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Global Biogeochemical Flux Observatory: Tasks, Strategy and Emerging Technologies

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I. Global importance of the ocean carbon cycle and the biological pump

Two decades of research under the Joint Global Ocean Flux Study (JGOFS) in the latter part of the 20th century brought a wealth of new knowledge on the cycling of carbon and other important elements in the oceans of our blue planet. For example, scientists traced and quantified the "fluxes" and "inventories" of CO_2 and other key carbon-containing species from the air-sea interface to deep ocean sediments in order to develop the first integrated picture of the ocean carbon cycle. These studies revealed the critical and pervasive roles of marine organisms in the transport, recycling and storage of carbon throughout the entire water column. The term "biogeochemistry" was coined to describe this new holistic genre of science.

The pelagic and coastal oceans, together with the Great Lakes, contain over 90% of the Earth's actively cycling carbon pools. According to the IPCC, terrestrial carbon (C), including that from the land plants and soil microbes, is estimated at 175 petamoles, and atmospheric C (CO_2) is currently 62.5 petamoles (pre-industrial values were 48.3 petamoles). On the other hand, the amount of C in the ocean interior is as large as 38,000 petamoles, 600x that present in the atmosphere, constituting by far the largest inventory of actively cycling C on this planet. This balance appears to have been maintained throughout most of Earth's atmospheric history, and is critical to maintaining a habitable planet in the future.

Some CO_2 is recycled from the ocean interior to the surface by various physical processes, including upwelling and ventilation of deep waters. However, an essential biological mechanism that replenishes this colossal CO_2 reservoir, maintaining atmospheric CO_2 and associated surface temperatures at an optimal level to sustain life is the "Biological Pump," which converts CO_2 to particulate organic carbon (POC) via primary production in surface waters and transfers a small fraction of this carbon to the global ocean interior. JGOFS research revealed the intricate mechanisms by which microscopic, low-density particles of organic carbon can escape from the euphotic zone and be transported to the interior, assisted by biogenic mineral ballasts. The settling velocities associated with the removal of this POC from the euphotic zone to the ocean interior are as high as 100-200 m d^{-1}, enabling a steady state of POC production in and export from the euphotic zone to be maintained.

In order to understand the interactions and feedbacks between global climate change and associated transformations in the ocean, it is imperative to develop a complete understanding of the ocean's role in the global carbon cycle, particularly with respect to the biological pump. This requires a comprehensive, coordinated, and sustained measurement program. Such coordinated data gathering is feasible through the initiation of a Global Biogeochemical Flux (GBF) program and its alignment with other sustained observation programs such as the Ocean Observatories Initiative (OOI). Emerging technologies for observing ecosystem dynamics and constraining biogeochemical fluxes, coupled with rapid advances in molecular biology and biogeochemistry, are capable of providing unprecedented insights into the mechanics of the biological pump and its interplay with surface ocean productivity and other elements of the global carbon cycle. In order to promote ideas and an overall research philosophy for the GBF-OOI, and to discuss the feasibility of such a major, multi-faceted ocean observation program, an OCB-sponsored scoping workshop will be held from May 23–25, 2011 in Woods Hole, MA USA.

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Table 1.

II. Basic strategy of GBF-OOI

The primary objective of GBF-OOI is to obtain integrated time- and depth-series data and discrete samples of sufficient quality and spatiotemporal resolution to accurately constrain carbon fluxes and cycling throughout the global oceans. These data sets are critical to evaluating the evolution and stability of ocean carbon reservoirs, and will support global carbon cycle research and biogeochemical modeling communities in a collective quest to understand and predict changes in ocean chemistry and biology. This will require the execution of a highly coordinated observational strategy sustained over several decades. Ocean observatories that comprise uniform, intercalibrated sets of advanced ocean sensors, instrumentation, and platforms will need to be deployed throughout the world's oceans in order to provide continuous measurements of all relevant parameters.

GBF-OOI Observatories will not be solely aimed at promoting process-oriented research, but will focus more broadly on collecting coherent global carbon flux and inventory data using the best-available technologies under identical experimental conditions with standardized error and accuracy reporting. Observational data and samples should be disseminated as quickly as possible to international ocean research and education communities. To facilitate uniform data (and error) reporting and maximize efficiency and cost effectiveness, samples will be distributed to centralized international analytical facilities. GBF-OOI data/sample distribution policies, which will be developed in accordance with OOI protocols, should be designed to most effectively address questions on local, regional, and global scales.

This program will be developed in close alignment with the OOI by a consortium of U.S. and international scientists, and coordinated by the GBF-OOI Science Steering Committee (Table 1). Partnerships will also be sought with international organizations (e.g., Global Climate Observing Systems (GCOS), United Nations (*1*)), and regional ocean observing programs (e.g., Integrated Marine Observing System (IMOS), Australia).

III. Specific Tasks

A. Accurate assessment of oceanic primary production

Quantifying global ocean primary production (PP) is fundamental to our understanding of the role of the oceans in Earth's carbon cycle, the biological pump, and the capacity of the oceans to supply high-grade protein to a rapidly expanding human population. While global PP is a key variable in the ocean carbon cycle and is sensitive to global climate change, a sustained *in situ* observation of this parameter has thus far been extremely difficult to achieve with existing methods. Subsequently, there have been large discrepancies among published estimates of global annual PP over the last few decades, and questions concerning seasonal (and depth) variability in PP have been inadequately addressed.

Coupling novel robotic technologies for quantification of *in situ* PP with broader scale information from remote sensing is within reach. Novel autonomous instrumentation such as time series "Incubation Productivity System" (IPS) devices using C, N, and O stable isotope tracers, and *in situ* optical technology such as Fast Repetition Rate (FRR) fluorometers can yield high-temporal resolution and depth-integrated assessment of net and gross PP. Such measurements at key ocean sites, including those targeted by the OOI, combined with improved satellite-based ocean color observations and modeling efforts, would yield more robust model-based estimates of global ocean PP.

While satellite ocean color observations provide estimates of surface ocean primary production and its spatiotemporal variability, observations are limited to the surface layer only; pigment structure and photosynthetic activity deeper in the water column are inaccessible. Major advances in the accuracy of export production (EP) estimates are possible by coupling improved constraints on PP with synoptic organic carbon flux measurements down to and within the mesopelagic and bathypelagic zones. Combined with parallel observations of biological community variability and the role of microbes, this will greatly improve our understanding of the overall controls on the biological pump and our ability to predict how it may respond in the future.

Long-term deployments of vertical arrays of synchronized IPS devices, FRR fluorometers, or similar systems possessing a high-resolution time-series schedule (and synchronized with time-series particle trap collections) could provide depth-integrated, temporally resolved assessments of epipelagic zone productivity spanning an annual cycle. Incubations with multi-isotope tracers could also provide information on production rates of other biogenic materials, including particulate inorganic carbon (e.g., $CaCO_3$ in coccolithophorids) and silica (e.g., SiO_2 in diatom frustules), which are invaluable for studying ocean acidification and assessing the ballasting role of different inorganic phases in relation to the biological pump.

The development of mooring capabilities for precise deployment of instrumentation within the euphotic zone represents an important challenge for *in situ* surface ocean biological productivity measurements and for establishing links between field data and satellite-based ocean color observations. New electro-mechanical technology will precisely (± 0.5 m) maintain surface-expressed instrumentation within 15 m of the air-sea interface.

Although new *in situ* technologies will improve PP estimates at specific sites, satellite ocean color observations will play a critical role in the integration of *in situ* data with new ocean models for reliable global estimates of PP. It will therefore be important to synchronize *in situ* biological observations with satellite schedules to enable the necessary optical-biological inter-calibration. The provision of abundant high quality 3-D time-series data combined with the anticipated exponential increases in computing power in the near future will greatly facilitate the integration of biological, satellite, and modeling data for more accurate regional and global estimates of ocean productivity.

B. Constraining export fluxes of POC and other particulate material

During the JGOFS era, many U.S. and international programs deployed time-series sediment traps (TS-traps) throughout the world's pelagic oceans and continental margins. Data spanning over a decade of research have been compiled, resulting in multiple synthesis efforts, including those seeking to address the central questions of how the steady state between PP and POC export (the "Biological Pump") is maintained and how fine particles of POC are transported to the abyssal ocean and the seafloor to feed benthic ecosystems. JGOFS data also improved our understanding of seasonal variations in particle export within and between different oceanic regimes, the degree of attenuation of POC through the water column, and of the fluxes of ballast biominerals. These investigations revealed distinct oceanic regions in which fluxes are dominated by different biominerals, which is of critical importance for determining the factors influencing the attenuation of POC fluxes through the water column in the face of global climate change.

However, current estimates of settling fluxes and attenuation of POC and other particle-associated elements with depth include major uncertainties that preclude robust extrapolation to regional and global scales. For example, we still lack a well-constrained global estimate for the flux of POC and other biogenic components to the bathypelagic zone/ocean floor. Accurate determination of interannual- to decadal-scale variations in global fluxes will require carefully orchestrated deployments at uniform depths and coordinated time-series particle collection and measurement protocols.

C. Sustained observations of surface ocean microbial community structure

Another major knowledge gap is ocean biological community structure, both in surface waters and throughout the water column, how it varies in response to climate forcing, and in turn how this influences the efficacy of the biological pump. However, recent innovations in molecular biology, including the increasingly widespread application of "omics" (e.g., genomics, transcriptomics, proteomics, metabolomics), are catalyzing breakthroughs in marine microbiology and microbial biogeochemistry. Our appreciation of the enormous influence of microbial community structure on the biological pump and associated biogeochemical processes has grown tremendously with the advent of these novel methods. Observations of microbial community structure and function, coupled with assessments of biological productivity, are crucial if we are to develop a comprehensive understanding of the biological pump.

