of the puzzle that encompasses the complex responses of ocean biota to climate change (Boyd, 2011). The recent Ocean in a High-CO_2 World meeting provided some interesting statistics on how researchers are designing ever more complex environmental perturbation experiments (see article by Sarah Cooley, *OCB News*, Fall 2012). There has also been a growing focus on how concurrent changes in multiple oceanic properties will alter ocean biota, with special sessions at workshops run by intergovernmental organisations such as the North Pacific Marine Science Organization (PICES) and international programmes such as Integrated Marine Biogeochemical and Ecosystem Research (IMBER).

At the OCB Summer 2012 meeting,

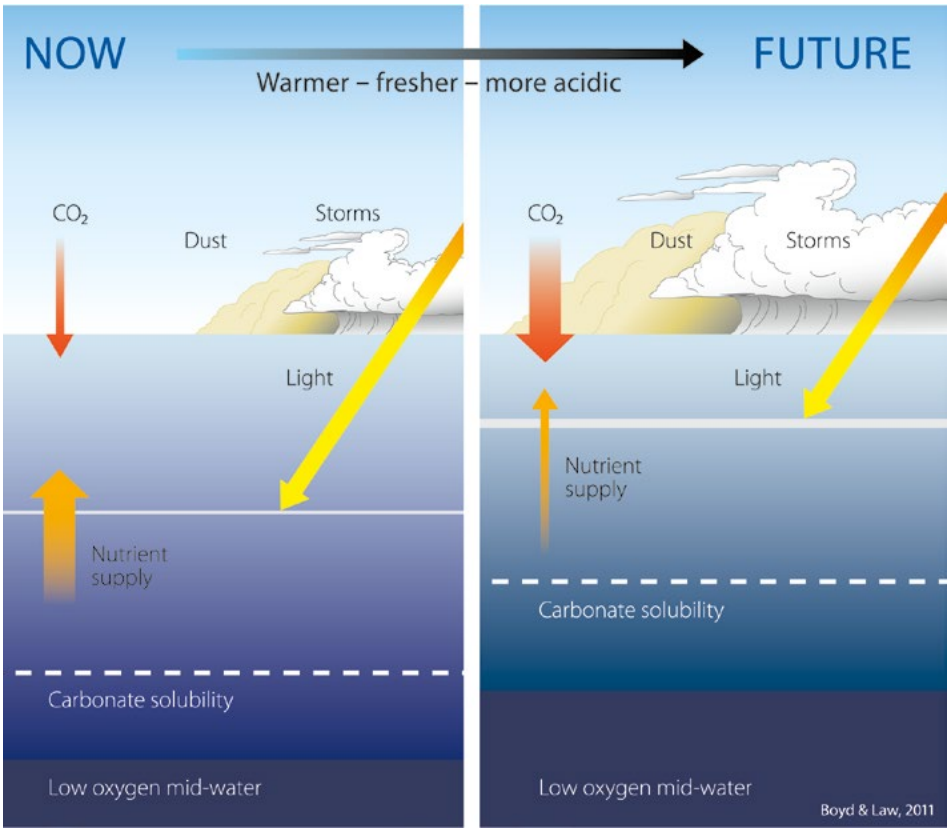

Figure 1. A summary of the many changes that are anticipated in ocean properties from surface waters to the deep ocean in the coming decades due to a changing climate (redrawn from Boyd and Law, 2011).

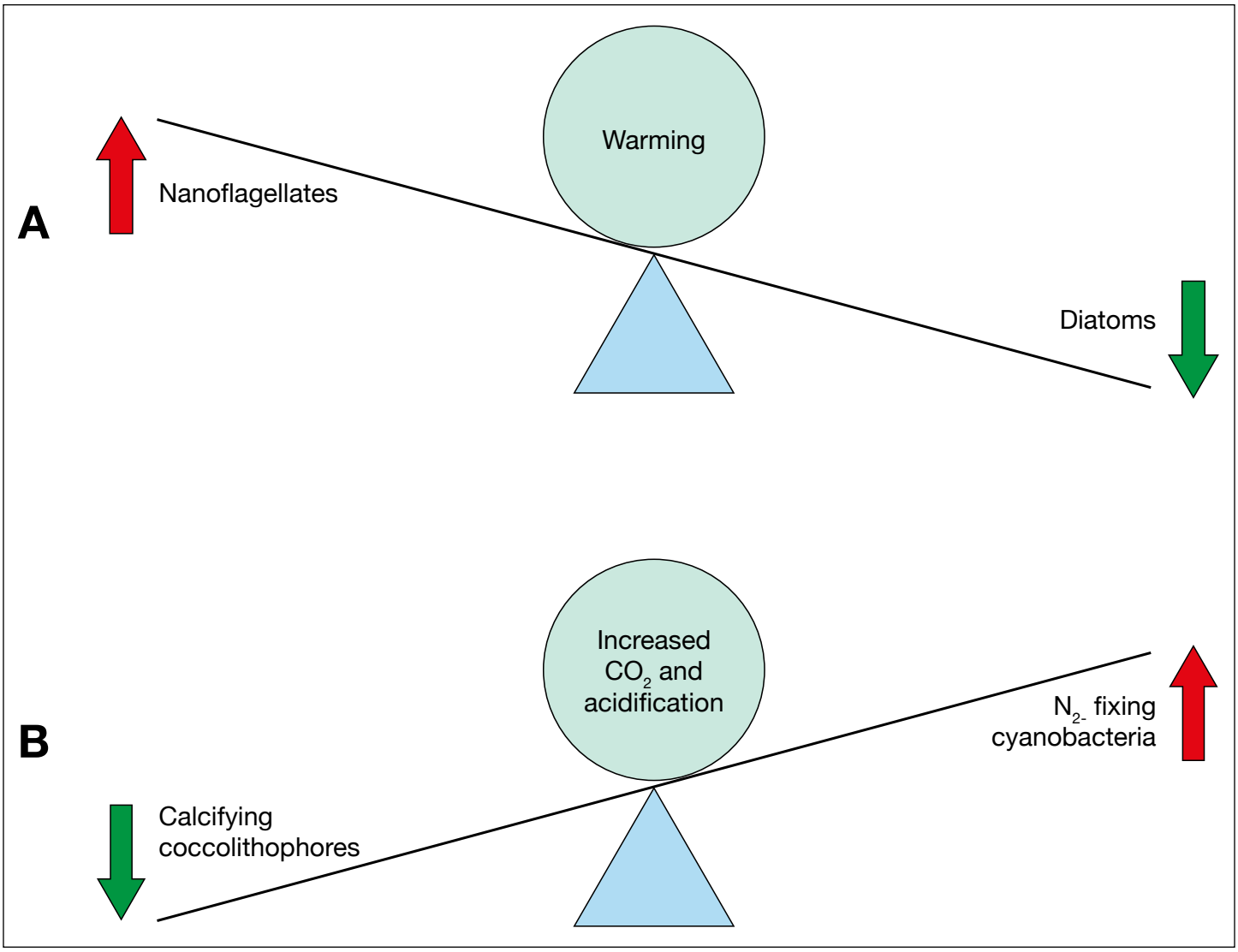

Figure 2. Altered environmental conditions that are often considered "stressors" to particular groups of organisms are usually beneficial to the growth or biomass of other groups, as illustrated here: **A.** In the Bering Sea, during an experimental warming manipulation, diatoms are "losers" but nanoflagellates are "winners "(Hare et al., 2007). **B.** In lab culture studies, high CO_2, acidified seawater conditions inhibit most calcifying coccolithophores (Riebesell et al., 2000), but promote the growth of N_2-fixing cyanobacteria in culture experiments (Hutchins et al., 2007; Fu et al., 2008).

Philip Boyd updated the community about some prior and forthcoming activities associated with the emerging theme of multiple environmental drivers and ocean biota. Ocean global change researchers now increasingly appreciate that in addition to acidification, marine organisms will face simultaneous changes in temperature, oxygen, salinity, light, nutrients, and micronutrients, along with interactions among these drivers (Fig. 1). Here, we provide a summary of several recent thematic issues of journals on the effects of a changing ocean on its biota, and also publicize the first dedicated meeting on this topic that will take place in mid-2014. We conclude by discussing some of the challenges that lie ahead in developing this research topic.

In late 2012, the journal *Marine Ecology Progress Series (MEPS)* published an open access theme section on "Biological responses in an anthropogenically modified ocean" (Boyd and Hutchins, 2012), that comprised seven papers and an Introduction to the theme section. These contributions focused on a wide range of topics from the response of the ocean's biological pump to a changing ocean (Passow and Carlson, 2012) to the range of environmental controls on calcifying coccolithophores (Raven and Crawfurd, 2012). Other research presented ranged from phytoplankton functional traits to the responses of

Research facet	Single Driver	Multiple Driver
Implementation	Difficult	Very difficult
Interpretation	Interpretation is complex	Very complex findings
Outreach	Can be conveyed	Difficult to simplify
Scope	Broad	Broadest
Relevance	High	Highest

Table 1. A comparison of the challenges and benefits of research on the effects of single versus multiple environmental drivers on ocean biota.

harmful algal blooms to changing oceanic conditions.

