Ocean Carbon and Biogeochemistry News

Studying marine biogeochemical cycles and associated ecosystems in the face of environmental change

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Carbon Budget for the Continental Shelf of the Eastern United States: A Preliminary Synthesis

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1. Introduction

The coastal ocean is gaining increased attention in global carbon cycle studies. Rates of primary production, export production, carbon flux to the sediments, and burial in the coastal ocean are much higher than their open-ocean counterparts, and thus the coastal ocean, despite its relatively small area, has the potential to be globally significant. The coastal ocean is also particularly susceptible to climate change because it interfaces with the land, atmosphere, and open ocean, all of which will see climate-induced changes in fluxes of carbon as a result of changing streamflow, sea level, meteorological fluxes, and basin-scale ocean circulation. Furthermore, as 50% of the global population lives within 100 km of the shoreline, the coastal ocean is directly influenced by anthropogenic activity, including eutrophication, fishing, dredging, shoreline armoring, and altered sediment inputs from rivers, processes that are likely to intensify in the future as population grows. Thus, the high rates of carbon cycling in the coastal ocean may change substantially over the 21st century and possibly have significant impacts on atmospheric carbon dioxide levels.

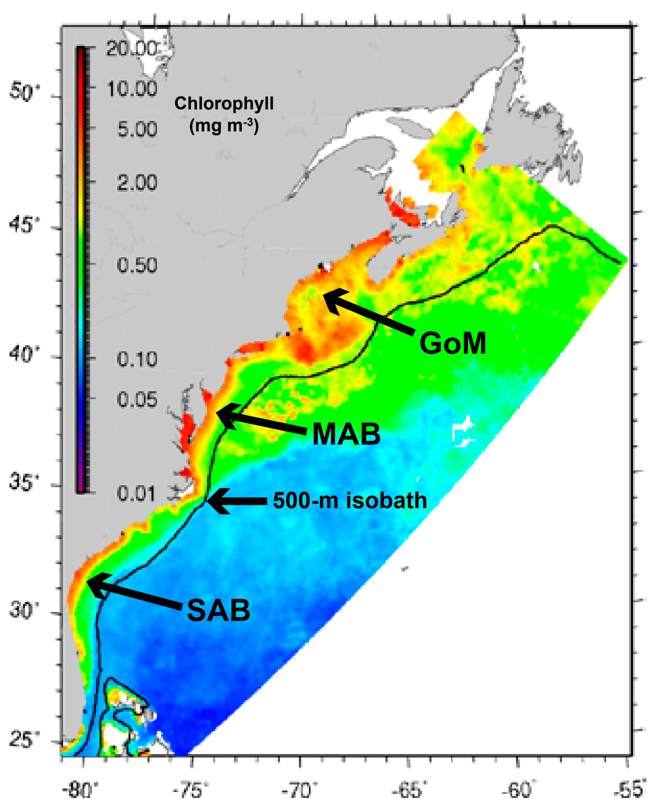


Figure 1: Study domain, showing locations of the Gulf of Maine (GoM), the Mid-Atlantic Bight (MAB), and the South Atlantic Bight (SAB), superimposed on the 2004 spring surface chlorophyll distribution as measured by the SeaWiFS sensor. Figure courtesy of Sergio Signorini.

Numerical models are the best tool for quantifying potential future changes in coastal carbon cycling. Such models should reflect the mechanistic understanding of carbon cycle processes and be skillful at simulating historical observations of relevant carbon cycle variables at a variety of spatial and temporal scales. A first-order metric for regional carbon cycle models is their ability to capture the regional carbon budget. Unfortunately, carbon budgets have not been developed for most coastal regions.

As part of the of the North American Carbon Program's Interim Synthesis activities, Paula Coble (University of South Florida) and Simone Alin (National Oceanic and Atmospheric Administration) are spearheading a coastal carbon cycle synthesis, one thrust of which is the development of carbon budgets for the main coastal regions surrounding North America using the published literature and ongoing studies. The main goal of the exercise is to provide an initial assessment of the major terms in the overall budget and to highlight the areas of greatest uncertainty, thereby motivating and focusing future carbon cycle studies in the coastal zones of North America. We volunteered to construct a carbon budget for the continental shelf of the eastern United States, and here we present preliminary results of that effort.

2. The domain

We divide up the continental shelf of the eastern U.S. into three main sub-regions (Figure 1): the Gulf of Maine (GoM), the Mid-Atlantic Bight (MAB), and the South Atlantic Bight (SAB). We consider the shoreward boundary of the domain to be the head of tide and the seaward boundary to be the 500-m isobath. Source waters for the study region are dominated by the Labrador Sea and Scotian Shelf to the north and the Gulf Stream to the south, which meet near the SAB/MAB boundary at Cape Hatteras. The sub-regions differ dramatically from each other in their physics and biogeochemistry, due in part to this circulation, but also to differences in bathymetry, latitude, and land use and cover along the coast and its watershed. The GoM is semi-enclosed with several deep sub-basins and a strong spring bloom. It also has strong winter mixing that creates conditions for the potential of returning CO_2 to the atmosphere. The MAB is strongly influenced by riverine inputs of terrestrial carbon and nutrients that are processed by large estuaries having long residence times, such as Chesapeake Bay, Delaware Bay and the Hudson River Estuary. The SAB has a landward boundary containing extensive tidal marshes and, at its seaward boundary, is strongly influenced by Gulf Stream intrusions and filaments that generate blooms every few weeks.

3. Carbon fluxes of interest

We estimated fluxes at the boundaries between the water column and (1) land, (2) the atmosphere, (3) sediments, and (4) the open ocean. The internal fluxes of primary production, respiration, and net community production have also been considered. Units used in the analysis are Tg C yr^{-1} (1 Tg = 1 teragram = 10^{12} g) and mol C m^{-2} yr^{-1}.

3.1. Fluxes from land

Riverine inputs of carbon at the head of tide can be estimated from the product of the riverine volume flux and the concentrations of dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), and particulate organic carbon (POC). Inputs of particulate inorganic carbon (mainly calcium carbonate) are believed to be modest in the study area. Freshwater fluxes are reasonably well known for the region, but the availability of DIC, DOC, and POC concentration data are infrequent enough to require interpolation techniques. Available concentration data for a river can be regressed against volume flux, and then the estimated time-varying concentrations are multiplied by the volume flux to determine the net carbon flux. This technique has not yet been applied systematically across the U.S. East Coast. Rather, an estimate of the mean concentration is typically made and then multiplied by the mean flow. DIC concentrations reported at river gauging stations for the East Coast range from 100 to >4000 µmol l^{-1}, with major tributaries such as the Susquehanna, Connecticut, and Hudson rivers in the range of 800, 400, and 1000 µmol l^{-1}, respectively. In the GoM watershed, riverine DIC ranges from 100 to 600 µmol l^{-1}, decreasing in concentration from south to north.