Field-deployable devices capable of performing autonomous molecular biological assays and optically recognizing and distinguishing different algal populations are emerging, which opens the door for *in situ*, near real-time assessment of microbial community structure and function. For example, the Environmental Sample Processor (ESP) (*2, 3*) enables remote observations of microbial community structure, as well as abundance of functional genes and cell metabolites. The deployment of ESPs or similar instruments on highly engineered moorings that enable long-duration placement at precise depths within the euphotic zone (e.g., 20 m deep) would yield TS-data that are complementary with those obtained from *in situ* productivity instruments (IPS). Coupled with chemical, physical, and other biological information provided by GBF-OOI "core-measurements," it would be possible to examine roles that specific members of the microbial community play in biogeochemical cycling on a temporal scale not previously possible, and in locations that are inaccessible by ship throughout much of the year.

Improving our understanding of the microbes driving the biological pump requires not only sustained molecular and biogeochemical observations of microbial ecosystems in the upper euphotic zone, but throughout the entire water column and down to the sediment-water interface. For example, a newly emerging molecular biological tool will enable high-frequency collection and preservation of RNA samples aboard a deep ocean platform deployed at any depth, including the sediment-water interface.

D. Provision of time-series water and suspended particle samples and observations of zooplankton communities in the ocean interior

Improved understanding of the interplay among dissolved organic carbon (DOC), POC, and microbial activity, and the role of microbes in ocean carbon cycling throughout the water column requires observations over a range of spatial and temporal scales. Collection of discrete *in situ* water samples over a range of depths, combined with suspended particle, Bacteria, and Archaea sampling will yield time-series to help quantify dissolved and particulate materials and their variability. Such sampling will be extended to the benthic realm, where higher rates of remineralization and microbial activity are reported.

Zooplankton are most abundant in the mesopelagic or "twilight" zone, feeding on the POC that is supplied from the euphotic zone, thereby playing a critical role in the Earth's carbon cycle (*4*). Technologies to observe and quantify diel vertical migration of zooplankton are still premature, but a shuttling zooplankton video recorder (*5*) mounted on a moored profiler may be feasible.

IV. Technological readiness of GBF-OOI observatories

We envision array clusters that include >20 GBF-relevant instruments (not including OOI-contextual sensors) and two *in situ* robotic laboratories along 4 dedicated moorings (Fig. 1). We call this cluster a "unit GBF-OOI Observatory," with each mooring forming a quadrilateral pattern with an edge spanning 12 nautical miles of seafloor in the pelagic ocean. For continental margin sites, GBF-OOI observatories would be deployed with essentially the same instrumentation, but array patterns would be adjusted to accommodate local seafloor topography. A detailed deployment plan will be developed with input from the GBF-OOI SSC and the international ocean science community, including modelers, satellite researchers, engineers, and other OOI affiliates. A few years of trial deployments will be required, and as the scientific and engineering capacity of GBF-OOI grows, the number and geographic distribution of Observatories will increase.

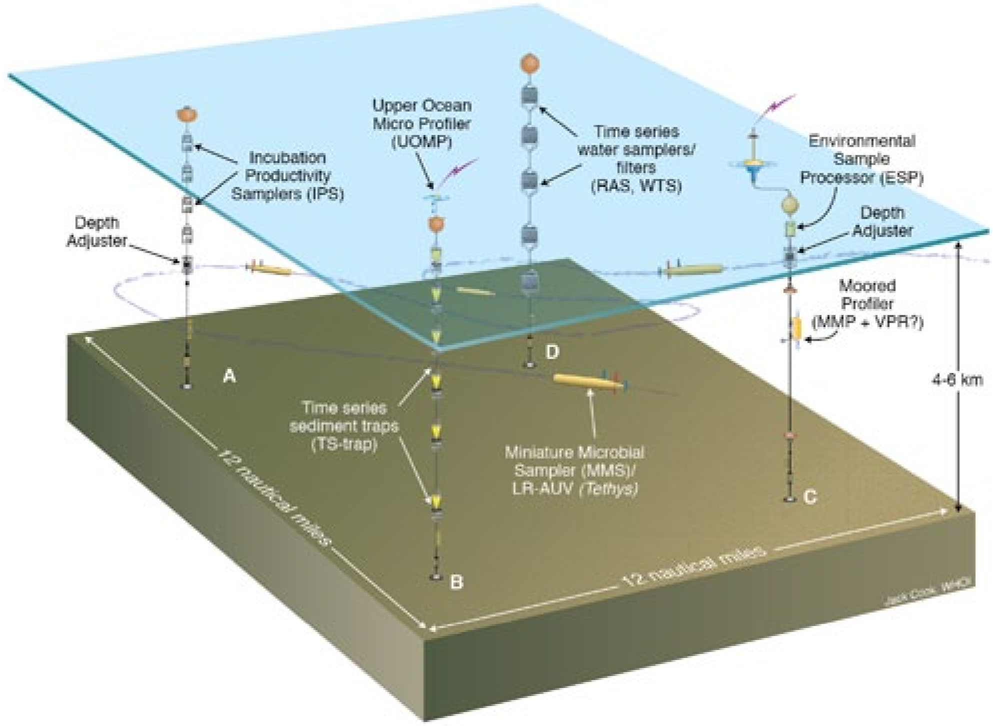

Figure 1. A Unit Undersea Observatory consists of 4 mooring platforms spaced ~12-miles apart. Over 20 robotic sensors, samplers, and processors are deployed on the moorings and some are housed in the shallow floats. A power and communications buoy at the C-mooring site houses the main data transmitter for the entire Observatory. All GBF instruments/samplers and contextual sensors (e.g., CTD) on global Observatories will be operated via a single time-series command in order to synchronize the measurements. We envision deploying a robotic AUV to collect in situ microbial samples for laboratory analysis on land.

Ocean platform technology

Crucial to the realization of a GBF-OOI Observatory is the development of reliable platform systems capable of precise and controlled placement of sophisticated biogeochemical sensors, experimental systems, and sampling devices over a wide range of depths, including close proximity to the sea surface and the sediment-water interface. Important recent advances in mooring design and engineering include: (1) Advanced computational technology for the numerical design of mooring arrays; (2) Extensive use of synthetic mooring cables; (3) Moorings with self-generated or fuel cell-supported power supply; (4) Data and image transmission cyber-technology per OOI protocols; (5) Utilization of flexible electro-mechanical hoses to stabilize instruments moored in the semi-wave zone; (6) Automatic depth adjustment devices for more precise deployment of instruments; and (7) Efficient, high-precision depth sounding capacity to survey and select Observatory locations.

Instrument technology and sample processing

A GBF-OOI Observatory will utilize a combination of established, recently developed, and nascent technologies. Ocean observing instrumentation is increasingly benefiting from advances in fluid engineering, robotic process control, emerging plastic/metal alloys, and information technology. Water, particulate, and microbial samples will be analyzed via robotic processing as much as possible to minimize analytical errors and ensure prompt turnaround of analytical data.

Operation and synchronization of the instruments

Synchronization of sensor measurements with *in situ* sample collection is critical for deriving global estimates of PP and biogeochemical fluxes. This can essentially be achieved via development of a master "start/stop" command timetable for all GBF-OOI instruments deployed throughout the global ocean.

V. Unit GBF-OOI Observatory mooring elements

Four moorings dedicated to characterization of biological and biogeochemical processes (Fig. 2) are envisioned for each unit GBF-OOI observatory. This would include: **A.** an array of *in situ* incubation systems utilizing multi-isotope tracers for determination of depth-integrated primary productivity, biogenic SiO_2, and $CaCO_3$ production; **B.** a TS-sediment trap array deployed in mesopelagic and bathypelagic waters for determination of deep ocean biogeochemical fluxes; **C.** platforms for *in situ* assessment of microbial community structure and dynamics using genomic sensors and a shuttling plankton video recorder mounted on a moored profiler; and **D.** an array instrumented with autonomous TS-samplers capable of collection and preservation of water and suspended particle samples for biogeochemical and molecular biological analysis in the laboratory. More detailed information and illustrations of the GBF-OOI technology are available in the GBF-OOI Community White Paper.