In 2013, the journal *Evolution* will publish a special section (edited by Daphne Fairbairn and Sinead Collins) that brings together a set of papers focused on the potent linkages between experimental evolutionary biology and the biota in aquatic systems. These contributions provide valuable insights into the role that experimental evolutionary biology can play in helping to understand the responses of ocean biota to changing environmental conditions, as recently reported by Lohbeck et al. (2012). Some of the contributions of this special section are already available online as advanced publications, such as the Introduction to the section by Reusch and Boyd (2013). Understanding the adaptive responses of marine organisms to selection by climate change will also be the topic of a session at the upcoming 2013 OCB summer meeting (co-organized by T. Rynearson and D. Hutchins).

Terminology – stressors or drivers?

In the Introduction to the *MEPS* theme section, Boyd and Hutchins (2012) reappraise the rich literature on the topic of environmental stressors from the freshwater and ecotoxicology literature. They point out that although the term "multiple stressors" has been widely used in these canons, as the focus has often been on the detrimental effects of pollutants, it is not always the best term to use when discussing environmental change in the marine environment. They put forward a case that changing oceanic conditions will result in both detrimental effects for some groups or species (the "losers") and beneficial effects for others (the so-called "winners"). For example, warming has been suggested to favour nanoflagellates relative to diatoms, while higher dissolved carbon dioxide concentrations may be disadvantageous to coccolithophores, and at the same time benefit nitrogen-fixers (Fig. 2). Thus, the generic term "driver" is a broader and often more accurate descriptor than stressor when discussing the general effects of global anthropogenic change on ocean biota.

A glance through the prior literature also revealed that the potential interactive effects of multiple drivers – the so called synergisms and antagonisms – on the biota had been poorly defined. To redress this, Boyd and Hutchins provide a list of revised definitions in their Introduction, and stressed the need to more rigorously contextualise the use of such definitions in publications. For example, they point out that synergisms and antagonisms each require a further qualifier to detail whether they are describing negative or positive effects for the organism. Synergisms and antagonisms can be used to refer to initial interactions between environmental drivers that subsequently affect the biota, or to interactive effects on the biota that result in a direct biological consequence.

An ecosystem level approach

Another key issue that is addressed in their Introduction to the *MEPS* theme section is the effects of multiple drivers across different trophic levels. For example, phytoplankton at the base of the food web may be influenced by changes in up to six different drivers (light, pH, CO_2, temperature, nutrient and trace metal supply, and their interplay), whereas higher trophic levels will be directly influenced by fewer oceanic properties. There is also the important issue of differential susceptibility to a changing ocean and its potential to restructure food webs. Boyd and Hutchins (2012) note that much of the ongoing research on multiple environmental drivers and ocean biota is on primary producers, but effects of changing oceanic conditions on higher trophic levels could be equally influential in reshaping ecosystems and their functioning. At higher trophic levels, there are also the potentially confounding effects of the interplay of 'bottom up' environmental and 'top down' ecological controls, along with other 'top-down' anthropogenic pressures such as harvesting (Fig. 3). Several recent reviews have also raised some of these issues (Brose et al. 2012; Caron and Hutchins, 2012).

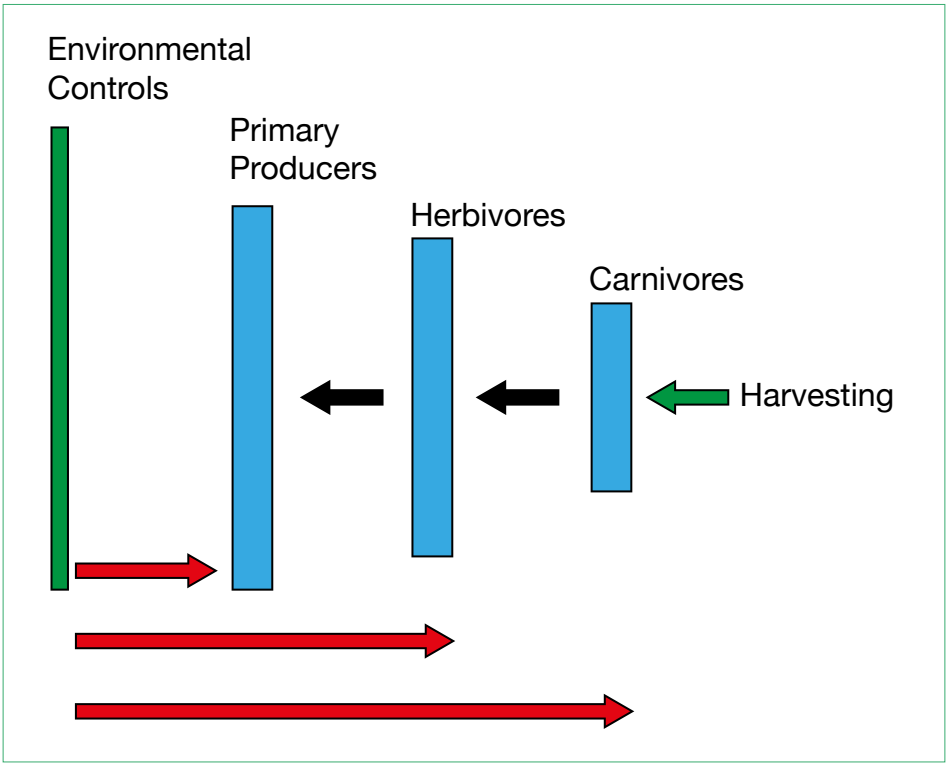

Figure 3. Interplay of bottom-up (altered environmental conditions) and top-down anthropogenic change (harvesting) on marine ecosystems. The bottom-up effects of climate change on the environmental controls will have both direct (e.g., altered physiological performance) and indirect (e.g., floristic shifts and consequent changes to trophodynamics) effects on ecosystems. Top-down effects such as harvesting will also alter grazing dynamics. Taken together with the range of complexity (i.e. number of trophic levels, range of pathways) that characterizes different food webs, this will result in a wide range of permutations of food web responses to climate change (Griffith et al., 2011).

The Challenge

The study of the effects of multiple drivers on ocean biota represents a major step up in complexity of virtually all facets of research relative to that encountered when investigating a sole driver such iron supply or ocean acidification (Table 1). Such issues will also become increasingly evident as the scientific community attempts to communicate the findings of such studies to policymakers. There is much to be learned from the rapid progress made by the ocean acidification community (Boyd, 2011). Central challenges in the coming years include building a research community and developing methodologies to conduct complex multivariate experiments. Equally important will be engaging research and government agencies, and informing them of the need to directly tackle the issue of how multiple environmental drivers will alter the ocean's ecosystems and biogeochemistry in the coming decades.

In order to help set up a forum to specifically address some of the above issues, members of the OCB community have been actively seeking a suitable workshop for a dedicated meeting. In 2012, David Hutchins (USC), Adina Paytan (UCSC), Shannon Meseck (NOAA), and Philip Boyd (NIWA) submitted a successful application for a new Gordon Research Conference (GRC) to be broadly focused on how the full spectrum of drivers in the changing ocean will affect all levels of marine food webs. This first Ocean Global Change Biology GRC will take place July 6-11, 2014 at the Waterville Valley Resort (Waterville Valley, NH, Chair D.A. Hutchins). We hope to entrain strong interest and participation by the OCB community at this meeting, as we begin to plan strategies to meet the next challenge thrown at us by global climate change.

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Eddies initiate the North Atlantic spring phytoplankton bloom

By Amala Mahadevan (Woods Hole Oceanographic Institution)

The subpolar gyres are biologically, some of the most highly productive regions of the ocean and act as a strong sink for atmospheric CO_2 (Sabine et al., 2004). In many locations, the surface mixed layer transitions from being less than 10 meters in the summer, to hundreds of meters in depth during the winter. The strong seasonality in light, surface fluxes, and consequently, mixed layer depth, spurs a large biological response. In the spring, immense phytoplankton blooms result (Fig.1) when the nutrient-replete mixed layer overcomes light limitation due to increasing solar radiation and density stratification.

Numerous studies dating back to the 1950s (Sverdrup, 1953; Evans and Parslow, 1985) have addressed the onset of the spring phytoplankton bloom. During the winter, the ocean surface is strongly forced by heat loss and winds, and the mixed layer deepens (to several hundred meters in the North Atlantic) and becomes replete with nutrients. Phytoplankton cells are carried to depth by turbulent eddies and are not sufficiently exposed to light to sustain growth. With the advent of spring, the hours of daylight increase, and the depth of the mixed layer shoals. This suppression in the depth and strength of vertical mixing enables phytoplankton to remain in the sunlit layer and grow rapidly. Sverdrup (1953) postulated that since phytoplankton growth rates depend on light, which decays exponentially with depth, and loss rates, which are depth-independent, there must be a critical depth of mixed layer, less than which the vertically integrated growth over the mixed layer would exceed losses and lead to a bloom.