A major challenge in estimating carbon fluxes onto the shelf from land is quantifying the processing of carbon in the nearshore systems that include estuaries and tidal marshes. Carbon cycling in these systems is intense, and thus such processing needs to be considered. The physics of these systems differ. We can think of estuaries as chemostats through which riverine water flows and is altered by biogeochemical processes en route to the sea. Fluxes of carbon between marsh systems and the shelf, however, do not necessarily require a net water flux. Rather, tidal currents carry different concentrations of carbon depending on whether the flow is landward or seaward; processes within the marshes alter carbon concentrations, especially during high-water slack tide. In our study area, tracer-based approaches have been applied to estimate carbon fluxes from marshes and sediments.

We found a total of six studies that estimated carbon fluxes from U.S. East Coast rivers, estuaries, and marshes. Based on this literature, we estimate that at least ~5 Tg C yr^{-1} are transported onto this shelf, with roughly 60% of this carbon being in the form of DIC, 30% as DOC, and 10% as POC. We subjectively estimate the uncertainty in these fluxes to be ~50%.

3.2. Air-sea fluxes

Carbon crosses the air-sea interface mainly through diffusive exchange of CO_2. Estimates are indirect in that the flux is computed from pCO_2 measurements and wind-and temperature-based exchange coefficients. The best-sampled sub-region is the SAB, due to efforts over the past decade by the research group of Wei-Jun Cai. Here, the ocean is a sink of ~0.5 Tg C yr^{-1}, with an uncertainty of ~50%. Mike DeGrandpre (University of Montana) and others participating in the Ocean Margins Program estimated the MAB to be a stronger CO_2 sink, ~1.6 Tg C yr^{-1}, with an uncertainty of ~60%. The most reliably sampled portion of the GoM is along the western edge where Joe Salisbury and Doug Vandemark have been conducting a time-series study. Here, a five-year annual average yields an air-sea flux indicative of a slight source of 0.45 ± 0.55 mol C m^{-2} yr^{-1}. There are no estimates of the net air-sea flux for the GoM as a whole.

Carbon is also transferred from the atmosphere to the ocean as DOC in precipitation. Using published estimates of DOC concentration in precipitation (50-100 mmol m^{-3}) and the fairly well known rate of precipitation over the shelf (~1 m yr^{-1}), we estimate the DOC precipitation input to be about 0.3 ± 0.1 Tg C yr^{-1}. However, isotopic analysis of precipitation by Peter Raymond has shown that rainwater DOC is primarily of marine origin, and hence does not represent a net carbon input.

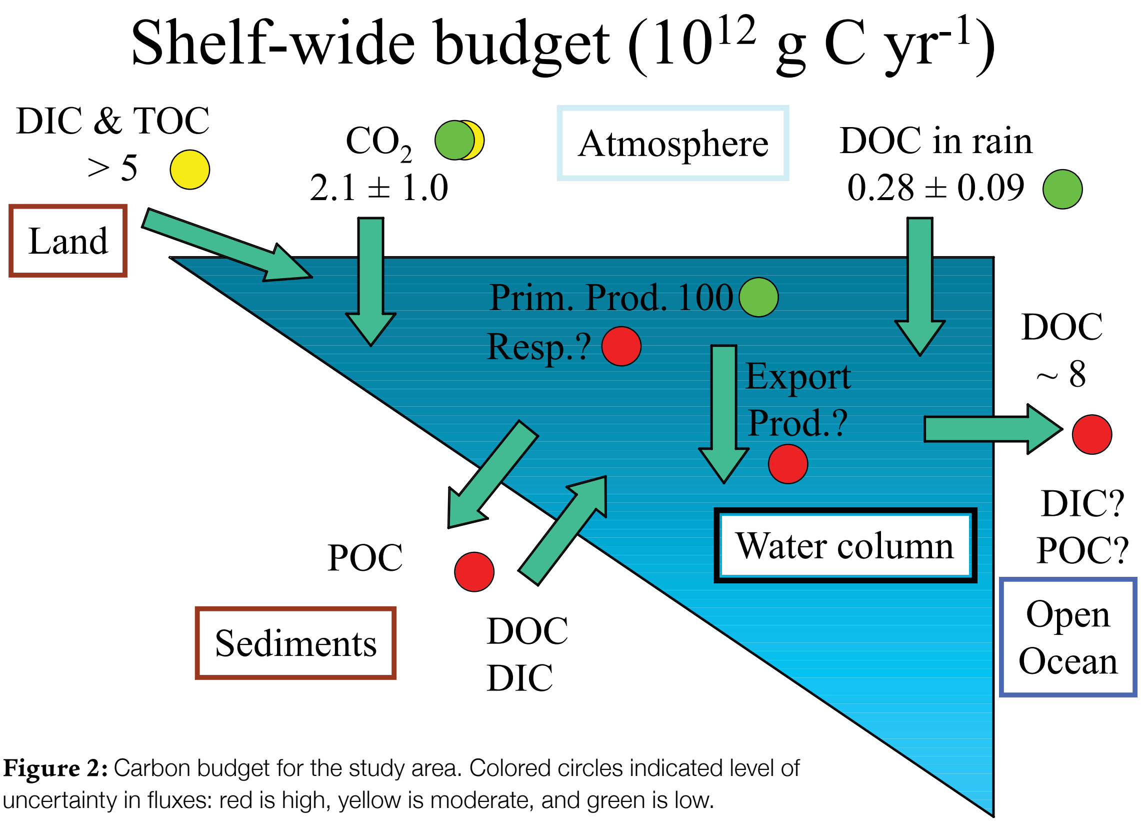


Figure 2: Carbon budget for the study area. Colored circles indicated level of uncertainty in fluxes: red is high, yellow is moderate, and green is low.

3.3. Carbon fluxes at the sediment water interface

Carbon crosses the sediment water interface in sinking particulate form and as a diffusive flux (typically upward) of dissolved carbon. Remarkably, there are only limited estimates of sedimentary carbon fluxes along the U.S. Eastern Continental Shelf (though there are more flux estimates on the continental slope).

In the SAB, DIC diffuses out of the sediments under dark conditions but may diffuse into the sediments as a result of benthic photosynthesis, as demonstrated by the work of Rick Jahnke (Skidaway Institute of Oceanography) and others. However, the net role of the sediment in the SAB is to decompose POC and release DOC and DIC to the water.

Another poorly known carbon flux in the nearshore zone is that associated with groundwater. Discharge of fresh (terrestrial) groundwater occurs in rivers downstream of gauges, in estuaries, and directly to the coastal ocean. Rates of discharge show large spatial variability and are difficult to quantify, but global estimates suggest that the rate of discharge to estuaries and coasts (submarine groundwater discharge, or SGD) is in the range of 6 to 10% of riverine discharge.