VI. Justification of effort and investment

The development and long-term operation of GBF-OOI Observatories

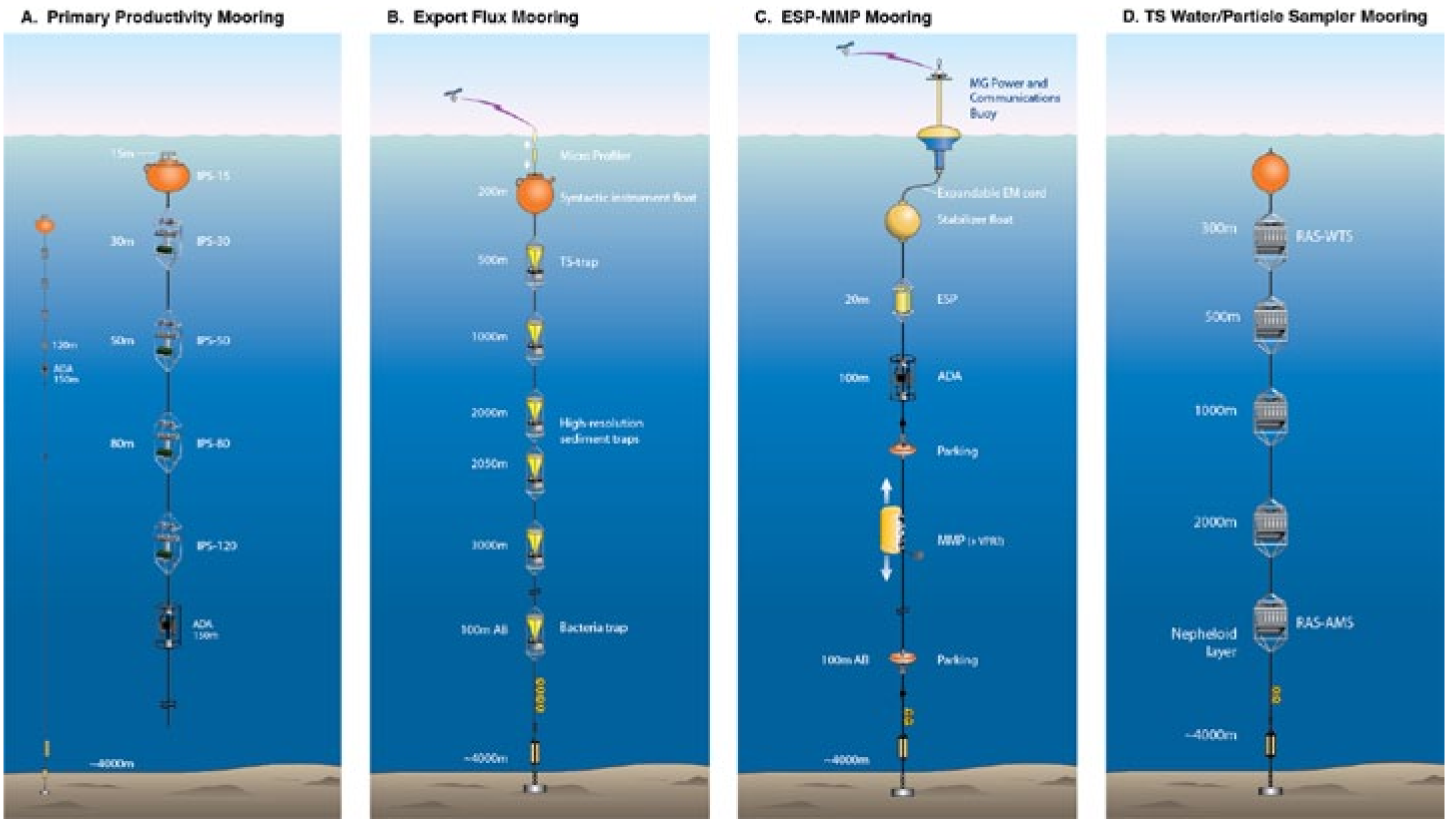

Figure 2. Configuration of four moorings (A-D) that constitute a unit deep ocean Observatory. Although not shown, time-series samplers/sensors can be deployed on the seafloor near the anchor connecting with an automatic anchor recovery system. The engineering status of individual sensors, samplers, and processors can be found in Table 2 of the GBF-OOI Community White Paper.

involves a substantial investment of resources (money, time, manpower, etc.) relative to conventional shipboard data gathering. However, the proposed GBF-OOI program will provide an unparalleled capacity to investigate biological activity in the ocean, biologically mediated export of carbon to the deep ocean, and the role of the oceanic biological pump in the global carbon cycle. The comprehensive, coherent time-series data sets from key oceanic regimes emanating from this concerted observation program will allow major advances in our understanding of ocean biogeochemistry in the context of the Earth system. It will connect microbially mediated processes to ocean-wide fluxes, combine genomic-level studies with assessments of elemental budgets, and allow extrapolations to the global ocean through remote sensing. This program will catalyze further innovations in ocean instruments and observation platforms, and will serve as a broad template for both ocean science research and education.

The proposed GBF-OOI program is shaped by the urgent need to understand the ocean's capacity to take up anthropogenic CO_2. In addition to constraining productivity in and export from the surface ocean, this program will provide key constraints on organic carbon consumption with depth and remineralization rates that influence CO_2 generation and storage in the global ocean. There are other pressing reasons to initiate this study. For example, grave concerns exist over global food availability in the near future, and whether ocean productivity can sustain the fisheries essential for many cultures. Accurate assessments of present and future ocean productivity are crucial for making robust predictions, and the observations proposed here are essential for calibrating remote sensing data in order to develop global assessments of ocean productivity.

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The contents of above article have not been thoroughly discussed by the GBF-OOI Science Steering Committee. This article adopted unanimous opinions offered to us on the White Paper (2010) and our own recent views on the GBF-OOI.

Carbonate Chemistry on Remote Coral Reefs: Natural Variability and Biological Responses

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Introduction

Over the next century surface water pH is predicted to drop by 0.3-0.5 pH units, a process termed ocean acidification (OA), as a result of increased atmospheric carbon dioxide (pCO_2). Reduction in seawater pH, correlated to a decline in calcium carbonate saturation state (Ω), will likely affect rates of calcification in marine organisms (*1*, *2*). The potential negative effects of OA are likely to be greatest for ecosystems where the foundation and framework species are calcifiers. Coral reefs are therefore among the most vulnerable to changing seawater carbonate chemistry as the resident corals and coralline algae deposit calcium carbonate and build the complex habitats that support extremely high levels of biodiversity in these systems (*3*, *4*). Thus not only are the corals and other calcifying reef organisms likely to suffer directly from OA, but the cascading consequences of habitat loss to the flora, fauna, and human societies dependent on these systems is likely to be great (*5*). There is an urgent need to understand the effects of OA on coral reef species, communities, and landscapes in an effort to predict the biological consequences of global change on these vulnerable natural systems.

The major contributors to carbonate accretion on coral reefs include both the scleractinian corals and the red crustose coralline algae (CCA) (*6*, *7*). The calcified green algae *Halimeda* are also important players in carbonate production in tropical systems as this genus dies when it reproduces, leaving behind the calcified skeleton which eventually breaks down to form sand. All of these photosynthetic organisms play important ecological roles on coral reefs. Corals provide food resources, habitat and shelter for many of the organisms that are present in reef ecosystems. CCA grow over dead coral skeletons and act as growing cement or living glue. Certain species of CCA also provide important cues for settlement and metamorphosis of coral larvae (*8*). Species of *Halimeda* are important food resources for herbivorous fishes and *Halimeda* has been shown to produce up to 90% of the sand in some tropical locations (*9*).

Several fundamental differences exist in the mechanisms by which these different reef calcifiers precipitate calcium carbonate that may influence their relative susceptibility to OA. Corals and *Halimeda* largely precipitate aragonite while CCA deposit high magnesium calcite, a more soluble polymorph of calcium carbonate ($CaCO_3$). Further, corals (mixotrophs that feed and photosynthesize) and other 'higher order' organisms have the ability to actively sequester calcium (Ca^{2+}), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-) via ion channels in cell walls to adjust the internal saturation state where calcification occurs (*10*). $CaCO_3$ in many 'higher order' organisms is essentially excreted from the tissues. Among benthic reef algae (photoautotrophs), the calcification process is less complex and not as tightly regulated. Calcification occurs intracellularly as a result of CO_2 or HCO_3^- uptake, which indirectly increases Ω near the cell surface and causes abiogenic precipitation (*4*). For this reason, certain groups of algae may be more susceptible to changes in ambient pH and carbonate chemistry than invertebrates.

A number of mesocosm experiments have tested the response of reef corals and CCA to the potential effects of ocean acidification and most of these have shown negative but somewhat variable responses. In most cases, reductions in pH and Ω lead to reduced growth rates, lower calcification rates, reduced rates of productivity, and increased levels of bleaching or necrosis. Much more limited data are available for fleshy reef algae, but it is likely that these taxa will respond oppositely to increases in pCO_2. If fleshy reef algae are carbon-limited, increases in pCO_2 may enhance their productivity and subsequent growth. The response of *Halimeda* and other calcified macroalgae is more difficult to predict, as increased pCO_2 could simultaneously enhance productivity and suppress calcification. If corals and calcifying algae are both negatively affected by OA, the fleshy algae will likely become the dominant benthic reef organism. Phase shifts from coral to fleshy algal dominance have become common around the tropics as a result of a myriad of human disturbances, and OA may increase the frequency or persistence of these reef state transitions.

Despite numerous mesocosm and lab experiments, there are limited data linking coral or algal growth and physiology with variability in carbonate saturation states *in situ*. However, the studies that do exist show significant correlations between Ω_{Ar} and coral calcification rates. On the reefs of Bermuda, coral calcification rates were positively associated with aragonite saturation states (*11*, *12*). Another recent study identified significant reductions in coral calcification rates over the last ten years on the Great Barrier Reef and the authors suggest declining aragonite saturation states and increasing temperature stress as the likely cause (*13*). In order to gain a realistic understanding of how OA will affect reef biota now and in the future, more field data are needed that make use of natural experiments along known gradients in pH or total CO_2.

Much of what we know about carbonate chemistry on coral reefs comes from offshore monitoring programs, sensors deployed on deep water moorings, sporadic point sampling, cross-reef control-volume sampling, and/or high frequency short-term sampling from a limited number of sites. Much less is known about the spatial and temporal variability in carbonate chemistry on the reef benthos where calcification is actively occurring. Offshore or surface sensor deployments are certainly important for documenting ambient or background oceanographic conditions. But because benthic organisms have the ability to alter biogeochemistry at or near the reef benthos through the biological processes of photosynthesis, respiration, and calcification, we believe that it is essential to gain a better understanding of the dynamics in carbonate chemistry on the reef benthos where calcification is taking place.

Methods and Results

Adapting a multidisciplinary approach, our research program is designed to address several outstanding questions regarding ocean acidification effects on coral reefs. First, using recently developed sensors, we seek to quantify natural variability in pH and other carbonate chemistry parameters on the coral reef benthos at numerous locations with high temporal frequency. In particular, we aim to understand natural variability in carbonate chemistry on "quasi-pristine" reefs in the absence of confounding local anthropogenic disturbances such as pollution. Second, we seek to determine the potential influence that physical oceanography and different biological communities (coral versus fleshy and calcified algae) may have on carbonate chemistry on coral reefs; are biological feedbacks on carbonate chemistry occurring within benthic boundary layers? Finally, using both field and laboratory experiments, we aim to determine how differences and variability in pH and carbonate chemistry affect competing benthic organisms (corals versus fleshy and calcified algae) and reef communities.