The shoaling of the mixed layer

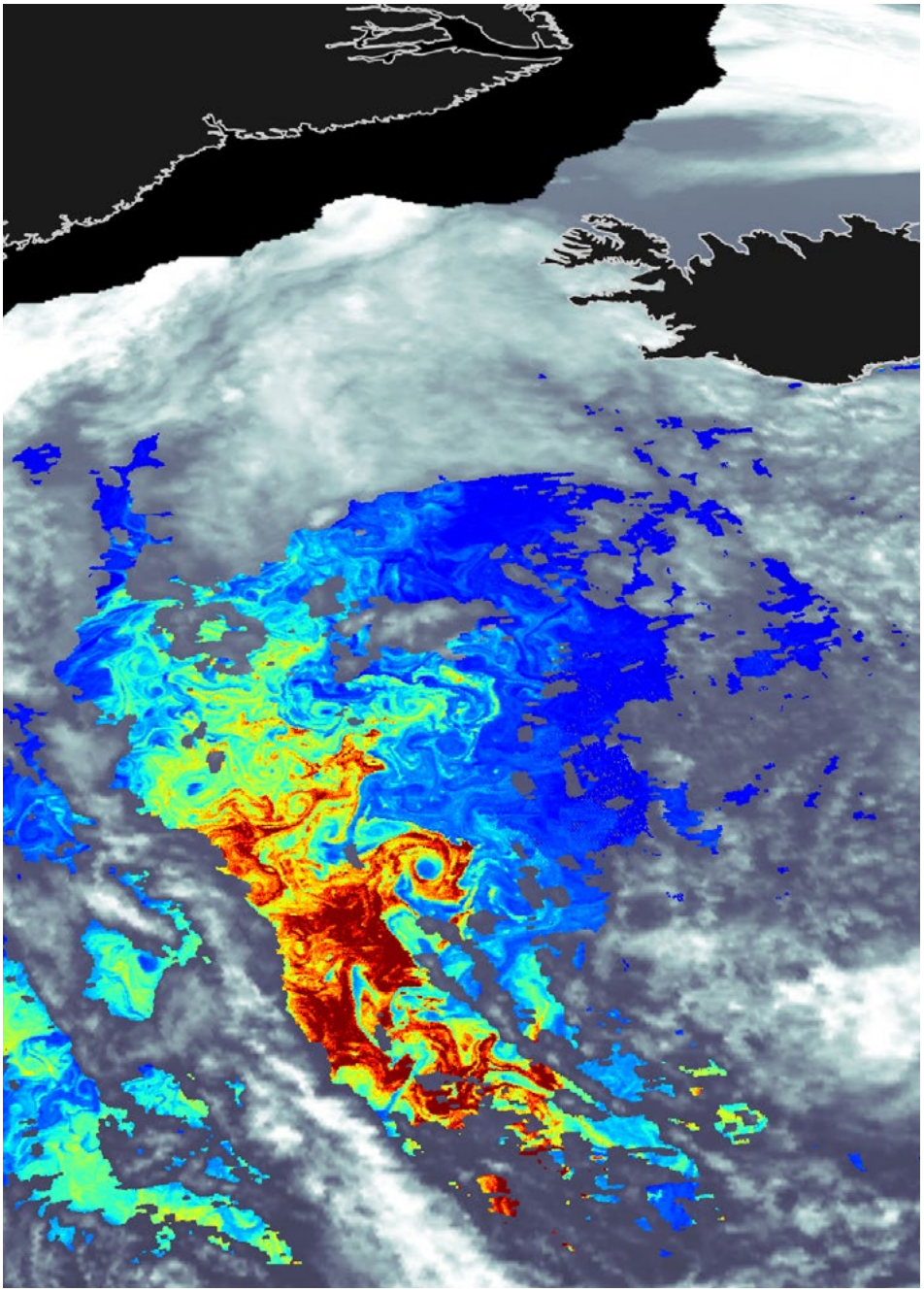

Figure 1. Satellite view of the phytoplankton bloom on April 18, 2008 in proximity of the North Atlantic Bloom experiment. The colors indicate chlorophyll (Chl) concentration as measured by the Moderate Resolution Imaging Spectroradiometer (MODIS). Clouds over the ocean are also reconstructed from the satellite data. The Chl data is on a linear color scale from 0 to 2. The clouds are based on the daily PAR product from MODIS. Exceptionally high values of Chl near Iceland and in some other places are masked out. The figure is generated from NASA's MODIS satellite fields by Dr. Bror Jonsson, Princeton University.

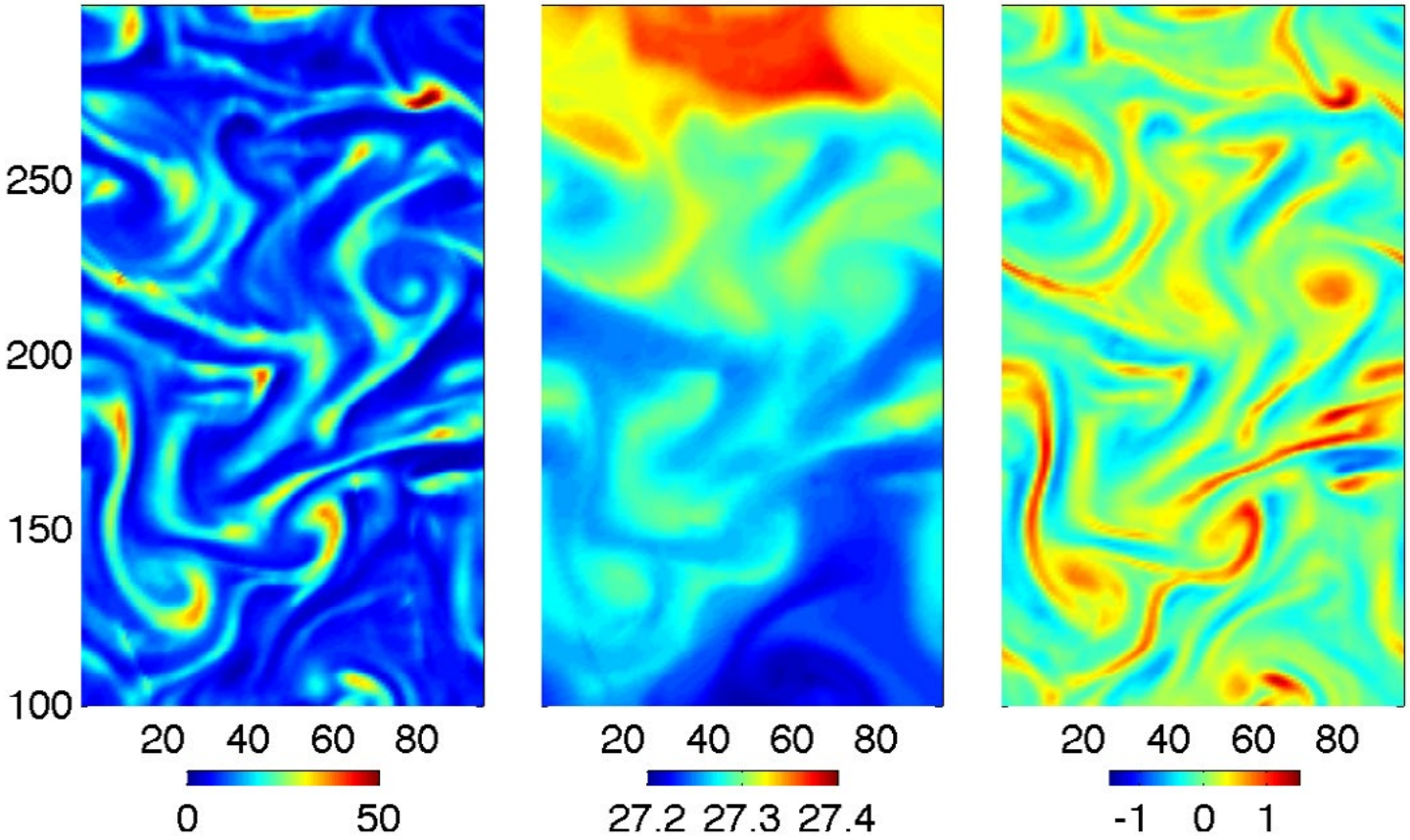

Figure 2. Surface fields from our Process Study Ocean Model showing particulate organic carbon (mg/m^3) (left panel), density anomaly (middle panel), and relative vorticity normalized by f (right panel), within a field of mixed layer eddies. The axes are in kilometers.

is traditionally ascribed to surface warming, which makes the near-surface more buoyant and stably stratifies the water column. In a field experiment conducted in 2008 at approximately 60° N, 25° W to observe the North Atlantic Bloom, Perry et al. (2012) found the onset of the spring phytoplankton bloom to occur about 20 days prior to the spring transition from sustained negative (cooling) to positive (warming) air-sea heat flux. This suggests that one-dimensional approaches to modeling convective and shear-driven mixing in response to surface cooling and winds, and stratification in response to warming and precipitation, may not entirely explain the evolving structure of the mixed layer.