Concentrations of DIC and DOC in groundwater are highly variable. In groundwater collected at a number of sites along the U.S. East Coast and the Florida Gulf coast, total dissolved C concentrations range from ~100-12,000 µmol l^{-1} and are typically dominated by DIC (unpublished data of Kevin Kroeger). Based on typical C concentrations and a global estimate of SGD rate, it is estimated that SGD contributes carbon to the coastal ocean at a rate of ~30% of the riverine flux. Flux rates in specific regions likely deviate substantially from that value, however. For instance, DIC flux to the SAB due to groundwater discharge through extensive salt marshes and direct discharge to the coast were each estimated to be of similar magnitude to the riverine flux.

Additional and complicating processes to consider are: (1) modifications of the carbon content of fresh groundwater during passage through salt marshes and during mixing with saline groundwater prior to discharge, potentially complicating interpretation of the carbon source; and (2) carbon fluxes associated with widespread occurrence of saline groundwater circulation through permeable estuarine and marine sediments.

3.4. Cross-shelf exchange

Cross-shelf exchange of carbon occurs when water advected onto the shelf has a different carbon concentration than water advected off of the shelf. Uncertainties are high in the cross-shelf exchanges partly because of the spatially and temporally varying frontal regions that make it difficult to close the water budget. We identified four observational studies that quantified cross-shelf exchange in various sub-regions. All found the shelves to export carbon to the open ocean on the order of several Tg C yr^{-1}. One estimate, however, was not significantly different from zero, and some did not provide error estimates. The best known cross-shelf flux in the study domain is probably that of DOC, due to work by Penny Vlahos and Matt Charette (Woods Hole Oceanographic Institution), which is ~8 Tg C yr^{-1}, with an estimated uncertainty of at least 50%.

3.5. Primary production

As on most continental shelves, the fixation of CO_2 during photosynthesis is probably the largest and best-constrained flux of carbon in our study area. Syntheses of direct measurements of primary production using the radiocarbon method show that each sub-region contributes about equally to a total fixation of 100 Tg C yr^{-1}. We estimate the error in this flux to be ~20%. On an areal basis, the flux is 26 mol C m^{-2} yr^{-1}, which is about twice the global average.

3.6. Respiration and net community production

Respiration is poorly constrained in the study area. An exception is the SAB, where it was recently shown that respiration and photosynthesis are approximately balanced. This is in contrast to an earlier suggestion of large net heterotrophy in the SAB.

Several studies of net community production in the mixed layer of the GoM show that it is 10-50% of primary production, with a best estimate of ~30%. On the MAB shelf, net community production is ~20% of primary production.

4. Summary and Outlook

Figure 2 shows our preliminary synthesis of the carbon budget of the East Coast of the United States. The best known fluxes (in decreasing order of certainty on a fractional basis) are primary production, riverine input, and air-sea exchange of CO_2. Fluxes that are very poorly known include sediment fluxes, cross-shelf exchange, and respiration. Despite the uncertainties, it is clear that internal fluxes (primary production and probably water column respiration) greatly exceed boundary fluxes. Thus small fractional errors in the internal terms may mask the larger fractional errors in the boundary fluxes.

The fluxes discussed above could be refined by some additional short-term synthesis. For example, we have not investigated the literature on estuarine processing of carbon, which will likely produce useful insights. There are also data on riverine and groundwater carbon concentrations that should be synthesized to improve the estimates of fluxes from these systems. It would be advantageous to include alkalinity fluxes in such an analysis due to the importance of alkalinity in setting the surface ocean pCO_2 and hence the air-sea carbon flux. Satellite products would likely further reduce uncertainties in primary production and provide additional, useful information on its seasonal and interannual variability. Finally, though the thrust of this exercise has been to provide model-independent estimates of the carbon budget, we believe that progress will be most rapid by combining observations with models. A high-resolution carbon cycle model over the study domain was created by Katja Fennel (Dalhousie University) and John Wilkin (Rutgers University); the model is being further developed by the USECoS (U.S. Eastern Continental Shelf carbon cycling) project team, led by Marjorie Friedrichs and Eileen Hofmann (Old Dominion University). Carbon budgets are being investigated in this model, coupled with measurements of DOC and POC by Antonio Mannino (NASA).

Longer-term investments will be needed to better constrain carbon fluxes associated with cross-shelf exchange, the sediment-water interface, respiration, and processing in marshes and estuaries. The lack of observations of these carbon fluxes and associated stocks in the coastal zone of the Eastern U.S. is striking, particularly given the view that this is a relatively well studied region.

It seems that the coastal zone has fallen through the cracks of carbon cycle research, which is well developed on the land and in the open ocean. To remedy this problem, we believe that the view of the coastal carbon cycle needs to change from one in which boundaries are rigidly drawn between the land and ocean to a continuum view that encompasses processes in rivers, estuaries, marshes, the continental shelf, and slope waters. Multidisciplinary studies, which bring together scientists that work in these domains, are urgently needed.

C-MORE EDventures: Helping Scientists Build their 'Toolboxes'

by Amy Apprill (WHOI)

Today's ocean biogeochemistry research programs frequently necessitate scientists stepping beyond their standard 'toolbox' into research areas with new and less familiar methods. Learning new tools often comes with a steep learning curve, and the lack of available written support material for many methods provides an additional challenge for students and researchers.

In order to help scientists build their methodological toolboxes, C-MORE's education program recently sponsored a series of workshops focused on the analysis of microbial sequence data utilizing the specialized phylogenetics software platform ARB (latin, 'arbor' = tree). The idea for the workshops came from Woods Hole Oceanographic Institution (WHOI) post-doctoral scholar Amy Apprill, who wanted to partake in an educational experience where she could share the tools she grasped during her Ph.D. at the University of Hawaii at Manoa (UH Manoa) working under the advisement of Dr. Michael Rappé (Hawaii Institute of Marine Biology, HIMB). Apprill was awarded a C-MORE EDventures grant to support the workshops. C-MORE EDventures is a program designed to fund innovative educational activities.

Students participating in a workshop held at the University of Hawaii-Manoa (photo by Grieg Steward).

Workshops on microbial sequence data analysis

The workshops targeted graduate students, post-docs, and early career scientists, and focused on methodology for analysis of sequence data from the most common phylogenetic marker for marine microbes, the SSU ribosomal RNA gene.

From June to August 2009, two workshops were offered at UH Manoa and one at WHOI. The first UH-Manoa workshop included students attending the Agouron Institute's 'Microbial Oceanography: Genomes to Biomes' summer course. The second UH-Manoa workshop convened participants from various departments within the UH system, whereas the workshop at WHOI attracted students from multiple research institutions and universities in the Woods Hole area, including WHOI, Marine Biological Laboratory, University of Rhode Island, and Massachusetts Institute of Technology. The workshop participants varied widely in their educational level (undergraduate to senior scientist), but all shared a common need to incorporate the data analysis techniques into their respective areas of research. The participants were engaged in diverse research programs that included coral microbial ecology, deep-sea microbiology, hydrothermal vent microbiology, marine metagenomics, human microbial ecology, and marine pathogens.