Study Site

The majority of our current OA research takes place at the Palmyra Atoll Research Consortium (PARC) field station located in the central Pacific and run by the Nature Conservancy (Figure 1A). Palmyra Atoll represents a unique ecosystem because of its extreme isolation and lack of current direct local human impacts. There are no permanent residents on Palmyra and, aside from military occupation in the 1940s-50s when the atoll was significantly restructured, there are little direct impacts on the adjacent marine

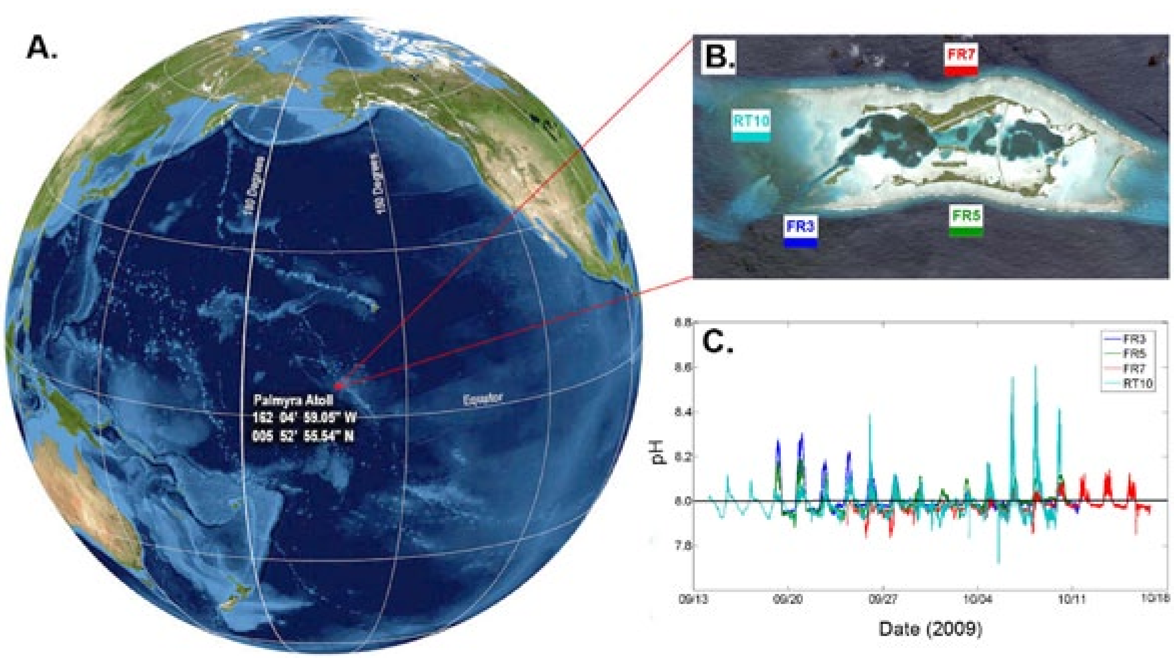


Figure 1. A) Map showing the location of Palmyra Atoll in the central Pacific. B) Satellite image of Palmyra showing the location of the pH sensor (SeaFET) deployments in the fall of 2009. C) Preliminary data spanning a 5-week window of variability in pH across 3 reef sites. The "FR" sites are from 10m depth forereef locations and the "RT" site is a 5-m reef terrace location.

communities. Furthermore, Palmyra Atoll and associated flora and fauna are part of the National Refuge System managed by the US Fish and Wildlife Service and the waters and coral reefs surrounding Palmyra were recently designated (2009) as part of the new Pacific Island Remote Area (PRIA) National Marine Monument. Thus the coral reefs of Palmyra atoll represent an ideal setting to study the effects of global stressors such as OA on marine communities because of the lack of local confounding stressors. The reef communities of Palmyra are considered to be relatively healthy with reef building corals and crustose coralline algae (CCA) making up greater than 50 % of the benthic cover on the forereef and shallow reef terrace habitats (54 and 78 % cover, respectively, Smith unpublished data). The articulated calcareous green algae *Halimeda* are by far the most common macroalgae on Palmyra's reefs and account for on average 22 and 10 % cover on the forereef and reef terrace habitats, respectively.

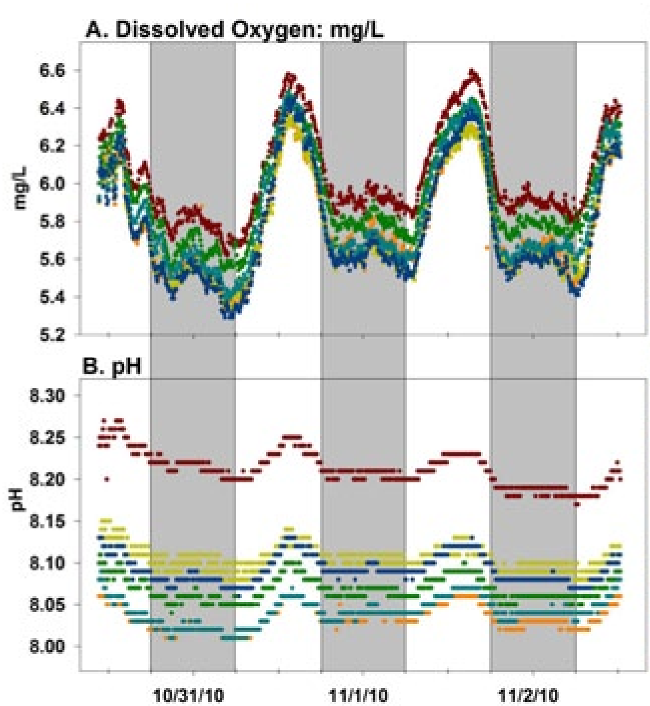
Natural Variability in pH on Quasi-Pristine Coral Reefs

In the past, it has not been possible to continuously monitor pH and other carbonate chemistry parameters remotely and reliably for extensive periods of time due to problems associated with fouling, corrosion, and drift of typical pH electrodes. However, the development and testing of new sensor packages has recently made measurement of at least pH possible for months at a time with little to no maintenance. Dr Todd Martz at Scripps Institution of Oceanography has exhaustively tested the Honeywell DuraFET® Ion Sensitive Field Effect Transistor (ISFET) pH sensor in both the laboratory and field (*14*). ISFET sensors are solid-state devices requiring no moving parts and perform with exceptional stability over multiple months of deployment. The Martz Lab has and continues to design new sensors that allow for remote monitoring of pH (SeaFET), temperature, salinity, and dissolved oxygen (SeapHOx).

In the summer of 2009, using SeaFET pH sensors (n=4), we quantified both spatial and temporal pH variability across a subset of the sites on Palmyra (3 sites on the forereef at 10 m depth and 1 reef terrace site at 5 m depth). While the duration of this deployment was only 2 weeks, the data are compelling and suggest that these locations are highly dynamic, exhibiting diurnal variability spanning 0.3-0.4 pH units. Of the 4 sites we examined, the greatest variability was detected at the shallower backreef site where residence time is likely longer than at any of the more hydrodynamically active forereef sites. The shallow backreef site also receives higher levels of irradiance and thus likely has higher rates of production than the deeper forereef sites. The clear diurnal signal in all 4 data sets strongly suggests that photosynthesis and respiration are driving the patterns in surrounding seawater pH. At present, we are continuously monitoring physical oceanography and carbonate chemistry using the SeaFETs and bottle samples for total alkalinity (A_T) and total dissolved inorganic carbon (C_T) at multiple shallow and deeper sites on Palmyra and at other uninhabited islands in the central Pacific through an ongoing collaboration with NOAA's Coral Reef Ecosystem Division based out of Honolulu, HI.

Potential Effects and Feedbacks of Biological Communities on Carbonate Chemistry

Because benthic reef organisms are largely photosynthetic, they have the potential to significantly influence benthic carbonate chemistry. By taking up CO_2 (or HCO_3^-) during daylight and releasing CO_2 at night through respiration and as



Tent	Coral	CCA	Macro algae	Turf
●	0	30	58	11
●	8	42	42	7
●	38	31	11	14
●	40	14	13	32
●	48	39	3	8
●	76	11	6	2

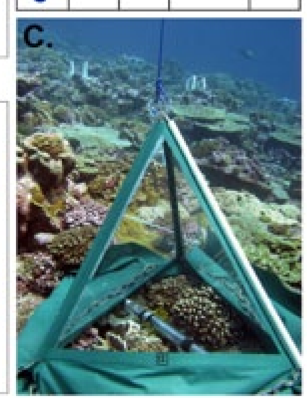


Figure 2. A) Dissolved oxygen concentration and B) pH measured every 5 minutes using optodes and electrodes, respectively inside C) benthic chambers (n=6) at 10 m depth on Kingman Reef in the Northern Line Islands in the fall of 2010. The gray shaded areas in plots A and B indicate night time hours while the non-shaded areas indicate day time.

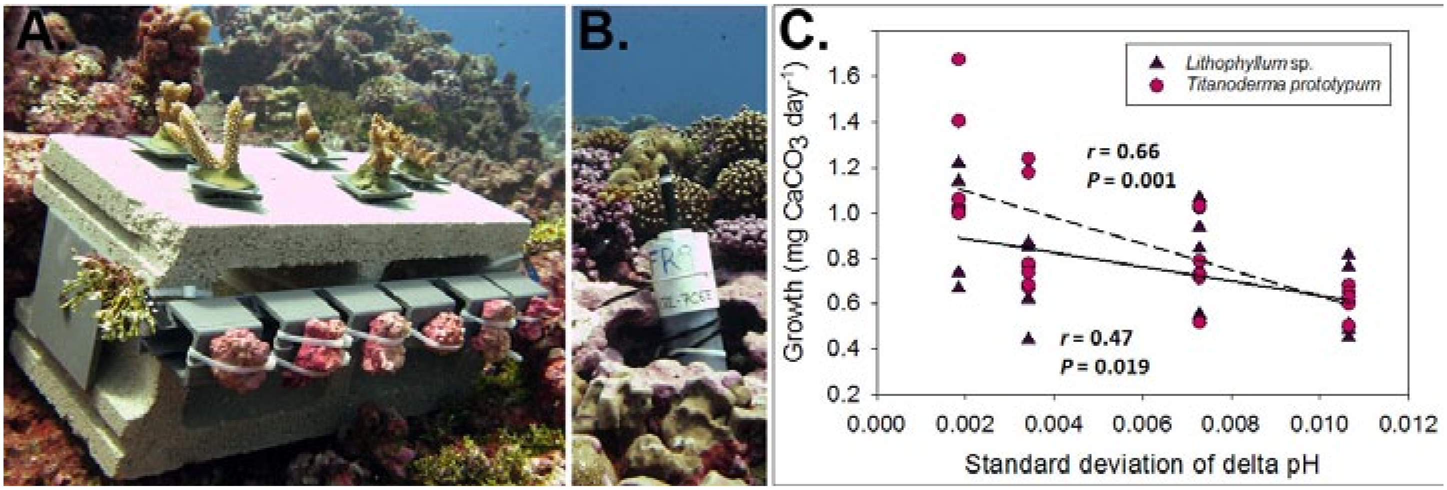


Figure 3. A) Minireefs used to measure coral, CCA and net community calcification on Palmyra Atoll at 10 m depth. B) A DuraFET pH sensor deployed on the reef benthos directly adjacent to minireef deployments and C) the relationship between rates of calcification in 2 species of abundant Crustose Coralline Algae (CCA) and the variability in the daily range of pH.