Our recent understanding of mixed layer eddies and their role in altering the density structure of the mixed layer has revamped our thinking of how the mixed layer responds to surface fluxes. The surface ocean is rife with fronts (lateral density gradients) with cooler (denser) surface waters toward the poles arising from a (largely latitudinal) variation in surface buoyancy fluxes. The fronts are in near geostrophic balance; a west-to-east along-front flow balances the south-to-north density variation. Baroclinic instability of such fronts causes meandering, and fronts can spontaneously sharpen (weaken) by frontogenesis (frontolysis). Where fronts sharpen, the frontal jet accelerates, and the large local shear and vorticity become as large as the planetary vorticity, resulting in submesoscale dynamics. An eddying flow field results (Fig. 2). Mixed layer eddies grow by tapping the potential energy that is stored in the fronts. In the process, they slump the isopycnals and stratify the mixed layer by converting the horizontal density gradient into a vertical density gradient (Fig. 3).

During the winter and early spring, a wrangling persists between turbulent mixing, which makes isopycnal surfaces vertical (creating and deepening the mixed layer), and mixed layer eddies that slump these surfaces (fronts), releasing their potential energy and enhancing stratification. A heat (and buoyancy) loss from the ocean surface generates convective mixing, which homogenizes density in the vertical, making isopycnal surfaces vertical. Winds contribute by driving an

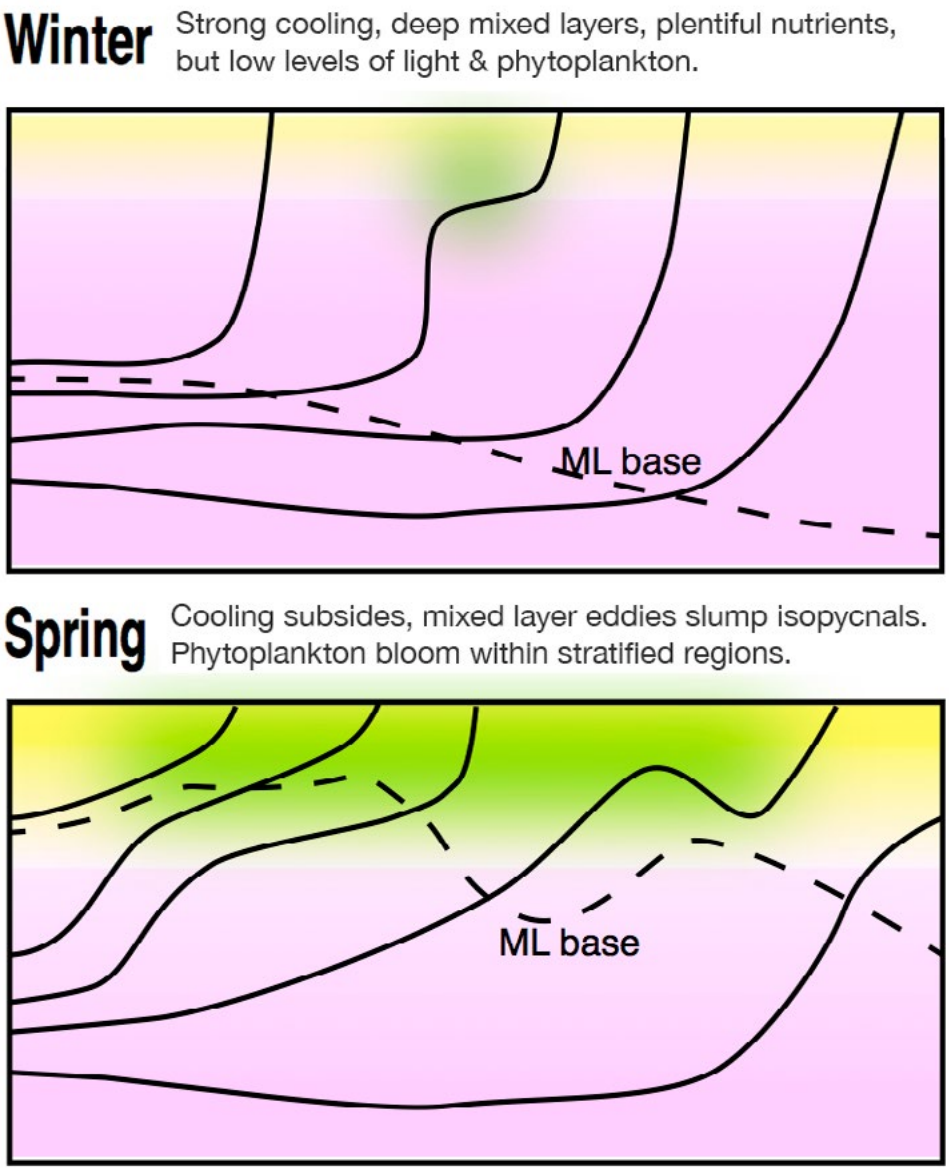

Figure 3. Schematic showing vertical section of density (black lines) during winter, when isopycnals in the mixed layer are vertical, and in spring, when isopycnals slump and generate stratification, inducing a phytoplankton bloom. Pink denotes nutrients, yellow denotes light, and green denotes phytoplankton. The base of the mixed layer is indicated as a dashed line (illustration by Melissa Omand).

Ekman flux to the right of the wind in the North Atlantic. When winds act in the direction of the frontal geostrophic flow (downfront), the surface Ekman transport drives cold water toward the warm side of the front, generating convective mixing that reinforces the front (Thomas, 2005). When winds are locally upfront, they transport lighter water over denser water, causing stratification.

In recent work (Mahadevan et al., 2010), we examined the competition between downfront winds and mixed layer eddy-driven slumping of isopycnals using model simulations. A scaling estimate can be derived for a balance between the strength of the eddy-driven mean overturning streamfunction (in a plane normal to the front) $\psi e = 0.06 b_y H^2/f$ associated with the lateral frontal buoyancy gradient b_y and mixed layer depth H (Fox-Kemper et al., 2008), and the wind-driven overturning $\psi w = \tau/(\rho f)$, where τ is the wind stress, ρ the density, and f the Coriolis parameter. Similarly, we have examined the competition between the vertical buoyancy flux due to surface heat loss, which generates vertical mixing, and mixed layer eddies, which stratify (Mahadevan et al., 2012). A threshold is identified in each of these cases, when the stratifying effect of mixed layer eddies counters the mean destratifying effect of cooling or downfront winds.

Using typical values for the horizontal density gradients and mixed layer depth from the North Atlantic Bloom experiment (NAB08), we find that mixed layer eddies will stratify the mixed layer when the cooling abates below about 100 w/m^2. Thus, the mixed layer can become stratified even before warming sets in. In NAB08, winds aided in the stratification because they shifted from westerly (downfront with respect to the mean front direction) to easterly (upfront) around the same time that the cooling weakened, and provided a stratifying Ekman flux.

Using the Process Study Ocean Model (Mahadevan, 2006) to simulate the three-dimensional processes in the mixed layer of the North Atlantic (Mahadevan et al., 2012), we showed how mixed layer eddies are generated and tend to stratify the mixed layer. We initialized our model with vertical and horizontal density gradients typical of the subpolar North Atlantic from NAB08 observations in early winter and forced it with wind and heat fluxes for the period Feb-April. In the presence of strong cooling (winter), convective mixing overpowers the stratifying effect of the mixed layer eddies (Fig. 4a). Though the eddies are active and draw from the potential energy of the fronts, the surface layer remains well mixed to about