For the workshops, Apprill created a series of tutorials designed to guide the user step-by-step through the process of raw sequence analysis, quality controlling and aligning sequences, creating phylogenetic trees, designing primers and probes, and creating new databases. During the workshops, each participant utilized the ARB software and was guided through the tutorials using a practice dataset of marine bacterial SSU rDNA sequences. Participants reported very positive experiences during the 2-day workshop, and most felt that they had mastered the skills necessary to analyze their own data.

The workshops also provided unique teaching experiences for Apprill and co-instructors Erin Banning (Ph.D. student, WHOI) and Megan Huggett (post-doc, UH/HIMB). The instructors spent two days challenged by questions from the ambitious students and felt that their knowledge and understanding of the ARB software increased from the experience.

Workshop materials available on the web

The workshop materials (lectures, tutorials and practice datasets) are now freely accessible on the web. The materials are targeted at instructors wanting to teach similar workshops at their institutions or for students to work independently to improve their skills. Please visit the C-MORE website to access workshop materials.

Any questions about the educational materials should be directed to Amy Apprill (apprill@whoi.edu; 508-289-2649).

A laboratory-field training course at the University of Hawai'i at Mānoa

Microbial Oceanography: **Genomes to Biomes**

May 31 to July 10, 2010

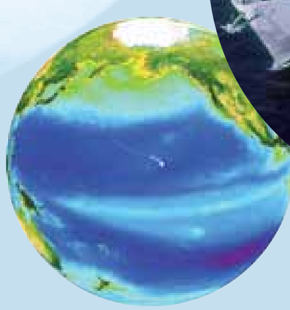
Application Deadline: Friday, January 29, 2010

Sponsored by the Agouron Institute, the University of Hawai'i at Mānoa's School of Ocean and Earth Science and Technology (SOEST), the National Science Foundation (NSF), and the Center for Microbial Oceanography: Research and Education (C-MORE)

The 2010 summer course is offered to graduate students and postdoctoral scholars with interests in marine microbiology and biological oceanography. The course will be led and directed by Matthew Church, Ed DeLong, David Karl, Michael Rappé, and Grieg Steward.

For course information and application materials, please visit **cmore.soest.hawaii.edu/agouron/2010/**

Marinobacter aquaeolei image above courtesy JGI.



AGOURON INSTITUTE

SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY
UNIVERSITY OF HAWAI'I AT MĀNOA

OCB Welcomes New Scientific Steering Committee Members

OCB just completed its 2009 SSC member elections and would like to thank the OCB community for all of the excellent nominations. We are pleased to welcome the following new members, who bring a broad range of expertise to the SSC:

Craig Carlson *(University of California, Santa Barbara)* - Marine microbial ecology, bacterioplankton, and dissolved organic carbon

David Hutchins *(University of Southern California)* – phytoplankton biology, marine nutrient and carbon cycling

Kenneth Johnson *(Monterey Bay Aquarium Research Institute)* – marine biogeochemical sensor development

Cindy Lee *(Stony Brook University)* – Ocean carbon cycle, marine geochemistry of organic compounds, organic and inorganic nitrogen-cycle biochemistry, silicate and carbonate biomineralization

Taro Takahashi *(Lamont-Doherty Earth Observatory)* – CO_2 cycling through oceans and atmosphere, industrial CO_2 accumulation

The SSC has also re-elected **Chris Sabine** *(NOAA Pacific Marine Environmental Laboratory)* to continue serving as an ex-officio member of the SSC. Chris is playing a leadership role in the development of the next U.S. Carbon Cycle Science Plan.

We would like to thank departing SSC members **Debbie Bronk** *(Virginia Institute of Marine Science)*, **Burke Hales** *(Oregon State University)*, **David Karl** *(University of Hawaii)*, and **Wade McGillis** *(Lamont-Doherty Earth Observatory)* for their vision and hard work over the past three years. They have contributed a great deal to the conceptual evolution and implementation of OCB during its critical inaugural period.

The OCB SSC, established in February 2006 jointly by NSF, NASA and NOAA, promotes, plans, and coordinates collaborative, multidisciplinary research opportunities related to carbon cycling and associated marine biogeochemical cycles and ecosystem processes. SSC members serve a term of 3 years with approximately 1/3 membership turnover per year. For more information on OCB and its current SSC, please visit http://www.us-ocb.org/about.html#SSC.

Report from the 2009 OCB Summer Workshop

July 20-23, 2009, Woods Hole, MA

by Heather Benway (OCB Project Office, WHOI)

The 4th annual OCB summer workshop co-sponsored by the National Science Foundation, National Aeronautics & Space Administration, and National Oceanic & Atmospheric Administration took place July 20-23, 2009 at the Woods Hole Oceanographic Institution in Woods Hole, MA, convening 147 participants.

The workshop opened with a session on the next U.S. Carbon Cycle Science Plan (CCSP) that included presentations highlighting the priorities of the next CCSP and providing atmospheric, oceanic, terrestrial, social science, and decision support perspectives. An interdisciplinary panel of CCSP working group members then fielded audience questions and solicited feedback from the OCB community, which focused primarily on CCSP scope, ocean research and observing system priorities, and more effective integration with social science and decision support communities.

A plenary session on ocean acidification highlighted new research frontiers such as the application of genomics to assess various physiological responses to ocean acidification. Another speaker explored potential changes in the marine nitrogen cycle in response to ocean acidification. The final presentation showed evidence of ecological regime shifts in response to changing ocean chemistry and explored the predictability of such thresholds with models.

In a session focused on ocean observations, presentations included new insights on the ocean carbon system derived from Repeat Hydrography measurements, a discussion of Ocean Observatories Initiative (OOI) infrastructural capabilities for OCB research, and applications of glider technology for global ocean biogeochemistry measurements, as well as a report from the 2009 OCB scoping workshop on floats and gliders.

OCB is working with the North American Carbon Program (NACP) and members of the OCB community to coordinate a coastal synthesis to summarize observational and modeling results on coastal carbon fluxes and quantify the role of these systems

Meeting report:

Benway, H. M. and S. C. Doney (2009). Multidisciplinary perspectives in marine biogeochemistry and ecology: Fourth annual Ocean Carbon and Biogeochemistry summer science workshop. Eos 90 (45). For further information, please visit workshop website.

(i.e., source vs. sink) in the North American carbon budget. An overview of coastal synthesis activities was presented with regional highlights for the east coast, the Arctic, and the Gulf of Mexico.

Following on a 2009 OCB scoping workshop, there was a plenary session and community discussion on the future of OCB research in the Southern Ocean, which plays a critical role in climate and biogeochemical cycles. In addition to a report on the scoping workshop, plenary talks included an overview of the Southern Ocean GasEx program, followed by new insights on air-sea CO_2 fluxes based on SOGasEx water column data and satellite algorithm development. The final plenary speaker discussed new results on Southern Ocean particle fluxes and implications for carbon cycling.