they calcify, it is important to understand how much these benthic producers actually influence the surrounding seawater chemistry. The potential influence that these benthic organisms may have on reef water chemistry will largely be driven by irradiance, benthic boundary layers, and local hydrodynamic regimes. To begin addressing these issues in coral reef subtidal forereef environments (10 m depth or greater), we have designed benthic production chambers in which we can measure *in situ* carbonate chemistry and physiological parameters over time. Using polyethylene clear sheets and gas-impermeable fabric, these tents or pyramids (1m x 1m x 1m) are secured to the benthos with stainless steel stakes and a large skirt that is secured with galvanized chain to seal the tent from the surrounding environment. Inside the tents we house Eureka Manta2 Multi-parameter sensors that measure temperature, salinity, pH, and dissolved oxygen (DO) with high temporal resolution for short periods of time. The tents are also plumbed with external submersible marine pumps and batteries that cycle water out of the tents and directly into custom-made Niskin bottles for carbonate chemistry analysis.

Our approach is to select plots composed of unique benthic assemblages to understand how different functional groups may influence carbonate chemistry in the surrounding seawater. While much of this work is ongoing, we have successfully deployed 6 benthic tents on six different islands in the northern Line Islands chain in the Central Pacific, each for at least 48 hours. Figure 2A-B shows an example of the data obtained during a 60-hour deployment on Kingman reef in the Northern Line Islands during a recent expedition in the fall of 2010. The most obvious pattern in both the DO and pH data sets is the strong diurnal signal, again suggesting that biological processes are driving the patterns in seawater chemistry in these plots. While all plots showed similar diurnal trends in DO and pH, the magnitude of these trends varies from plot to plot. The plots dominated largely by macroalgae generally have the highest levels of DO, mirrored by high pH, suggesting that as CO_2 is taken up for photosynthesis this directly raises seawater pH near the reef benthos. Some of the other pH data are not as clearly related to productivity of different benthic organisms present in these plots, but may instead be driven by calcification. We are currently developing multivariate descriptors of the benthic communities (including abundance of calcifiers and polymorph dominance) and analyzing bottle samples taken from the tents for changes in A_T and C_T to verify respiration, productivity, and calcification rates.

We are hopeful that by using these benthic chambers we will gain a better understanding of the potential effects that different benthic reef communities may have on carbonate chemistry. Of course we realize that these data are somewhat biased by confining particular water bodies into enclosed chambers in habitats that otherwise naturally receive fairly dynamic water movement. Nonetheless, we feel that this approach is necessary to begin understanding some of the feedbacks between chemical oceanography and benthic reef community composition. To our knowledge, these are some of the first measurements of their kind made in deeper forereef environments. These habitats are inherently challenging to work in, but are also extremely important to study, as they are where corals tend to be the most abundant in reef ecosystems.

Experimental Investigations on the Effects of Ocean Acidification on Coral Reef Primary Producers

Most experimental OA research to date has focused on micro- or mesocosm laboratory experiments using a variety of techniques to manipulate pCO_2, A_T, and/or pH. These experiments are very important for isolating the independent effects of OA on physiology of particular species, but more *in situ* data are needed to elucidate how reef organisms respond to their natural chemical environments. While our research group does use classic lab-based CO_2 bubbling experiments to assess the potential effects of OA on a variety of reef organisms (primarily fleshy and calcified seaweeds), we have also been developing a field research program to assess how reef organisms respond to natural variability in carbonate chemistry. Using "minireefs," which are glorified cinderblocks that house multiple coral nubbins, crustose coralline algal rhodoliths, and PVC settlement tiles, we can measure variability in growth and calcification rates in these organisms across a number of locations. Currently we have minireefs and SeaFET pH sensors co-located at 5 different sites on Palmyra Atoll (Figure 3A and B).

In the fall of 2009 during the initial deployment of the SeaFET sensors on Palmyra (Figure 1C), we quantified calcification rates for two common species of CCA (*Lithophyllum* sp. and *Titanoderma prototypum*) using buoyant weighing methods and minireefs described above. Our preliminary data indicate species-specific differences in CCA calcification rates and a strong correlation between calcification rates and natural variations in the daily amplitude of pH over a 3-week time period (Figure 3C), suggesting that CCA require a consistent chemical environment to calcify. The compelling nature of these data warrants further investigation over longer time periods and across a broader survey of benthic taxa.

Summary & Future Directions:

Our multidisciplinary research program is designed to address several fundamental but yet outstanding questions regarding the potential effects of ocean acidification on coral reef ecosystems. Because most coral reefs around the world have suffered from various degrees of local human influence (overfishing, sedimentation, nutrient pollution, etc.), it is difficult to isolate the independent effects of OA in these systems. To address these issues our research program focuses on remote coral reefs on uninhabited islands in the central Pacific where there are no confounding local impacts. We seek to gain a better understanding of how OA will affect intact reef ecosystems and with this information we hope to develop predictions for how these communities will change with future increases in pCO_2. It is our hope that these results will contribute to an overall improved understanding of the biological, chemical, ecological, and potential societal implications of increasing carbon in the atmosphere and the oceans, particularly for highly vulnerable ecosystems such as coral reefs.

Acknowledgments:

This research is supported by the Gordon and Betty Moore Foundation, and generous donations from Scott and Karin Wilson, the WWW Foundation, and the Rhodes family. The labs of A. Dickson and T. Martz have provided invaluable assistance and support. We would like to thank Scripps Institution of Oceanography Development office, the Palmyra Atoll Research Consortium, the Nature Conservancy, the U.S. Fish and Wildlife Service and NOAA's Coral Reef Ecosystem Division for help and support.

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Building a CDOM Database for a Coastal Carbon Synthesis Project

Christopher L. Osburn (NC State University), Thomas S. Bianchi (Texas A&M University), Robert F. Chen (University of Massachusetts-Boston), Paula G. Coble (University of South Florida), Eurico J. D'Sa (Louisiana State University), and Cyndy Chandler (BCO-DMO)

Introduction

Managing the data generated after a project's completion can be a difficult task. To many oceanographers, a database might be a collection of Excel spreadsheets or other rudimentary storage mechanism(s), which becomes formidable to access once a project ends. Many funding agencies now require data management plans in which investigators must detail the manner in which a project's data will be archived, made available to the research community, and communicated to the general public. The purpose of this article is two-fold: (1) to share the challenges faced and successes realized in developing a data synthesis product that is now part of an ocean biogeochemistry database, and (2) to invite researchers from the OCB community to augment the data synthesis product.

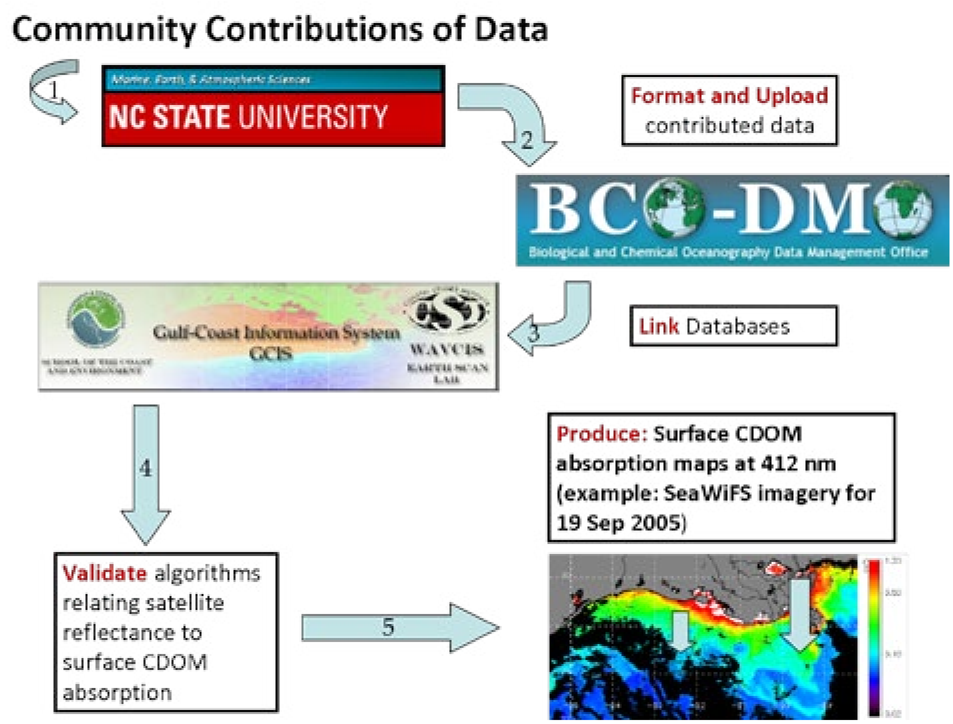


Figure 1. Work flow diagram for CDOM database.