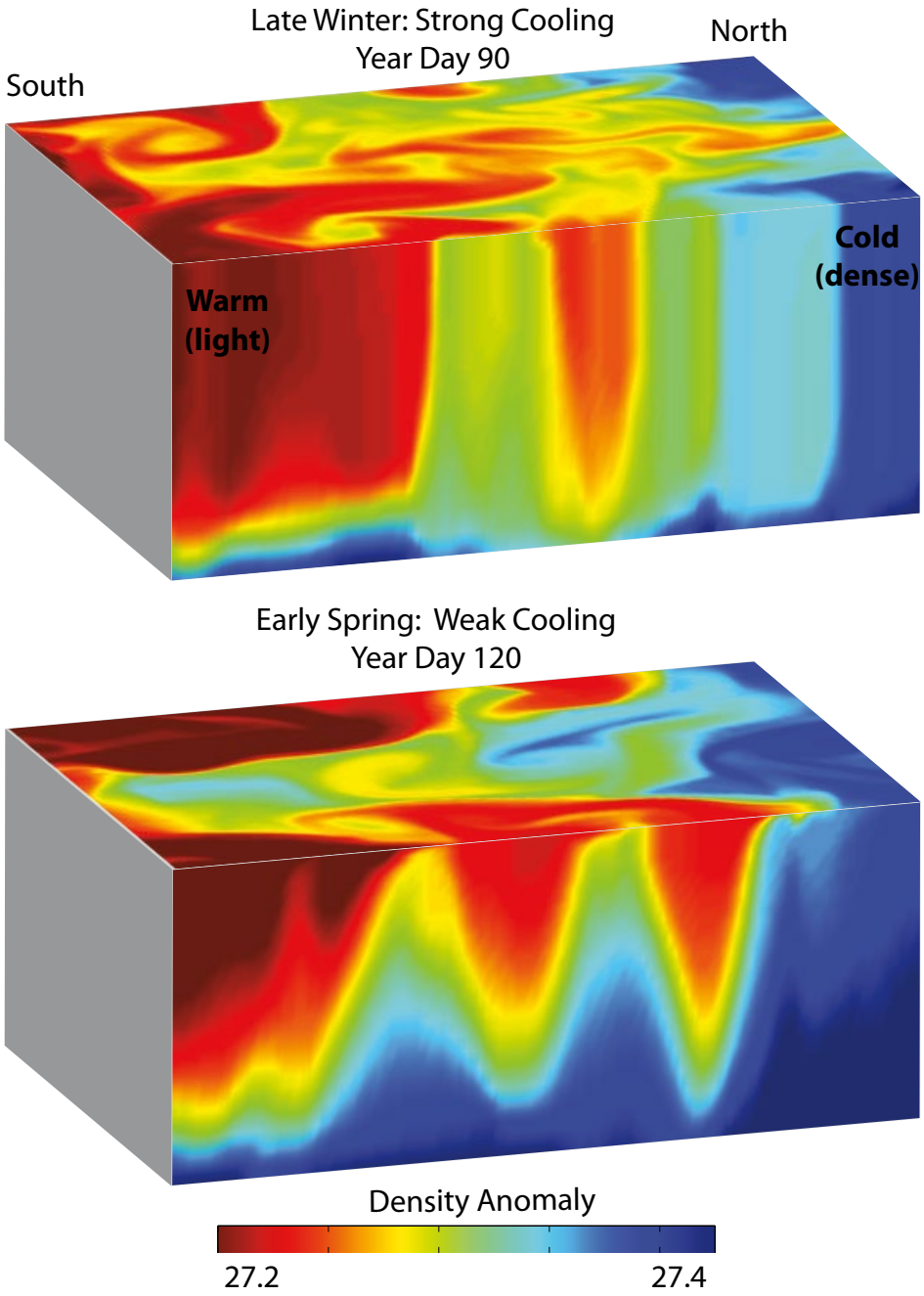

Figure 4. Density anomaly from our process study ocean model (a) in late winter, when strong cooling keeps the mixed layer vertically homogenous even though the mixed layers are active; (b) in early spring, when mixed layer eddies have generated stratification and made the mixed layer depth variable and shallow in places, where phytoplankton bloom.

300 meters depth. When the cooling subsides, and NAB08 winds also switch from westerly to easterly, the mixed layer eddies are able to overcome vertical mixing and stratify (shoal) the mixed layer (Fig. 4b). However, the mixed layer depth becomes highly variable, and the field of eddies and stratified areas at eddy edges are simultaneously advected by the eddying flow. Thus the bloom is highly heterogeneous (Fig. 2), and bears the signature of lateral eddy processes when viewed from space (Fig. 1).

We have showed that the evolution of the mixed layer and the onset of the spring bloom are highly heterogeneous on lateral scales of a kilometer and are induced by lateral and vertical processes. Present day ocean carbon cycle models do not resolve mixed layer eddies, which are submesoscale; they simulate the spring bloom through stratification induced by surface warming, a one-dimensional process, and thereby do not capture the precise timing and heterogeneity of the bloom. Further work is needed to determine if the initiation of stratification and premature triggering of the bloom by mixed layer eddies is prevalent in situations other than what we observed in NAB08, and to what extent the process affects the phenology and productivity of the phytoplankton over the seasonal time scale.

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C-MORE Scholars Program: An interview with Christina Johnson

Christina Johnson is a senior majoring in Global Environmental Science at the University of Hawai'i at Mānoa. She is also a Fellow in the C-MORE Scholars undergraduate research program, which she joined in Fall 2010. Christina will be graduating in spring 2013. The interview was conducted by Jessica Ayau.

How has the C-MORE Scholars Program impacted your undergraduate experience?

My participation in C-MORE and the Scholars Program has been indispensable to my undergraduate career, providing me early education in experimental development, field and laboratory work, data handling and analysis, synthesis of research findings, and the dissemination of research findings through the preparation of scientific posters, symposium talks, and written reports. I will come away from this program with a much better understanding of the inner-workings of academic research in my intended field of study. In addition to this, I will also come away from the Scholars program with a high degree of training in professional development, leadership, and community outreach.

What research are you working on as a Scholar?

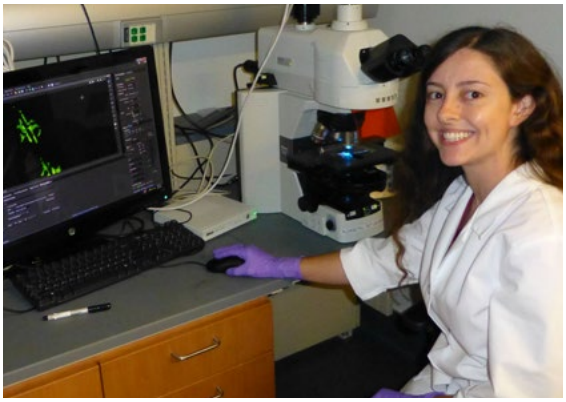
I am interested in the microbially-mediated coupling of major marine biogeochemical cycles. My scholars projects have focused on a particular marine microbial interaction between the carbon (C) and nitrogen (N) cycles through open ocean assemblages of microorganisms called *diazotrophs*. These microbes come in several flavors, but are united by their ability to tap into a vast, yet widely unavailable storehouse of the vital nutrient, nitrogen. Diazotrophs are unique because they possess the biochemical machinery necessary to transform N from its most abundant, unusable form (N_2, about 80% of our atmosphere) into bioavailable forms that are useful to, and highly demanded by, other life forms. This transformation of unavailable N_2 to useful N represents quite an energy investment on the part of the diazotroph; to supplement the energetic cost of the procedure, the diazotrophs that I study turn to sunlight energy and photosynthesis for financing. Since the "synthesis" part of photosynthesis involves the creation of sugars and other organic compounds from carbon dioxide (CO_2), diazotrophs represent a coupling of important transformations within the N and C cycles. In the three years I have participated in the Scholars program, my research has focused on different questions regarding this model.

What are your long-term career goals?

I want to do my part to embroider greater detail into the scientific understanding of global biogeochemical science by helping elucidate transformations mediated by marine microbial machinery. I plan to pursue academia and broad-level science writing. I want to contribute at least as much literature written in language appreciable to the non-specialist as I contribute to technical journals. I reject the notion that science should remain unavailable to the "uninitiated" – I'm sort of a diazotroph myself in that respect. My N_2 is scientific knowledge, locked away in technical language, awaiting science bilinguists to make it useful to others. So, in the long-term I hope to build my expertise as a microbial oceanographer, contribute new knowledge to the field, and write the story in language accessible to the non-specialist.

What do you plan on doing after you graduate?

I plan to pursue graduate studies in microbially-mediated biogeochemistry in Fall of 2013, and I hope to carry out a post-graduate internship in the summer prior to that. I am currently speaking with research groups at several institutions – at this point, I can't predict where on Earth I will be this time next year!



Second meeting for U.S. Ocean Acidification Investigators being planned

Now that OA research in the U.S. has been going on for a few years, it is time to assess where the community is, where it is going, and what work still needs to be done. To accomplish this, the OCB Ocean Acidification subcommittee will convene OA researchers once more at the second meeting for U.S. Ocean Acidification investigators in Washington, DC, from September 18-20, 2013 at Gallaudet University's Kellogg Conference Center. This meeting will provide attendees with the opportunity to share and learn about recent research results, as well as many ways to help shape the developing U.S. national ocean acidification research efforts. Meeting activities include many panel, plenary, and breakout discussions designed to explore how current U.S. OA research and organizational support fit together, and to identify where greater synergies can be encouraged.

More information can be found at the workshop website, where registration is also now open. Register early to reserve your spot, as space is limited!

OCB-OA Headlines

» Paul G. Allen Ocean Challenge, as part of a larger ocean health initiative, and in collaboration with The Oceanography Society, is offering a $10,000 prize for the most promising new science-based concept for mitigating environmental and/or societal impacts of ocean acidification (application deadline: July 31, 2013, more information)

» In early 2013, the National Research Council released its review of the National Ocean Acidification Research and Monitoring Plan. This document summarized the findings of a group charged by the FOARAM act to review the Interagency Working Group on Ocean Acidification's Strategic Plan for federal research and monitoring of ocean acidification.

» Friday Harbor Laboratories and University of Washington are hosting an Ocean Acidification Research Apprenticeship from April 1- June 7, 2013. Applications were due January 25, but applications will be accepted past that date if space is available. Students will participate in an OA mesocosm experiment, having specific research topics to complete. Class lectures will focus on the chemistry and biology of mesocosm experiments, and field trips will be conducted to put lessons in context.

» New thematic series *Ocean Acidification: Approaches to mitigation and adaptation* to be published in Carbon Balance and Management. Manuscripts can be submitted via the online submission system, clearly stating in your covering letter that your submission is intended for the 'Ocean Acidification: Approaches to mitigation and adaptation' thematic series.