To facilitate scientific and programmatic links with GEOTRACES, SOLAS, and IMBER, the meeting included a session on feedbacks between micronutrients and marine ecosystems. The session began with two plenary presentations, one on GEOTRACES that included background, future plans, and new insights from the Atlantic transect, and the other an overview of current research on micronutrient-ecosystem interactions. The session segued into a community discussion during which workshop participants made brief presentations describing relevant measurements, process studies, or scientific themes they wished to publicize or advocate.

Report from the OCB Scoping Workshop

"New Frontiers in Southern Ocean Biogeochemistry and Ecosystem Research" June 8-11, 2009 (Princeton, NJ)

by Nikki Lovenduski (University of Colorado) and the Workshop Planning Committee (C. Deutsch, E. Hofmann, T. Ito, J. Russell, J. Sarmiento, W. Smith, P. Strutton)

The Southern Ocean makes significant contributions to the global budgets of heat, carbon, freshwater and nutrients, and plays a crucial role in the global climate system. This OCB Scoping Workshop was focused on carbon cycling and marine ecosystems in the Southern Ocean, and their response to climate variability and change. The workshop had four main objectives: (1) to provide a critical overview of recent advances in the scientific understanding of the Southern Ocean, (2) to build a collaborative Southern Ocean community across multiple disciplines, (3) to identify key research questions of scientific significance, and (4) to formulate implementation plans for collaborative research in the Southern Ocean.

The plenary presentations covered a wide range of topics, including climate dynamics, circulation and sea ice, air-sea fluxes, biogeochemistry, and food web and ecosystem processes, and represented the diversity in Southern Ocean biogeochemistry and ecosystem studies. Future changes in climate are expected to exert substantial impacts on biogeochemical cycles and ecosystem processes of the Antarctic. Breakout discussion groups identified critical research questions leading to new research directions, including

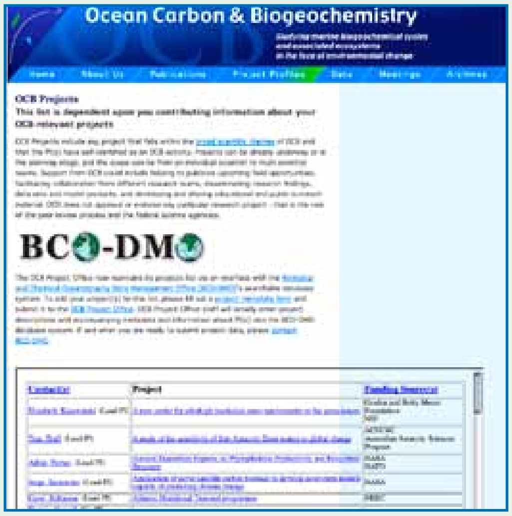
(a) the response of ecosystem and biogeochemical cycles to climate change, (b) the uptake of anthropogenic carbon dioxide, and (c) the response of the natural carbon cycle to climate change.

A full workshop report by the workshop organizers is in preparation. Details of the meeting and slides of plenary presentations are available from the workshop website.

Upcoming OCB Activities

- **OCB Summer Workshop** (July 19-22, 2010 at the Scripps Institution of Oceanograpy (SIO), Scripps Seaside Forum, La Jolla, CA)
- **OCB Scoping Workshop: *The molecular biology of biogeochemistry: Using molecular methods to link ocean chemistry with biological activity*** (dates and venue TBD) – Organizers: Jim Moffett, Eric Webb
- **OCB Scoping Workshop: *Sea Change: Charting the course for ecological and biogeochemical ocean time-series research*** (September 21-23, 2010 at University of Hawaii, Honolulu, HI) – Organizers: Matt Church, Frank Muller-Karger, Mike Lomas

New Developments on the OCB Website



New Projects Page

We invite you to visit the new OCB Projects web page. Rather than a static list of projects, we have been working with the Biological and Chemical Oceanography Data Management Office (BCO-DMO) to interface with their searchable database system. To add your project(s) to this list, please fill out a project metadata form(s) (available for download on the page) and submit it to the OCB Project Office. OCB Project Office staff will enter project descriptions and accompanying metadata and information about PI(s) into the BCO-DMO database system. If and when you are ready to submit project data, please contact BCO-DMO directly.

Student Opportunities

» To view student opportunities, please visit http://www.us-ocb.org/archives/index.html.

Community Data and Education Resources

» Lamont-Doherty Earth Observatory Global Surface pCO_2 Database (v. 2008) now available at CDIAC
» Carbon in the Atlantic Ocean (CARINA) database now available at CDIAC
» Global Carbon Project publishes the new global carbon budget and carbon trend analyses including 2008
» Global carbon cycling education/outreach website and applet tool
» IGBP Climate-Change Index
» New IGBP book "Carbon and Nutrient Fluxes in Continental Margins -- A Global Synthesis" edited by KK Liu, Larry Atkinson, Renato Quinones, Liana Talaue-McManus
» Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007.The Guide to Best Practices for Ocean CO_2 Measurements. PICES Special Publication 3, 191 pp. now available online from CDIAC

Related Program News

» IMBER announces next IMBIZO: IMBER IMBIZO ll *- Integrating biogeochemistry and ecosystems in a changing ocean: Regional comparisons* (October 10-14, 2010, Crete, Greece)
» GO-SHIP sponsors IOCCP and CLIVAR to move forward with the development of a sustained program for repeat hydrography (details)

OCB Co-Sponsors U.S. Participation in International Meetings

» MARine Ecosystem Model Intercomparison Project (MAREMIP) Kickoff Workshop (October 28-30, 2009 in Cambridge, UK)
» AGU Chapman Conference on the Biological Carbon Pump of the Oceans (September 1-4, 2009 in Brockenhurst, Hampshire, England)

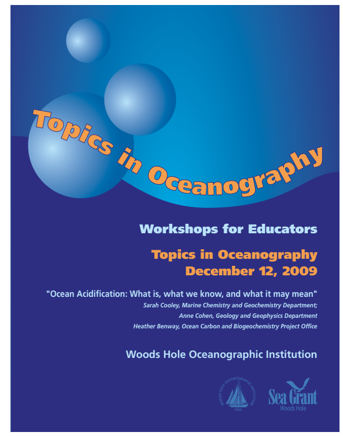
OCB Project Office Welcomes Sarah Cooley

The OCB Project Office would like to extend a warm welcome to Dr. Sarah Cooley, who will be working half time on ocean acidification activities in support of the OCB Ocean Acidification subcommittee. Sarah received her Ph.D. in 2006 from the University of Georgia, and is currently a postdoctoral investigator at the Woods Hole Oceanographic Institution in Scott Doney's lab. Her interests include analytical and computational inorganic carbon chemistry, ocean acidification forecasts from coupled climate models, socioeconomic implications of ocean acidification, and communicating science to nonscientists.