Background

As part of the NASA Applied Science Program, Gulf of Mexico Initiative, a project was launched to synthesize bio-optical data on chromophoric dissolved organic matter (CDOM) in coastal regions of the Gulf of Mexico—an immediate goal of the North American Carbon Program (NACP) and the Ocean Carbon & Biogeochemistry program (OCB) as part of a larger Coastal Interim Synthesis Activity to stimulate the synthesis of observational and modeling results on carbon cycle fluxes and processes along the North American continental margins. CDOM effects on water quality and water clarity are part of a high priority issue identified by the Gulf of Mexico Alliance (GOMA). The investigators for this project each had historical CDOM data from rivers and coastal regions of the Gulf of Mexico, ranging from the Texas-Louisiana Shelf to the West Florida Shelf. Thus, this project amounted to a "data rescue," in which several unrelated projects focused on a similar region were merged into a "mega-cruise" format, to make these data publicly available. The goal of the project is to have an accessible database of CDOM data and information that meets two objectives. One objective is to provide coastal oceanographers with a repository for CDOM data from which the data can be retrieved and to which future cruise-related data acquisitions can be added. The second objective is to provide a resource for decision makers that require water clarity data on spatial and temporal scales compatible with the use of satellite imagery.

Developing the CDOM Database

A database manager from the Biological and Chemical Oceanography Data Management Office (BCO-DMO), Ms. Cyndy Chandler, has advised this team on the development and maintenance of the CDOM database. BCO-DMO, funded by the NSF Division of Ocean Sciences, provides data management support for some of the NACP-OCB Coastal Synthesis projects. The database was conceived as a geospatial synthesis, meaning all data admitted would be geo-referenced with latitude and longitude for later use in remote sensing algorithm calibration and validation work, as well as to contribute to coastal carbon synthesis activities. Thus, this particular database development falls under the NACP-OCB Coastal Synthesis: Gulf of Mexico region. BCO-DMO provided data and metadata formatting guidelines, which were used to formulate this project's data submission policy. This was an important first step because each PI had their CDOM and ancillary oceanographic data arranged in different formats.

In developing the guidelines for data submission, the team resolved three key components:

1. Strict adherence to data file format;
2. Minimum of latitude, longitude, depth, and time, in addition to key CDOM-related data identified;
3. Inclusion of metadata (including cruise IDs, where known).

These components were realized as the team balanced available data versus user input. Several "end-users" of CDOM information conferred with the team to decide on final pieces of information to include in the database. These end-users comprised scientists and resource managers, who advised the team on critical data and formats that would be most useful for them. These conversations were important for the team and its advisory panel to answer the "who, what, when, where, and why?" questions that were necessary to ensure the functionality of the database. By making these key components an important part of the development and maintenance of this database, the time spent editing contributed data files has been dramatically reduced, and the efficiency of data processing and posting to the database has improved.

Each contributed dataset was linked to a specific research cruise, thus providing temporal and spatial coverage and associated metadata. The metadata requirements were important so that users of the archived CDOM data could identify sample collection and analysis methods, as well as information on instruments and operating conditions involved in data acquisition. Also included in the metadata are points of contact and references to research articles and/or technical reports in which the data had already been published. An important feature of the data admission guidelines was that data should only be contributed after publication elsewhere. This policy protects the intellectual property of the persons involved with the original data collection and analysis, and through associated metadata files, enables proper citations of the datasets by database users.

The workflow for data admission, processing, and inclusion in the database is shown schematically in Figure 1. As data are contributed to NCSU (#1), they are formatted into files amenable for uploading to the database, which is hosted by BCO-DMO (#2). The CDOM database is then linked (#3) to a decision support science website, the Gulf Coast Information System (GCIS: http://gulf-coast.lsu.edu/index.html), which is maintained by Dr. Eurico D'Sa (Department of Oceanography and Coastal Sciences, Louisiana State University). Existing CDOM remote sensing algorithms using SeaWiFS reflectance to predict CDOM absorption coefficients are being validated (#4) with data already contributed. GCIS uses the algorithms to produce surface CDOM absorption maps (#5) as water quality data products for end-users.

To date, the CDOM database is functional, but will benefit from further contributions of CDOM data that expand the spatial and temporal coverage to the greatest extent possible. The data currently housed in the database are measurements made on discrete samples collected from the water column. Flow-through CDOM data are also being processed, and will be made available. Thus, the database is being designed to accommodate both discrete and time-series observations, the latter of which may originate from towed array or moored platforms. A final anticipated outcome of this project is an estimate of CDOM and dissolved organic carbon (DOC) fluxes from the terrestrial environment into the coastal waters of the northern Gulf of Mexico, a significant unknown in the coastal carbon budget of this region.

Invitation for Data Submission

This project is now in its final year for which community data submission will be encouraged. The CDOM database may be viewed at http://osprey.bcodmo.org/dataset.cfm?id=13650&flag=view. Any interested parties wishing to contribute data to this ongoing effort may contact Dr. Chris Osburn, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, closburn@ncsu.edu. Information on submitting data, guidelines, and an Excel data submission template are available at http://www4.ncsu.edu/~closburn/gmx_cdom/index.html.

Acknowledgments

The work described in this article was funded under NASA ROSES A.28 Gulf of Mexico Initiative. We thank John Haynes and Duane Armstrong for their support of this project.

OCB Hosts Three C-MORE Science Kits in Woods Hole

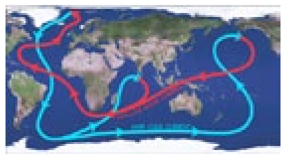
OCB is now hosting three C-MORE Science Kits: Ocean acidification, marine mystery, and ocean conveyor belt. The ocean acidification and marine mystery kits have recently been the subject of science education publications in *Science Scope*, the peer-reviewed journal of the National Science Teachers Association (NSTA) aimed at middle school teachers:

- "Ocean Acidification: Hands-on experiments to explore the causes and consequences" by Barbara C. Bruno, Kimberly A. Tice, Noelani Puniwai and Kate Achilles published February 2011 (*Science Scope*, Vol 34, No 6).
- "A Watery Whodunit: The Case of the Missing Zooxanthellae," by Kimberley A. Thomas, Barbara C. Bruno, Kate Achilles, and Sarah B. Sherman, published March 2011 (*Science Scope*, Vol 34, No 7).

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

http://cmore.soest.hawaii.edu/education/teachers/science_kits/requestform.htm

Grants for Education in Microbial Science (GEMS)

C-MORE awards grants (up to $1,500) to foster awareness in microbial science. Any educator may apply for one of these grants, but preference will be given to public school teachers, non-profit organizations, and first-time applicants. C-MORE-affiliated students and researchers are also encouraged to apply for grants to help fund their outreach activities. Funds may be requested for equipment, consumable supplies, substitute teacher compensation for relevant professional development experiences, bus transportation for field trips, and other projects related to microbial science. Every grant requires a C-MORE or University of Hawai'i sponsor, so we expect this program to significantly promote interaction among C-MORE scientists, other stakeholders in science and education, teachers, and students. To find a sponsor, please visit the C-MORE team webpage. Any member of the C-MORE team, including graduate students, can serve as a sponsor. Learn more about GEMS.

Next application deadline is
Monday, May 02, 2011!

To apply: Download the GEMS application form

Check out the new C-MORE animation!

Fully narrated C-MORE animation now available on the C-MORE education web page

Recent OCB Workshops and Activities

Coastal Carbon Fluxes in the North American Continental Margins
December 11-12, 2010 (San Francisco, CA)
by Heather Benway

The contribution of coastal margins to regional and global carbon budgets is not well understood, largely due to limited information about the magnitude, spatial distribution, and temporal variability of carbon sources and sinks in coastal waters. Building on recommendations put forth during the 2005 North American Continental Margins (NACM) Synthesis and Planning Workshop (Hales et al., 2008) and progress made since then, the Ocean Carbon & Biogeochemistry (OCB) Program has been collaborating with the North American Carbon Program (NACP) to develop a Coastal Interim Synthesis Activity to stimulate the synthesis of observational and modeling results on carbon cycle fluxes and processes along the North American continental margins. This activity has been divided geographically into five regions: East Coast, West Coast, Gulf of Mexico, Arctic, and Great Lakes.

A coastal interim synthesis workshop, coordinated by OCB and NACP, and sponsored by NASA, convened 56 participants at the Courtyard Marriott in San Francisco, California.

The goals of this workshop were to gather active members of the coastal research community with a diverse range of expertise to:

- Identify existing datasets, publications and ongoing and previous studies that could contribute to the development of regional coastal carbon budgets (and ultimately be archived in a community database)
- Determine the fluxes and processes that should be included in regional carbon budgets and associated models to ensure consistency and inter-comparability

The workshop opened with a series of plenary talks to address important elements of coastal carbon budgeting, including land-to-ocean fluxes, carbon cycling in estuaries and coastal vegetation, cross-shelf exchange, and sedimentary processes. Participants then divided into smaller breakout groups to discuss important fluxes in the coastal carbon budget, including river-estuary, sedimentary, cross-shelf, air-sea, and biological (e.g., photosynthesis and respiration) fluxes. Breakout participants identified key processes involved in these fluxes and how they are quantified, the temporal and spatial scales of their measurements, and how effectively they can be parameterized in models. Workshop participants then divided into regional groups (see above) to identify existing data sets, process studies, and modeling resources that could contribute to a coastal carbon synthesis, with an emphasis on regional products that have emerged since the 2005 NACM meeting. The workshop concluded with presentations of modeling and database development case studies, followed by an open discussion session on the most effective way to tap existing data and modeling resources across a broad coastal research community toward the development of preliminary regional coastal carbon budgets.

Expected products of the Coastal Interim Synthesis Activity include:

- **Special journal volume** targeting publications on key processes involved in coastal carbon cycling and preliminary coastal carbon budgets for each of the five aforementioned regions (target release: summer 2012)
- **Comprehensive science plan** for coastal ocean carbon and related biogeochemical research that identifies current knowledge gaps and ranks research and observing priorities to guide future agency funding initiatives (target release: end of 2013)

For further information, including links to presentations made at the workshop, regional coastal carbon budget updates, and seminal reports, please visit http://www.whoi.edu/workshops/coastal_synthesis/.