Ocean Acidification Short Course: Studying Ocean Acidification and its Effects on Marine Ecosystems Cananéia, Brazil

by Joan Kleypas (NCAR)

Course Summary

A three-day ocean acidification short course was recently held in Brazil, near the Universidade de São Paulo Cananéia Field Station, from Dec 4-6, 2012. This was an abbreviated course to introduce the basics of ocean acidification research to Brazilian colleagues, and to encourage capacity building among our international partners. Participants were provided information on the CO_2-system chemistry of ocean acidification and how to measure it; how to design experiments to measure the impacts of ocean acidification on marine organisms and communities, and an understanding of what resources, instrumentation and tools are available for conducting ocean acidification research. The workshop was organized by Dr. Ilana Wainer, Instituto Oceanográfico Universidade de São Paulo (IOUSP), and sponsored IOUSP, IGBP, and SOLAS-IMBER. The course convened four instructors (Andrew Dickson, Chris Langdon, Joanie Kleypas, and Lisa Robbins) and approximately 20 participants (graduate, postdoctoral, and faculty levels) from multiple sub-disciplines of biological and chemical oceanography.

The short course drew heavily from the *Guide to best practices for ocean acidification research and data reporting* (Riebesell et al. 2010) and from the personal expertise of the instructors. It did not include hands-on work with measurements or instrumentation, but was rather designed as a basic template for future capacity-building workshops in other countries. The course was deemed highly successful in providing the participants with the essential information to design and conduct ocean acidification research, but also in helping them form a cooperative group for exchanging ideas and resources. An immediate outcome of this workshop was a White Paper written by the participants to establish a Brazilian Ocean Acidification (BROA) program, which they submitted to various Brazilian Agencies.

Details of the workshop are posted at: http://www.inpe.br/igbp/curso_oceanos/index.php

Important Dates

- **March 27-28, 2013:** Gulf of Mexico coastal synthesis team meeting (St. Petersburg, FL)
- **July 22-25, 2013:** OCB Summer Workshop (Woods Hole, MA)
- **September 18-20, 2013:** U.S. Ocean Acidification PI Meeting (Gallaudet University's Kellogg Conference Center, Washington, DC)

Partner Program Updates

IMBER

- IMBER Open Science Conference (June 23-27, 2014, Bergen, Norway) – deadline to submit a proposal for sessions and workshops is **March 15, 2014.**

SOLAS

- 2013 SOLAS Summer School (August 23-September 2, 2013 in Xiamen, China)
- Annual (2012) reports available for two SOLAS projects:
  - Sources and sinks of climatically-active gases in the Eastern Boundary Upwelling and Oxygen Minimum Zone (OMZ) systems
  - Air-sea exchange of greenhouse gases using satellite data

2013 OCB Summer Workshop

The annual OCB summer workshop will be held **July 22-25, 2013 in Woods Hole, MA**. The plenary sessions for this year's workshop will be as follows:

- ***Estimating rates of biological carbon transformations (e.g., net community production) across biogeochemical time-series*** (Chairs: Ricardo Letelier, Craig Carlson)
- ***Trace element-biota interactions*** (Chairs: Mak Saito, Sonya Dyhrman)
- ***Southern Ocean processes*** (Chairs: Jorge Sarmiento, Kendra Daly)
- ***Marine microbes, climate change, and evolution*** (Chairs: Tatiana Rynearson, David Hutchins)

The workshop website and registration will be available this spring, and the final speaker line-up will be posted there.

Recent and Upcoming OCB Co-Sponsorships and Travel Support

- IMBER IMBIZO III (Jan. 28-31, 2013, Goa, India)
- International Ocean Colour Science Meeting (May 6-8, 2013, Darmstadt, Germany)
- 45th International Liege Colloquium on Ocean Dynamics (May 13-17, 2013, Liege, Belgium)
- Summer Satellite Remote Sensing Training Course (May 31-Jun 14, 2013, Ithaca, NY)
- 9th International Carbon Dioxide Conference (ICDC9) (Beijing, China)
- Ocean Optics Summer Class: Calibration and validation of ocean color remote sensing (July 7-August 2, 2013, Walpole, ME)
- Researcher Colloquium *Key Uncertainties in the Global Carbon-Cycle: Perspectives across terrestrial and ocean ecosystems* (curricular component of NCAR Advanced Studies Program (ASP) Student Colloquium Carbon-climate connections in the Earth System) (August 5-9, 2013, Boulder, CO, application deadline: **April 15, 2013** – apply here)

Joint Scientific Working Groups with U.S. CLIVAR

An Update from the *Heat and Carbon Uptake by the Southern Ocean* Working Group

by Joellen Russell and Igor Kamenkovich (co-chairs)

The primary objective of this working group is to reduce uncertainties in climate projections by defining the role of the Southern Ocean in climate through the development of Data/Model Metrics based on a unified framework of theory, quantitative datasets, and numerical modeling. The specific focus is on the two critical paths leading to the improvement of the Southern Ocean simulation in climate models:

- Identification of critical observational targets and development of data/model metrics in collaboration with our colleagues based on the currently available observational data, both physical and tracer, and the assimilative modeling (re)analyses
- Evaluation and development of our understanding of the importance of mesoscale eddies in the heat and carbon uptake and of the response of the Southern Ocean to a changing climate, using high-resolution numerical studies and theory

More specifically, this Working Group will:

- Propose targeted process or measurement campaigns that will allow alignment of model-derived and observational evidence
- Propose targeted process or sensitivity studies in higher resolution models, with appropriate tracers and outputs, to identify the importance of mesoscale eddies in heat/carbon uptake and examine response of the Southern Ocean to changing climate

Recent Activities:

The first in-person meeting of the Southern Ocean WG took place in San Francisco, CA Dec. 7-8, 2012. Eleven members were present. All participants gave short (20min) presentations on their modeling and observational studies directed toward better understanding physical and biogeochemical processes in the Southern Ocean. These talks were followed by in-depth discussions in break-out groups, which addressed: (i) observational metrics needed for alignment of model-derived and observational evidence; (ii) model biases and ways of their reduction; (iii) strategies on planning an observational campaign for detecting and understanding SO changes; (iv) most critical observations and detection of "tipping points". Members discussed specific steps toward producing the planned deliverables.

Planned deliverables:

- Observationally based data/model metrics for the consistent evaluation of modeling efforts by Southern Ocean and Antarctic scientists
- White Paper(s) for the scientific community and funding agencies that: (i) assesses the state of our understanding of the role of eddies in the Southern Ocean in both the data and the models; and (ii) identifies the most critical observational targets needed to fill in the gaps in our understanding of the role of the Southern Ocean in present and future climate
- Workshop/Conference jointly sponsored with the Oceanic Carbon Uptake Working Group, open to Southern Ocean and Antarctic scientists as well as carbon cycle scientists, with the goal of (i) sharing the developed metrics for model evaluations; (ii) identifying important biases in the AR5/CMIP5-type model simulations of present and future climate; (iii) providing guidance for estimating and reducing uncertainty in climate projections
- Summary of WG activities/products for the U.S. CLIVAR and OCB newsletters and websites

An Update from the *Ocean Carbon Uptake* Working Group

by Annalisa Bracco, Taka Ito, Curtis Deutsch (co-chairs)

The U.S. CLIVAR/OCB Ocean Carbon Uptake Working Group was established in 2012 to identify common metrics of physical ocean/climate forcing (primarily wind strength, mixed-layer stratification, and ocean mixing), compare metrics in the various models and in the observations for the North Atlantic and the Tropical Pacific, and coordinate model evaluation of the climatic influence on CO_2 uptake at different time scales.

The Ocean Carbon Uptake WG's scientific objectives are to:

- Foster and promote collaboration between members of the U.S. CLIVAR and OCB communities and between modelers and theoreticians within each community
- Advance our understanding of the processes responsible for ocean carbon uptake and their representation in climate models

Recent Activities:

The first in-person meeting of the Ocean Carbon Uptake WG took place in San Francisco, CA Dec. 5, 2012. The meeting consisted of five short scientific presentations:

1. An overview of the IPCC WG 1 second order draft on ocean carbon cycling (*T. Ito*)
2. Trends in the oceanic oxygen in the CMIP-5 models (*C. Deutsch/T. Ito*)
3. Interannual variability of Indian Ocean productivity in CMIP-5 (*A. Bracco*)
4. Response of the Natural Ocean Carbon Pumps in the 21st Century Climate Change (*J. Palter*)
5. Regional patterns of climate change in global warming (*S. Xie*)

Working group members then revisited the working group's scientific objectives (listed above) and discussed specific tasks and outcomes, including a review of the most current literature to identify processes with poor representation in models that yield large uncertainties in ocean carbon uptake. Scientific discussions focused on identifying potential metrics for testing model biases in ocean carbon uptake (e.g., anthropogenic carbon inventory, mixed layer depth, ocean heat uptake, etc.), identifying key physical processes in the atmosphere and ocean that control ocean carbon uptake (e.g., winds, mode water formation, etc.), and potential problems and biases with historic data sets.

Next steps:

Working group members will review relevant chapters from the IPCC-WGI AR5 second order draft to assess the current status of CMIP-5 carbon cycle models, specifically to identify processes that are poorly represented. Then the group will discuss possible diagnostics and experimental improvements.