OCB Ocean Acidification Outreach

» We invite you to visit and contribute to the OCB Ocean Acidification website "Resources for Scientists and Educators." Please send your contributions, including new papers (citations only), reports, outreach materials, and presentations to Sarah Cooley in the OCB Project Office.

» A new OCB Ocean Acidification teaching kit developed by Sarah Cooley is now available for download from the OCB website. The activities described in the kit employ simple, inexpensive household materials to help teachers demonstrate the chemical and biological concepts behind ocean acidification.



» The OCB Project Office has purchased a C-MORE science kit on ocean acidification that is available for use in the northeastern US. To reserve the kit, please fill out the C-MORE kit request form.

» OCB scientists Cooley, Cohen, and Benway recently participated in a Teacher Workshop on ocean acidification in Woods Hole, MA (see article in Education/Outreach column).

International Ocean Acidification Headlines

» The Guide to Best Practices in Ocean Acidification Research and Data Reporting has completed its open community review process and publication is expected in early 2010.

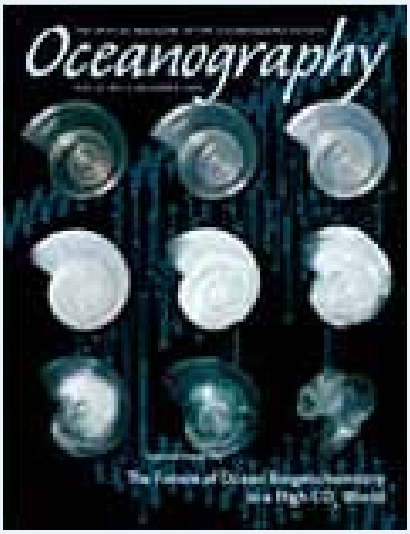
» "Ocean Acidification: The Facts," an introductory guide for policy advisers and decision makers, was released in December 2009 at the UN Climate Change Conference in Copenhagen. The guide was written by a team of researchers from France, Germany, the UK, the USA, and Australia, and coordinated by the European Project on Ocean Acidification (EPOCA). The guide is available for download from the EPOCA website in five different languages.

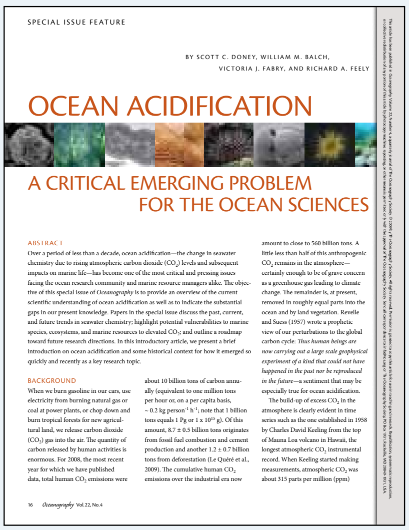
» SOLAS-IMBER Ocean Acidification working group's first meeting December 1-3, 2009 at UNESCO (Paris, France)

» A new EU Research Initiative started in September 2009: Biological Impacts of Ocean Acidification (BIOACID)

» Science Policy Briefing on the "Impacts of Ocean Acidification" now available

» The sponsors (IOC, IGBP, Marine Environment Laboratories of the IAEA, and SCOR) of the 2nd Symposium on the Ocean in a High-CO_2 World publish "Ocean acidification: A Summary for Policymakers"





SPECIAL ISSUE FEATURE

BY SCOTT C. DONEY, WILLIAM M. BALCH, VICTORIA J. FABRY, AND RICHARD A. FEELY

OCEAN ACIDIFICATION

A CRITICAL EMERGING PROBLEM FOR THE OCEAN SCIENCES

ABSTRACT

Over a period of less than a decade, ocean acidification—the change in seawater chemistry due to rising atmospheric carbon dioxide (CO_2) levels and subsequent impacts on marine life—has become one of the most critical and pressing issues facing the ocean research community and marine resource managers alike. The objective of this special issue of *Oceanography* is to provide an overview of the current scientific understanding of ocean acidification as well as to indicate the substantial gaps in our present knowledge. Papers in the special issue discuss the past, current, and future trends in seawater chemistry; highlight potential vulnerabilities to marine species, ecosystems, and marine resources to elevated CO_2; and outline a roadmap toward future research directions. In this introductory article, we present a brief introduction on ocean acidification and some historical context for how it emerged so quickly and recently as a key research topic.

BACKGROUND

When we burn gasoline in our cars, use electricity from burning natural gas or coal at power plants, or chop down and burn tropical forests for new agricultural land, we release carbon dioxide (CO_2) gas into the air. The quantity of carbon released by human activities is enormous. For 2008, the most recent year for which we have published data, total human CO_2 emissions were about 10 billion tons of carbon annually (equivalent to one million tons per hour or, on a per capita basis, ~ 0.2 kg person^{-1} h^{-1}; note that 1 billion tons equals 1 Pg or 1 x 10^{15} g). Of this amount, 8.7 ± 0.5 billion tons originates from fossil fuel combustion and cement production and another 1.2 ± 0.7 billion tons from deforestation (Le Quéré et al., 2009). The cumulative human CO_2 emissions over the industrial era now amount to close to 560 billion tons. A little less than half of this anthropogenic CO_2 remains in the atmosphere—certainly enough to be of grave concern as a greenhouse gas leading to climate change. The remainder is, at present, removed in roughly equal parts into the ocean and by land vegetation. Revelle and Suess (1957) wrote a prophetic view of our perturbations to the global carbon cycle: *Thus human beings are now carrying out a large scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future*—a sentiment that may be especially true for ocean acidification.

The build-up of excess CO_2 in the atmosphere is clearly evident in time series such as the one established in 1958 by Charles David Keeling from the top of Mauna Loa volcano in Hawaii, the longest atmospheric CO_2 instrumental record. When Keeling started making measurements, atmospheric CO_2 was about 315 parts per million (ppm)

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Oceanography Special Issue on Ocean Acidification

Dick Feely, Barney Balch, Scott Doney and Vicki Fabry have edited a special issue on the Future of Ocean Biogeochemistry in a High CO_2 World for *Oceanography* with gratefully acknowledged support from NSF (OCE-BIO and OCE-CHEM), NASA, and NOAA. The special issue was published in December 2009.

Community White Paper "An International Observational Network for Ocean Acidification"

Dick Feely spearheaded community input to a whitepaper outlining the details of an international ocean acidification observing network for the OceanObs'09 conference (21-25 September 2009, Venice). To view this and many other OCB-relevant whitepapers, please visit http://www.oceanobs09.net/blog/.

Photo courtesy of OceanObs '09 Web site

OCB Community provides input to EPA on Ocean Acidification

The EPA published a notice of data availability (NODA) regarding its "aquatic life criteria for pH of marine waters" under the Clean Water Act. The OCB Ocean Acidification Subcommittee together with the OCB Project Office compiled a comprehensive response to this notice, which included input from numerous members of the OCB community. Download the final OCB response to the EPA Notice of Data Availability on ocean acidification or visit EPA docket.