To learn more and get involved with the coastal synthesis activity:

- Contact the OCB Project Office
- Join a regional team e-mail list

Important OCB Dates

- **March 22–24, 2011:** OCB Ocean Acidification PI Meeting **(by invitation)** (Woods Hole Oceanographic Institution, Woods Hole, MA)
- **May 23–25, 2011:** OCB Scoping Workshop: A Biogeochemical Flux program aligned with the Ocean Observatories Initiative (OOI) (Woods Hole Oceanographic Institution, Woods Hole, MA)
- **July 18–21, 2011:** OCB Summer Workshop (Woods Hole Oceanographic Institution, Woods Hole, MA) - **note joint science session with U.S. CLIVAR on July 19**

OCB SCOPING WORKSHOP REPORT

The molecular biology of biogeochemistry: Using molecular methods to link ocean chemistry with biological activity
November 8-10, 2010 (Los Angeles, CA)

Workshop Co-chairs: Jim Moffett and Eric Webb (Univ. of Southern California)

Workshop Planning Committee: Bob Anderson (LDEO), Ginger Armbrust (UW), Kevin Arrigo (Stanford), Bess Ward (Princeton), Keith Moore (UCI), Ben van Mooy (WHOI)

An OCB Scoping Workshop co-chaired by Jim Moffett and Eric Webb (University of Southern California) was held in Los Angeles in November 2010 entitled "The Molecular Biology of Biogeochemistry." The goal of this workshop was to assess the potential role of molecular biology to study marine biogeochemical cycles, particularly the carbon cycle, via large survey programs such as GEOTRACES. Rapid advances in molecular methods are providing new tools applicable to global surveys and other observational programs focused on the oceans' response to changing climate and other impacts. However, molecular biologists generally examine ecological problems like community diversity, whereas geochemists are more interested in functionality and rates. Here, geochemists and molecular biologists sought common ground to identify which molecular biological measurements would be most useful for understanding marine biogeochemical cycles and characterizing their response to climate change.

Workshop participants were enthusiastic about the integration of geochemical and marine biological tools in existing large survey programs but recognized the need for a new, stand-alone field campaign to characterize the biogeography of marine microbial communities that will complement the existing global survey and observational programs. The new program will characterize the distribution of microbial communities within the ocean on complete surface to bottom sections and couple these data with important geochemical measurements and rate measurements of key processes. Such a program was seen as essential to achieving the core scientific objectives in biogeochemistry that was the charge of the workshop. A stand-alone program is desirable for logistical and science reasons, but the core parameters in GEOTRACES are highly complementary. Therefore, a plan was outlined for a sectional survey cruise in Fall 2013 concurrently or back to back with a proposed GEOTRACES zonal section in the eastern tropical South Pacific. The effort will be spearheaded by workshop participants and led by Ginger Armbrust (UW). However, planning of the program is still at a very early stage, and input from the broader community of marine microbiologists, biogeochemists and modelers is essential.

The following objectives were developed as an organizational framework for the development of the hypotheses and approaches for the first sectional cruise and the program as a whole:

1. Characterize and define the connections between the presence and activity of microbes (*i.e.,* functional biogeography) and physical and chemical parameters, utilizing the tools of an unprecedented, large group of microbiologists and geochemists.
2. Utilize genomics, transcriptomics, proteomics, and metabolomics in combination with process measurements to define biogeochemical 'connections' and their constraints.
3. Integrate results from multiple sections to identify boundaries of microbial biogeographic provinces (analogous to the Longhurst provinces) over horizontal and vertical scales.
4. Develop an operational framework for many laboratories to collaborate together using a variety of molecular and biogeochemical tools that includes rigorous protocols for methodological inter-calibration and standardization
5. Incorporate the program's observations into a new generation of models that capture the connections between microbes and chemistry in an ocean perturbed by climate change.

These plans, along with a detailed summary of the meeting deliberations about the topics in points 1-5, were discussed at a recent ASLO Town Hall Meeting (Microbial Biogeography and Biogeochemistry) convened by Ben van Mooy (WHOI) and Bethany Jenkins (URI).

OCB Scientific Steering Committee (SSC) Membership Changes

We would like to welcome our seven newest OCB SSC members, who bring a wealth of expertise to the SSC:

Andreas Andersson (BIOS) — marine CO_2 and carbonate geochemistry, ocean acidification and its effects on marine calcifiers and coral reefs, calcium carbonate mineral dissolution and sediment composition

Tom Bianchi (TAMU) — organic geochemistry, biogeochemical dynamics in aquatic food chains, carbon cycling in riverine, estuarine, and coastal ecosystems, biochemical markers of colloidal and particulate organic carbon

Lisa Levin (Scripps) — benthic ecology, oxygen minimum zones

Jeremy Mathis (Univ. of Alaska, Fairbanks) — marine chemistry, biogeochemical processes, ecosystem dynamics, carbon and nitrogen cycling

Tatiana Rynearson (URI) — marine molecular ecology, evolution

Mak Saito (WHOI) — trace metal biogeochemistry focusing on bioactive metals and vitamins (Co, Fe, Mn, Cd, Zn, Ni, and B12), marine proteomics and metaproteomics

Dave Siegel (UCSB) — coupling of physical, biological, optical and biogeochemical processes on micro to ocean basin scales

On behalf of the OCB Project Office and the broader OCB community, we sincerely thank our departing SSC members **Bob Anderson (LDEO), Ginger Armbrust (UW), Kathy Barbeau (Scripps), Mary-Elena Carr (Columbia Univ.), Joanie Kleypas (NCAR), Steve Lohrenz (Univ. of Southern Mississippi),** and **Tammi Richardson (Univ. of South Carolina)**. The implementation of a program of this breadth is an enormous challenge, and their service to the community during this important spin-up period has been indispensable. More information on the OCB SSC, including its charge and terms of reference, can be found on the OCB website.

OCB Informational Resources

» OCB Policies and Procedures: A community guide on OCB's programmatic mission, objectives, and operating procedures

» **Coastal Synthesis Activity** - join a regional email list or visit coastal synthesis workshop website

» OCB Ocean Acidification Website

» OCB Ocean Fertilization Website

» Subscribe or post to the OCB email list

» Submit a paper to the OCB publications list

» Affiliate your funded project(s) with OCB

New Community Resources

Research Tools

- Microbiological Targets for Ocean Observing Laboratories (MicroTOOLs) workshop reports now available
- "Simulation and assimilation of global ocean pCO2 and air–sea CO2 fluxes using ship observations of surface ocean pCO2 in a simplified biogeochemical offline model" contributed by Vinu Valsala and Shamil Maksyutov (NIES/Japan) now available from CDIAC
- Archived ocean surface water radiocarbon data from surface dwelling, reef-building hermatypic corals now available at CDIAC
- CO2calc: A User-Friendly Seawater Carbon Calculator for Windows, Mac OS X, and iOS (iPhone)
- Updated Global Carbon Budget (2009)
- DMS fluxes and exchange velocities (Univ. of Hawaii)
- Updated DMS database (Kettle et al., 1999)
- Global monthly DMS climatology (Lana et al., 2011)

White Papers, Articles, and Reports

- IOC of UNESCO releases A Scientific Summary for Policymakers on Ocean Fertilization

continued on next page...

Related Project News

IMBER

New IMBER-endorsed Projects

- Amazon iNfluence on the Atlantic: CarbOn export from Nitrogen fixation by DiAtom Symbioses (ANACONDAS) (Contact: Patricia Yager, University of Georgia)
- The River Ocean Continuum of the Amazon (ROCA) (Contact: Patricia Yager, University of Georgia)
- Marine Ecosystem Evolution in a Changing Environment (MEECE) (Contact: Jessica Heard, Plymouth Marine Laboratory)

Upcoming IMBER Special Sessions

- European Geosciences Union General Assembly (April 3-8, 2011, Vienna, Austria)
  - IMBER/SOLAS special session: Sensitivity of marine ecosystems and biogeochemical cycles to global change (Co-conveners: Baris Salihoglu and Cecile Guieu)
  - Ocean acidification and its impact on polar ecosystems (Co-conveners: JP Gattuso, U. Riebesell and S. Widdicombe)
- 43rd International Liège colloquium on ocean dynamics (May 2-6, 2011, Liège, Belgium)
  - IMBER special session: Tracers at the ocean mesoscale and submesoscale (Co-conveners: Javier Arístegui, Xosé A. Álvarez Salgado, Antonio Tovar Sánchez)

SOLAS

- New DMS resources
- New opportunities through European Space Agency (ESA) OceanFlux
- IMBER/SOLAS special session at EGU 2011 (see details above): Sensitivity of marine ecosystems and biogeochemical cycles to global change
- SOLAS Metadata portal

GLOBAL CARBON PROJECT

- Canadell, J. G. (Ed.) (2010). Special issue: Carbon and nitrogen cycles. *Current Opinion in Environmental Sustainability* 2(4), 209-312.
- Dhakal, S., Shrestha, R. M. (Eds.) (2010). Special section: Carbon Emissions and Carbon Management in Cities. *Energy Policy* 38(9), 4753-5296.
- Ciais, P., Dolman, A.J., Dargaville, R., Barrie, L., Bombelli, A., Butler, J., Canadell, P., Moriyama, T. (2010). Geo Carbon Strategy Geo Secretariat Geneva/FAO, Rome, 48 pp.
- Updated Global Carbon Budget (2009)

U.S. CLIVAR

- U.S. CLIVAR Summit (July 19-21, 2011, **invitation only**) to be held in conjunction with the annual OCB summer workshop in Woods Hole, MA **(note joint science session with OCB on July 19)**

New Community Resources (cont.)

White Papers, Articles, and Reports (cont.)

- Ciais, P., Dolman, A.J., Dargaville, R., Barrie, L., Bombelli, A., Butler, J., Canadell, P., Moriyama, T. (2010). Geo Carbon Strategy Geo Secretariat Geneva/FAO, Rome, 48 pp.