Integrating Molecular Biology and Biogeochemistry at Sea

In 2010, OCB supported a workshop to explore the potential for more routine integration of molecular biological and biogeochemical sampling approaches at sea (Moffett et al., 2010). A pilot cruise/study merging molecular and biogeochemical measurements has since been conducted, and OCB supported a follow-on workshop (Feb. 11-13, 2013, Friday Harbor Laboratories) convening participants of the pilot study to examine the sampling and logistical challenges, data sets, and scientific outcomes of the cruise and discuss paths forward for larger-scale implementation of this integrated sampling approach. A brief report on the workshop will be published in the Spring/Summer OCB Newsletter and a summary will be presented at the 2013 OCB Summer Workshop (July 22-25, 2013, Woods Hole, MA).

NACP/OCB Coastal Synthesis Activities

OCB continues its partnership with the North American Carbon Program (NACP) to coordinate and facilitate research activities to refine carbon budgets for the coastal regions of North America. The Gulf of Mexico regional team meeting will take place **March 27-28, 2013 in St. Petersburg, FL**. To view the status of coastal carbon budgets for different regions of the North American coast, please view articles published in previous issues of the OCB newsletter (east coast, west coast, Gulf of Mexico, Arctic, Great Lakes). The east coast budget was updated as a result of the east coast team meeting in January 2012. Results are available in the meeting report. To get regular regional updates, please visit the Coastal Synthesis Wiki Site.

OCB community participates in IMBIZO III

S. Cooley, L. Levin

One hundred and seven natural and social scientists from around the world attended the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) Project's third biennial IMBIZO meeting (IMBIZO III) at the National Institute of Oceanography in Goa, India from 28-31 January. The overall theme for IMBIZO III was "the future of marine biogeochemistry, ecosystems, and societies." In this meeting, organizers sought to explore the linkages and interactions between humans and ecological and biogeochemical systems in the continental margins and open ocean in order to further our understanding of human-ocean-human interactions with respect to global change. This charge attracted attendees from a much broader range of disciplines compared to past IMBIZO meetings.

The IMBIZO format consists of three parallel workshops focusing on related issues, where participants come together for plenary presentations, discussion sessions, poster sessions, and socials. Local conveners from the National Institute of Oceanography, led by S. Waji Naqvi, worked very hard to make the logistical aspects of three workshops run in parallel a resounding success. Workshop 1, led by K.K. Liu (National Central University, Taiwan), addressed "Biogeochemistry-ecosystem interactions on changing continental margins." Workshop 2, led by Helmuth Thomas (Dalhousie University, Canada), focused on "The impact of anthropogenic perturbations on open ocean carbon sequestration via the dissolved and particulate phases of the biological carbon pump." Workshop 3, led by Alida Bundy (DFO, Canada), addressed "Understanding and forecasting human-ocean human interactions, drivers and pressures, with respect to global change." IMBIZO III was unique in that it placed a much stronger emphasis on including social scientists and having each workshop consider not just human's effects on marine ecosystems, but the resulting effects of change in the marine ecosystem back to human communities.

Day 1 began with keynote plenary presentations from Curtis Deutsch (UCLA) and Denise Breitburg (Smithsonian Environmental Research Center) representing Workshop 1, discussing "Ocean hypoxia from physics to fish" and "Nutrients, hypoxia, and fisheries: lessons about multiple stressors from the Chesapeake and beyond," respectively. They were followed by a keynote plenary presentation from Farooq Azam (Scripps Institution of Oceanography) representing Workshop 2, discussing the "Microbial carbon pump and ecosystem connectivity." Finally, Moeniba Isaacs (University of Western Cape, South Africa) represented Workshop 3 with a presentation titled "ADApT or Die: Finding Methodologies to secure the livelihoods and food security for fisheries-dependent communities around the world." Then, the attendees split into individual workshop groups for the remainder of the meeting, but reconvened in plenary discussions focused on aspects of each respective workshop at the end of each day.

Workshop 1, "Biogeochemistry-ecosystem interactions on changing continental margins" explored the following themes:

- Human impacts on continental margins
- Biogeochemical responses to climate change in continental margins
- Ecosystem responses to external forcing in continental margins
- Trends of warming-deoxygenation and their impacts
- Hypoxia and hypercapnia in upwelling system
- Interactions between natural and social sciences for better stewardship of continental margins

Twenty-six individual workshop presentations and multiple discussion sessions identified various drivers of biogeochemical variation on margins and the challenges of distinguishing among natural variation, climate change, and anthropogenic influence. System overviews were provided for San Francisco Bay, the North Sea, the Cariaco Basin, the Arctic, the Indian Shelf, and the Bohai, Baltic, Mediterranean and Adriatic Seas. Biological responses to biogeochemical variation, regional variation, complexity and compensation in responses were addressed for these systems.

Workshop 2, "The impact of anthropogenic perturbations on open ocean carbon sequestration via the dissolved and particulate phases of the biological carbon pump," sought to advance the science of including the microbial carbon pump and the biological pump in models (both numeric and conceptual) of carbon sequestration in the ocean and global carbon cycles. By bringing multidisciplinary attention to this topic, conveners also hoped to advance the discussion of how these processes

OCB community participates in IMBIZO III - continued

could be considered in plans seeking to enhance carbon sequestration. Interactions between the biological and microbial pumps were explored during sessions focusing on the nature of DOC, microbial processing of DOC and genetic diversity, interactions between the microbial carbon pump and biological pump, and system responses to anthropogenic perturbation.

Workshop 3, "Understanding and forecasting human-ocean human interactions, drivers and pressures, with respect to global change," focused on three broad themes:

- Analysis of societal changes in response to, or anticipation of, global change
- Identification of vulnerabilities to global change, evaluation of current capacities to address global change and societal response to global change
- Identification of key governance and policy thematic foci to empower societies to address global change

To develop insight on these themes, the workshop included presentations, posters, discussion sessions, and small-group roundtable discussions that considered the following three overarching questions:

- Taking into account the biogeochemical changes that are occurring in the shelf and oceanic waters, how can human societies optimize their capacity to adapt to global change?
- Do we need an integrative human-ocean-human framework?
- How can natural and social scientists optimize their cooperation to achieve integrated knowledge and understanding of the interactions between the natural and human systems to support proactive policy decisions?

Sessions in this workshop focused on analyzing societal changes in response to or anticipation of global change, identification of vulnerabilities to global change and evaluation of current capacities to address these, identification of key governance and policy thematic foci to empower societies to address marine environmental change, and methodological approaches to assess these issues.

Many participants at IMBIZO III felt that the inclusion of social scientists and the consideration of human-relevant issues brought a very different perspective to this meeting, but most agreed that there is much work to be done to bring together natural and social sciences more closely for future study of the human-ocean system. Each IMBIZO workshop is planning a special volume to circulate the findings from their sessions, and to highlight future possible directions for promoting this area of study.

IMBER Data Management Training Course and Workshop

S. Cooley

Just before the beginning of IMBIZO III in Goa, India, members of the IMBER Data Management Committee hosted a one-day workshop focused on making good data management practices a reality, providing real-world examples of these practices, and shedding light on the intersection of natural and social science data.

The workshop included plenary presentations in three groups: case studies showing the need for integrated assessment of natural and social science data; talks exploring why IMBER needs data management; and presentations describing data management in marine science and other relevant fields. Following these, a panel discussion explored the issues raised by presenters, and other issues brought up by audience members.

For most participants thinking primarily about natural sciences, simply learning about the variety and quantity of social science data that exist was eye-opening. The presentations and discussions also highlighted disconnects between natural and social science research and data management. In part, the lack of strong connections between the research areas leads to weaker connections between data management organizations. Better communication, interdisciplinary education, and new reward structures being implemented at many institutions for developing datasets and syntheses (rather than just publications) may help promote tighter research connections between disciplines, which will also advance the creation of multidisciplinary datasets that may need to be hosted by interdisciplinary consortia of data management organizations.

Global Inter-Comparability in a Changing Ocean: An International Time-Series Methods Workshop

by Heather Benway, Laura Lorenzoni, Maciej Telszewski

Biogeochemical ocean time-series represent one of the most valuable tools scientists have to characterize and quantify ocean carbon fluxes and biogeochemical processes and their links to changing climate. They provide the oceanographic community with the long, temporally resolved data sets needed to characterize ocean climate, biogeochemistry, and ecosystem change. However, in order to monitor and differentiate natural cycles and human-driven changes in the global oceans, it is important that time-series methodologies (sampling and analytical protocols) be transparent, consistent, and inter-comparable. Despite the fact that many biogeochemical time-series have used the JGOFS protocols as a basis for their sampling and analytical methodologies, several adaptations have been made based on local oceanographic conditions (e.g., open ocean vs. coastal) and several other factors. To date, no thorough intercomparison among time-series methodologies has been conducted at a global scale.

In order to address this important issue, an international time-series methods workshop was jointly convened by OCB and the International Ocean Carbon Coordination Project (IOCCP). The workshop was held November 28-30, 2012 at the Bermuda Institute for Ocean Sciences (BIOS), home of the Bermuda Atlantic Time-series Study (BATS), one of the longest ship-based biogeochemical time-series. The workshop was the third in a series of workshops focusing on shipboard biogeochemical time-series that started in 2008 with the "Changing Times: An International Ocean Biogeochemistry Time-series Workshop"; this was followed by the "Sea Change: Charting the course for ecological and biogeochemical ocean time series research" workshop in 2010. However, unlike the previous two, this workshop focused specifically on the methods employed by each time-series with the aim of enhancing data comparability between sites.