Ocean Acidification at COP-15

by Scott Doney

Marine biogeochemistry was a high-profile topic at the most recent United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP-15) in Copenhagen, Denmark. A number of U.S. OCB scientists attended to give presentations and meet with delegates, media, and observers from non-governmental organizations. Richard Feely (NOAA/PMEL) spoke at a special side-event on ocean acidification hosted by Oceana. The first "Oceans Day," a day-long meeting of scientists and policy makers devoted solely to marine impacts and adaptation strategies, was held at the European Environmental Agency. Sessions within Oceans Day highlighted a variety of marine carbon cycle science issues including coastal carbon storage, the UNEP Blue Carbon report, and ocean acidification. An ocean acidification panel at Oceans Day included contributions from Robert Dunbar (Stanford), Victoria Fabry (Cal. State San Marcos), and Scott Doney (WHOI). Scott Doney also gave a talk on ocean carbon dynamics and ocean acidification at the U.S. Center as part of a NOAA-sponsored event. In addition, ocean acidification was a featured topic on the NOAA Science on a Sphere, which was on display at the U.S. Center throughout the two-week conference.

Please visit http://www.us-ocb.org/2008-2009_OCB_OA_highlights.pdf to view a list of OCB ocean acidification activities for 2008-2009.

Soaring into the Future: Training the Next Ocean Acidification Researchers

A Report on the OCB Ocean Acidification Short Course
by Sarah Cooley (Woods Hole Oceanographic Institution)

Bright leaves and bright students both descended on Woods Hole, Massachusetts from November 2-13 during the OCB- and EPOCA-sponsored short course on ocean acidification (OA) research. The OCB Ocean Acidification subcommittee, chaired by Drs. Joan Kleypas and Richard Feely, provided critical guidance on the course scope, curriculum, and instructors. The 12-day course convened 20 instructors and 35 participants from 14 countries to participate in lectures, discussions, and lab activities focusing on the details of ocean acidification research.

Responding to the scientific community's need to train postdoctoral and faculty researchers in the emerging interdisciplinary field of ocean acidification research, the OCB Project Office and course faculty organized an intensive crash course consisting of more than 20 lectures and 20 laboratory activities, with added tours, discussions, and demonstrations to round out the course. Daily schedules lasted 9+ hours, but all the participants showed remarkable tenacity and energy while getting the most out of their time in "the Village."

The course began with a series of lectures and lab activities focused on OA chemistry. Over the first few mornings, Chris Sabine, Andrew Dickson, Jean-Pierre Gattuso, and Aleck Wang reviewed ocean carbonate chemistry, described analytical methods, and assessed the uncertainties among different parameters and calculations. Students learned from Chris Sabine, Kim Yates, and Jean-Pierre Gattuso how to use CO2SYS and seacarb to calculate carbonate system parameters, and they engaged the faculty in thoughtful discussions about acceptable levels of uncertainty. The first several afternoons of the course included hands-on practice in collecting high-quality seawater samples for inorganic carbon parameter analyses and measuring pH, dissolved inorganic carbon (DIC), total alkalinity (TA), and the partial pressure of CO_2 (pCO_2). Course faculty and other researchers, including Aleck Wang, Chris Langdon, Joe Salisbury, Kim Yates, Dan McCorkle, Chris Sabine, and Hugh Ducklow, generously loaned the instruments used in the course.

Please visit the course website for more information. Click on the "Course Materials" tab for links to the course syllabus, course lectures and background materials, and video footage of all lectures.

The next segment focused on biology and biogeochemistry, and included morning, evening, and weekend lectures by Dave Hutchins, Chris Langdon, Jean-Pierre Gattuso, Debora Iglesias-Rodriguez, Anne Cohen, Whitman Miller, Barney Balch, Brad Seibel, and Nann Fangue. Topics included

Instructors, students, and organizers of the OCB Ocean Acidification Short Course *(Photo by Mark Carls, NOAA/NMFS).*

biogeochemical feedbacks, experimental design, manipulating seawater carbonate chemistry, algal culturing, calcification and its measurement via several methods, physiology, and genomic techniques. During lab periods, students set up and conducted two multi-day experiments: 1) Tracking larval mollusk growth under ambient vs. elevated CO_2 conditions, led by Anne Cohen and Dan McCorkle with significant support from teaching assistants Meredith White and Kathryn Rose; and 2) Monitoring seawater chemistry (TA, DIC, and nutrients) changes to quantify coral calcification led by Michael Holcomb. In another experiment, the students conducted cellular pH and respirometry measurements on green crabs (*Carcinus maenas*) with Brad Seibel. Dan McCorkle and Anne Cohen kindly supplied lab space and equipment for the biological experiments. On free afternoons, students toured the labs of WHOI scientists Joan Bernhard (benthic foraminiferal ecology and paleoecology) and John Waterbury (algal culturing), and explored the MBL Marine Resources Center with Ed Enos.

The third and fourth segments of the course focused on modeling and datasets, and data management and reporting. Scott Doney conducted two lectures on biogeochemical modeling and presented Bob Key's material on using large databases such as GLODAP and CARINA. During an afternoon lab segment, Scott Doney also instructed students in using simple Matlab-based models. Reiner Schlitzer conducted a hands-on demonstration of Ocean Data View, during which students learned to navigate the software and generate section plots using GLODAP data. Cyndy Chandler educated course participants on data management and the importance of metadata. Alex Kozyr provided a detailed overview of the Carbon Dioxide Information Analysis Center (CDIAC)'s ocean CO_2 data holdings, data search, and visualization tools. During the last few days of the course, Chris Langdon and Michael Holcomb also led group analyses of data from the biological experiments.

This course was a decided success, owing in large part to the hard work of the OCB Ocean Acidification Subcommittee in designing the course, the dedication of the course faculty, who volunteered time and resources, and the enduring interest and enthusiasm of the students, who persevered through several late nights, a national holiday, and a weekend.

After the course, one of the students suggested that the course should have been given the acronym SOAR (Short-course on Ocean Acidification Research), as she brightly explained, because "students will come out of here and soar into their careers in OA research." With these can-do attitudes, soar they shall...