Journal Special Issues

- Canadell, J. G. (Ed.) (2010). Special issue: Carbon and nitrogen cycles. *Current Opinion in Environmental Sustainability* 2(4), 209-312.
- Dhakal, S., Shrestha, R. M. (Eds.) (2010). Special section: Carbon Emissions and Carbon Management in Cities. *Energy Policy* 38(9), 4753-5296.
- Launch of new journal Carbon Management

Education and Outreach

- NOAA/PMEL Carbon Group announces revised and enhanced website
- OCB scientist Galen McKinley (Univ. of Wisconsin - Madison) featured in NASA Science on the Road: Oceans, Carbon, and Climate

Ocean Acidification

Studying ocean acidification's effects on marine ecosystems and biogeochemistry

OCB Planning Spring Meeting For Ocean Acidification Researchers

The OCB-OA subcommittee and OCB Project Office are organizing a meeting for principal investigators working on ocean acidification (OA) research projects in Woods Hole on March 22-24, 2011. Researchers representing both academic and federal research institutions have been invited to this first-ever national gathering of OA researchers, where we hope to welcome one representative from each current research initiative or project. The meeting will bring these researchers together to promote networking and development of new collaborations while most research projects are still in their early phases.

This meeting will be somewhat different from OCB meetings in the past. Already, the list of researchers we've invited spans a wider range of disciplines and federal agencies than OCB meetings usually include. In addition to biogeochemists, we expect to host ecologists, paleoceanographers, instrumentation specialists, biologists of all types, socioeconomists, ecosystem modelers, and more. Meeting invitees' research is supported by NSF, NOAA, NASA, USGS, EPA, and Navy.

Overall, the meeting is designed to build capacity within the OA research community, to advance scientific research on OA as efficiently as possible, and to clarify the scientific frontiers within OA research. We also aim to accomplish the following goals:

- Strengthen scientific collaborations and minimize duplication of efforts.
- Build capacity for improving OA research.
- Identify short- and long-term research goals.
- Promote effective data management.
- Enhance communication with the public.
- Solicit feedback from the scientific community to guide future OCB activities.

The meeting will include a mix of plenary talks reviewing state-of-the-art knowledge on the 5 main themes of present OA research, synthesis presentations and panel discussions considering how present research efforts fit together, breakout sessions discussing overarching challenges in OA research, poster sessions, and plenary discussions concerning future directions in OA research. The meeting agenda can be found on the meeting website at http://www.whoi.edu/workshops/OAPI2011/ under the "agenda" tab.

Meeting participants are being asked to provide a 1-page abstract summarizing their own area of interest in OA research and how it relates to other OA research. This information will be used to assemble the synthesis presentations and discussions of how present research fits together. At the end of the meeting, OCB plans to host these materials on our website in a way that will provide an easy-to-navigate virtual directory of present research activities, locations, and focus topics.

Although this is the first national meeting for OA investigators, it is not likely to be the last! Future national OA meetings will likely become more traditional, science-focused meetings that have room for multiple representatives from each research project as the U.S. OA community grows, becomes better acquainted, and gathers more momentum.

Friday Harbor Ocean Acidification Course Announced

Graduate students at all levels are invited to apply for a new ocean acidification course being held this summer (June 20-July 22, 2011) at Friday Harbor, University of Washington's laboratory in the San Juan Islands. The five-week course, led by Michael O'Donnell and Terrie Klinger, is broadly focused on the experimental design of biological OA studies. Students will learn the fundamentals of inorganic carbon geochemistry and how to measure carbonate chemistry parameters correctly. They will also practice designing experimental systems that make use of cutting-edge best practices. At the same time, the course will provide an immersion in the OA research literature, providing a rapid introduction to the state of the science. Course activities will include lectures, laboratory exercises, and discussions focused around these three goals. More information can be found here, or by emailing moose@uw.edu or tklinger@uw.edu.

Ocean Acidification News Headlines and Community Resources

- New ocean acidification webpage at PMEL providing links to data, maps, and more.
- New ocean acidification data sets and accompanying docent script available for NOAA Science on a Sphere
- OCB helping to coordinate a series of ASLO web lectures on ocean acidification
- Ocean acidification impacts on shellfish workshop held July 7-10, 2010. Representatives from the shellfish industry, regulatory agencies, and research institutions attended. Workshop report.
- CO2calc, a user-friendly seawater carbon calculator for Windows, Mac OS X, and iPhone has been released. It includes a user-friendly graphical data entry format, dissociation constants published since 2000, air-sea CO_2 flux calculation capabilities, data tagging, latitude/longitude data integration capability, batch processing, and new output formats.
- Dr. Jeremy Mathis receives Alaska Ocean Leadership award
- The Bevan Series on Sustainable Fisheries hosts 10 lectures on ocean acidification this spring at the University of Washington; click through for archived lecture videos.
- Ocean Acidification Reference User Group (2010). Ocean acidification: questions answered, Laffoley D. d'A. & Baxter J. M. (Eds.), 24 p. European Project on Ocean Acidification (EPOCA)
- Bruno, B. C., K. A. Tice, N. Puniwai, K. Achilles (2011). Ocean acidification: Hands-on experiments to explore the causes and consequences. *Science Scope* (publication of the National Science Teachers Association) 34(6), 23-30.

OCB Calendar

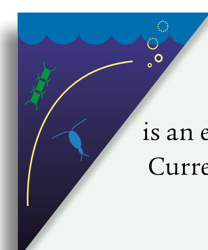
2011	
March 20–25:	Gordon Research Conference on Polar Marine Science - Exploring Complex Systems in Polar Marine Science (Ventura, CA)
March 22–24:	OCB Ocean Acidification PI Meeting (invitation only) (Woods Hole, MA)
April 1:	IGBP Science Symposium “Global Change: Mounting pressure on the Earth system” (Washington, DC) Register at https://www.regonline.com/builder/site/?eventid=938219
April 3–8:	European Geosciences Union General Assembly 2011 (Vienna, Austria)
April 3–4:	Climate change and ocean carbon - Field observation, remote sensing, and modeling - A joint international workshop of OCCOS and CHOICE-C (Xiamen, China)
May 2–6:	43rd International Liege colloquium on ocean dynamics (Liege, Belgium)
May 2–4:	11th AMS conference on polar meteorology and oceanography (Boston, MA)
May 22–26:	Ecosystem Studies of Sub-Arctic Seas (ESSAS) open science meeting (Seattle, WA)
May 23–25:	OCB Scoping Workshop: “A Biogeochemical Flux program aligned with the Ocean Observatories Initiative” (Woods Hole, MA)
May 31–July 8:	C-MORE summer course in microbial oceanography (Honolulu, HI)
June 13–15:	The aquatic ecosystem puzzle: Threats, opportunities, and adaptation (Siena, Italy)
June 15–July 1:	Cooperative Institute for Climate and Satellites—North Carolina (CICS-NC) Summer Institute on Climate Change: Turning Adaptation into Action - Define Your Strategic Advantage (Asheville, NC)
June 19–July 9:	BIOS summer immersion course: Microbial Oceanography: The Biogeochemistry, Ecology and Genomics of Oceanic Microbial Ecosystems (Bermuda Institute of Ocean Sciences)
June 20–July 22:	Graduate Course “Experimental approaches to understanding ocean acidification” (Friday Harbor Laboratories, University of Washington)
June 20–24:	7th EGU Alexander von Humboldt Conference on “Ocean Acidification: Consequences for marine ecosystems and society” (Penang, Malaysia)
June 27–30:	3rd Advances in marine ecosystem modeling symposium (Plymouth, UK)
June 28–July 1:	The future of the 21st century ocean: Marine sciences and European research infrastructures, an international symposium (Brest, Le Quartz, France)
July 3–7:	11th International Conference on the Biogeochemistry of Trace Elements (Florence, Italy)
July 4–15:	Darwin Summer School on Biogeosciences: Perturbation of the global carbon cycle (Utrecht and Texel, the Netherlands)
July 11–16:	Short Course: Radiocarbon in Ecology and Earth System Science (Irvine, CA)
July 18–21:	Annual OCB Science Workshop (Woods Hole, MA) – **note joint science session with US CLIVAR on July 19**
July 19–21:	2011 US CLIVAR Summit (Woods Hole, MA) - **note joint science session with OCB on July 19**
August 14–19:	2011 Chemical oceanography Gordon research conference (Andover, NH)

OCB Calendar (continued)

2011 (continued)	
August 14–19:	Goldschmidt conference 2011 (Prague, Czech Republic)
Aug 29–Sept 10:	SOLAS Summer School 2011 (Corsica, France)
September 12–15:	LOICZ Open Science Conference 2011: “Coastal Systems, Global Change and Sustainability” (Yantai, China)
September 19–23:	ICES Annual science conference (Gdansk, Poland)
September 22–23:	Plankton 2011: Plankton biodiversity and global change (Plymouth Guildhall, England, UK)
September 26–30:	World Conference on Marine Biodiversity (Aberdeen, Scotland)
October 22–29:	DISCCRS VI Interdisciplinary climate change research symposium (Colorado Springs, CO)
October 24–29:	Seventh WIOMSA scientific symposium entitled “Coping with global change” (Kenya)
October 24–28:	WCRP Open Science Conference: Climate research in service to society (Denver, CO)
October 24–26:	EUR-OCEANS conference ocean deoxygenation and implications for marine biogeochemical cycles and ecosystems (Toulouse, France)
November 29–December 2:	Earth observation for ocean-atmosphere interactions science - A joint ESA-SOLAS-EGU conference (Frascati, Italy)
2012	
March 26–29:	Planet Under Pressure: new knowledge towards solutions (London, UK)
September 24–27:	Third Symposium on the Ocean in a High-CO_2 World (Monterey, CA, contact: Ed.Urban@scor-int.org)

2011 Funding Opportunities

- **March 15:** NSF Frontiers in Earth System Dynamics full proposal deadline
- **June 1:** NASA ROSES 2010 - A4. Land Cover/Land Use Change proposal deadline
- **August 15:** NSF Biological and Chemical Oceanography proposal targets
- **September 1:** NSF Catalyzing New International Collaborations proposal target
- **November 15:** NSF Dynamics of Coupled Natural and Human Systems (CNH) proposal deadline



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