With representation from 17 countries and 33 time-series around the globe, the workshop brought together participants who possessed both an understanding of the scientific goals of their time-series and ample hands-on experience with sample collection and analysis. To set the stage for smaller group discussions, the workshop opened with plenary talks that highlighted scientific insights derived from shipboard and fixed-point time-series, as well as the logistical challenges of maintaining time-series, particularly in developing countries. Participants then broke into nine smaller groups to discuss sampling and analytical protocols. Each working group comprised representatives from multiple time-series, and focused on a different set of biogeochemical parameters, including pigments, in line (bow intake) measurements, CTD parameters, inorganic macro- and micronutrients, biomass, carbonate system, rates (primary and bacterial production), sediment trap fluxes, and organic matter.

With a focus on sampling, standardization, nomenclature and data reporting, and quality assurance and control (QA/QC) protocols, the working groups compared established methods and developed a consensus ranking of methods (optimal/good/acceptable) for each parameter. With the recognition that not all time-series can easily adopt the optimal method for each parameter, working groups identified metadata (method details and descriptors) that would facilitate comparison of data derived from different methods. Working groups also discussed newly emerging technology that might improve data precision and accuracy in the future.

The success of the workshop depended not only on the discussions at the meeting, but on the work done a priori by its participants. All time-series site representatives provided detailed information on the parameters they measure and the methods (and associated references) they use. This information was summarized for all time-series, and the cited methods were compiled on the workshop website. Participants were divided into working groups ahead of time and tasked with familiarizing themselves with the methods used for their respective set of parameters, which ensured that the discussions held during the workshop were as informed and productive as possible. Additionally, participants were asked to present posters on their time-series sites, which further enhanced the dialogue and increased visibility for all of the represented sites.

Global Inter-Comparability in a Changing Ocean - continued

Workshop outcomes and recommendations:

To improve internal consistency, time-series representatives recommended the following low-cost experiments for individual time-series:

- Niskin casts with repeat particulate sampling at regular time intervals to quantify impact of particle settling and revisit sample extraction order if necessary
- Quantitative comparisons of chlorophyll extraction using different solvents
- Primary productivity incubation time (e.g., 12 vs. 24 hour) comparison experiments

Suggested community intercomparison activities across multiple time-series included:

- Flow cytometer count inter-comparisons
- Nutrient inter-comparison using both commercially available and secondary (internally calibrated) standards
- Comparison of a suite of coulometer models being used for measuring dissolved inorganic carbon (DIC)

The working groups were very thorough and examined the methodologies carefully, and the detailed recommendations of these discussions will be published in the full workshop report, which will serve as a best practices road map for shipboard biogeochemical time-series to facilitate data intercomparability across sites and ocean basins. This report will include:

- Tiered method recommendations (optimal, good, acceptable) for each parameter
- Guidelines and additional metadata for comparing data generated using different methods
- Information about what global ocean time-series sites are measuring, what methods they are using, and how to access data and detailed methods documentation

The workshop web portal and email list will be transformed into an active web-based network of international time-series information that will be continually expanded to include new shipboard biogeochemical time-series.

Community Resources

Data and Research

- Global Carbon Project releases 2012 Global Carbon Budget
- Release of Version 2 of the Surface Ocean CO_2 Atlas (SOCAT) at 9th International Carbon Dioxide Conference (ICDC9) (Beijing, China, June 4, 12:15-13:30, more information)
- SCOR Working Group 131 'The Legacy of in situ Iron Enrichment: Data Compilation and Modeling' makes data from iron enrichment experiments available via
  - BCO-DMO (IronEx I and II, SOIREE, SOFeX North and South, SERIES, SEEDS I and II, SAGE)
  - PANGAEA (EisenEx, EIFEX, LOHAFEX)
  - British Oceanographic Data Centre (FeeP)

Reading

- OCB Scoping Workshop Report/Publication: Church, M. J., M. W. Lomas, F. Muller-Karger (2013). Sea Change: Charting the course for biogeochemical ocean time-series research in a new millennium. *Deep-Sea Research Part II: Topical Studies in Oceanography* (in press).
- Global Land Project (GLP) Report No.7: Incorporating human behaviour and decision making processes in land use and climate system models
- NOAA Winter 2013 edition of *Sea Ice Extent* newsletter
- Subcommittee on Ocean Science and Technology releases *Science for an Ocean Nation: Update of the Ocean Research Priorities Plan*
- Draft Climate Assessment Report released for public review (comments due April 12, 2013)
- National Academies Report *A National Strategy for Advancing Climate Modeling (2012)*

OCB Calendar

We maintain an up-to-date calendar on the OCB website.

*OCB activity | **OCB co-sponsorship | ***OCB travel support

2013	
March 10-15	Gordon Research Seminar (GRS) on Polar Marine Science (Ventura, CA)
March 27-28*	NACP/OCB Gulf of Mexico coastal synthesis team meeting (St. Petersburg, FL)
April 7-12	European Geosciences Union General Assembly 2013 (Vienna, Austria)
May 6-8***	International Ocean Colour Science meeting (Darmstadt, Germany)
May 13-17***	45th International Liege Colloquium on Ocean Dynamics (Liège, Belgium)
May 23-24	Southern Ocean Observing System (SOOS) Asian Workshop (Shanghai, China)
May 28-June 29	C-MORE 2013 Summer Course on Microbial Oceanography (Honolulu, HI)
May 31-June 14**	Summer Satellite Remote Sensing Training Course (Ithaca, NY)
June 3-7***	9th International Carbon Dioxide Conference (ICDC9) (Beijing, China)
June 16-July 6	BIOS Summer Course - Microbial Oceanography: The Biogeochemistry, Ecology and Genomics of Oceanic Microbial Ecosystems (BIOS, Bermuda)
July 7-August 2***	Ocean Optics Summer Class: Calibration and validation of ocean color remote sensing (Darling Marine Center, Walpole, ME)
July 22-25*	Annual OCB Summer Workshop (Woods Hole, MA)
July 22-August 23	Summer Course on Ocean Acidification Methodologies (Friday Harbor Laboratories, WA)
July 29-August 16	NCAR Advanced Studies Program (ASP) Student Colloquium Carbon-climate connections in the Earth System) (Boulder, CO)
August 5-9**	Researcher Colloquium *Key Uncertainties in the Global Carbon-Cycle: Perspectives across terrestrial and ocean ecosystems* (curricular component of NCAR ASP Student Colloquium Carbon-climate connections in the Earth System) (Boulder, CO)
August 12-16	2013 Community Earth System Modeling Tutorial (Boulder, CO)
August 19-23	PICES Summer School Ocean observing systems and ecosystem monitoring (Newport, OR)
August 23-September 2	2013 SOLAS Summer School (Xiamen, China)
September 18-20*	U.S. Ocean Acidification PI Meeting (Washington, DC)
September 23-25	International Conference on Marine Data and Information Systems (IMDIS2013) (Lucca, Italy)
October 12-19	DISCCRS VIII Interdisciplinary Climate Change Research Symposium (La Foret Conference and Retreat Center, CO)
December 9-13	2013 Fall American Geophysical Union (AGU) Meeting (San Francisco, CA)

OCB Calendar (cont.)

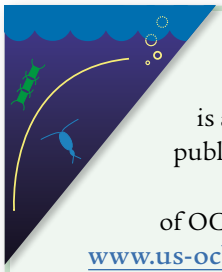
2014	
February 23-28	2014 Ocean Sciences Meeting (Honolulu, HI)
April 15-18	North pacific Marine Science Organization (PICES) Open Science Meeting Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems (FUTURE) (Kohala coast, Big Island, HI)
June 23-27	Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) Open Science Conference: Future Oceans – Research for marine sustainability multiple stressors, drivers, challenges and solutions (Bergen, Norway)
July 6-11	Gordon Research Conference Ocean Global Change Biology (Waterville Valley, NH)
OCB-RELEVANT FUNDING OPPORTUNITIES	
March 29	NASA Ocean Biology & Biogeochemistry NOIs due
April 1	NASA Interdisciplinary Research in Earth Science (IDS) full proposal deadline (ROSES '12)
April 15	NSF OPP Antarctic Research Proposal deadline
May 1	NASA Carbon Cycle Science Step 1 proposal due date (ROSES '13)
May 30	NASA Ocean Biology & Biogeochemistry full proposal deadline
July 31	NASA Carbon Cycle Science Step 2 proposal deadline (ROSES '13)
July 31	Paul G. Allen Ocean Challenge: Mitigating acidification impacts concept submission deadline
August 15	NSF Chemical and Biological Oceanography proposal deadlines

How can OCB help you?

» Looking to **publicize a recent paper**? Add it to the OCB peer-reviewed literature list, contact the Project Office about doing a science feature on the OCB website, or submit to the OCB Newsletter

» Want to **share news** about education and outreach resources, jobs, field opportunities, relevant upcoming meetings and special sessions, etc.? Post to the OCB email list

» Looking for **international travel support**? The OCB Project Office has limited funds for U.S. participation in international workshops and meetings that advance the programmatic mission of OCB. The OCB SSC reviews travel support requests three times a year: March, July, and November



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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