Instructor Chris Langdon (U. Miami) demonstrates total alkalinity titration *(Photo by Lisa Robbins, USGS).*

Instructor Dan McCorkle (WHOI) demonstrates electrode pH measurements *(Photo by Lisa Robbins, USGS).*

Course participants Nayrah Shaltout (Nat'l Inst. Oceanog. Fisheries), Dreux Chappell (URI), and Shannon Meseck (NOAA/NMFS) (left to right) set up CO_2 treatments for the larval mollusk experiment *(Photo by Joaquim Goes, Bigelow Laboratory for Ocean Sciences).*

OCB Scientists Participate in Woods Hole Teacher Workshop on Ocean Acidification

On December 12, 2009, OCB scientists Sarah Cooley, Anne Cohen, and Heather Benway participated in a teacher workshop on ocean acidification in Woods Hole, MA. The workshop, which was expertly organized by Katherine Madin, a marine educator with the Woods Hole Sea Grant Program, and graciously hosted by Karen Collasius and Kathy Patterson of the WHOI Exhibit Center, drew 16 teachers from New England schools. The program included morning lectures on the impacts of ocean acidification on marine chemistry and ecosystems services (Cooley), and marine biology (Cohen). In the afternoon, Cooley and Benway led hands-on lab activities to demonstrate the chemical and biological concepts of ocean acidification and provide the teachers with resources and ideas they could implement in their own classrooms.

Sarah Cooley helped teachers determine the pH of common household substances using homemade red cabbage juice as an indicator solution. *(Photo by Tom Kleindinst, WHOI)*

"Ocean acidification in a cup" experiment, in which teachers blew through a straw into a cup of seawater containing red cabbage juice pH indicator and watched the color change as more CO_2 enters the water *(Photo by Tom Kleindinst, WHOI)*

As part of the C-MORE (Center for Microbial Oceanography Research and Education) ocean acidification science kit, teachers used pH and CO_2 probes in a simple experiment with yeast to learn about ocean acidification. *(Photo by Tom Kleindinst, WHOI)*

MS PHDS Students Participate in 2009 OCB Summer Workshop

As part of our efforts on scientific outreach and broader impacts, the Ocean Carbon and Biogeochemistry (OCB) program partnered with the Minorities Striving and Pursuing Higher Degrees of Success in Earth System Science (MS PHDS) initiative. MS PHDS was developed by and for underrepresented minorities with the overall purpose of facilitating increased participation in Earth system science. This program offers networking and mentoring opportunities with federal agency program officers, professional society representatives, peers, researchers, and educators from different institutions across the country. It provides its members with professional development opportunities and exposure to various earth system science and engineering fields via participation in community activities and scientific conferences like the 2009 OCB Summer Workshop, held July 20-23, 2009 at the Woods Hole Oceanographic Institution (WHOI). This year, OCB hosted four students from the MS PHDS program:

» **Rafael Benitez-Joubert** – Rafael is a graduate student at the University of Puerto Rico, Río Piedras working toward an M.S. in Estuarine Ecology. Rafael is currently conducting research on tropical estuarine metabolism and carbon dynamics. *(OCB Mentor: **Peter Griffith**, North*

American Carbon Program)*

- **Adrienne George** – Adrienne is an undergraduate at Delaware State University majoring in Environmental Sciences. She is interested in coastal ecosystems, and has conducted marine biology and aquaculture research projects in Florida and Delaware. *(OCB Mentor: **Phoebe Lam**, Woods Hole Oceanographic Institution)*
- **Veronica Aponte** – Veronica is a graduate student at the Universidad Interamericana de Puerto Rico (UIPR), San German working on her M.S. in Environmental Science and has research interests in environmental toxicology. *(OCB Mentor: **Debbie Bronk**, Virginia Institute of Marine Science)*
- **Marta Rodriguez-Lopez** – Marta is a Ph.D. student in the College of Marine Science at the University of South Florida, and is conducting research involving seagrass uptake of radionuclides to examine biomagnification in the marine food web. *(OCB Mentor: **Susanne Menden-Deuer**, University of Rhode Island)*

Each student was paired with an OCB mentor to help further engage them in the scientific program, introduce them to colleagues, and provide guidance on career paths and professional development. In addition to attending the workshop, the MS PHDS students spent one day aboard the R/V *Discovery* with Captain Mike and instructors Hovey Clifford (WHOI), Bruce Tripp (WHOI), and George Hampson (Woods Hole Group) learning about basic oceanographic sampling and navigation techniques. After a brief introduction, students experienced hands-on exposure to a range of water, sediment, and biological sampling devices and measurements. The students also participated in tours of WHOI facilities, such as the National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) Facility and the Deep Submergence Laboratory.

Ocean Acidification Impacts on Larval Shell Formation of the Atlantic Bay Scallop *Argopecten irradians*: An Experimental Investigation

by Melissa Pinard (Morgan State University)

Objectives

The goal of this experiment was to assess the sensitivity of Atlantic bay scallop (*Argopecten irradians*) larvae to changes in seawater saturation state associated with ocean acidification.

Methods

We investigated the sensitivity of larval shell formation of the Atlantic bay scallop *A. irradians* by manipulating seawater CO_2 concentration on a laboratory scale. Fertilized bay scallop eggs were obtained two hours post-fertilization and were grown under four different CO_2 concentrations: 380 ppm, 560 ppm, 840 ppm, and 2280 ppm for 72 hours. We used microscopy to quantify the effects of elevated CO_2 on shell formation.

We set up four replicates of each CO_2 concentration in experimental beakers containing 800 ml of seawater. We bubbled the seawater in each experimental beaker with air of the respective CO_2 concentration, allowing the air and seawater to equilibrate for two days. On the second day, we obtained fertilized bay scallop eggs from a hatchery in Dennis, MA and transferred them into the different CO_2 treatments. A total of ~1.1 million larvae were obtained from the hatchery. We examined subsamples of the spawn under a microscope to obtain initial estimates of larval density, and then transferred ~5,000 larvae to each beaker.

We took daily pH measurements to monitor conditions as the larvae grew. The larvae were harvested 72 hours post-fertilization by pouring the beaker contents through a 45-micron sieve and rinsing with ethanol to kill the larvae. The larvae were then rinsed and decanted into a glass vial using ethanol. Each vial was filled to the 5-ml mark with ethanol to ensure all vials contained the same amount of solution. 12 of the 16 vials were analyzed (3 replicates from each of the four CO_2 treatments).

To estimate the number of recovered larvae per vial, we counted the larvae in each of three 0.5-ml subsamples. We photographed (Fig. 1) the larvae from each subsample. Using SPOT Microscope Digital Imaging Software, we then took hinge length measurements of larval shells from the different CO_2 treatments (Table 1, Fig. 2).

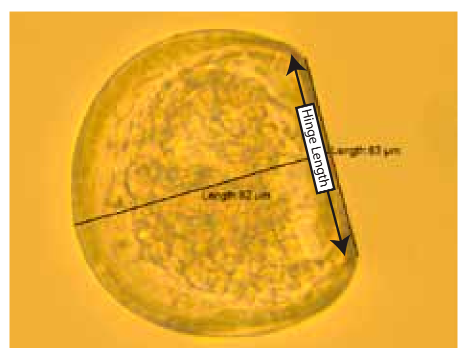


Figure 1: Larval shell from 560-ppm CO_2 treatment (Photo by Melissa Pinard).

Results and Discussion

At extremely high CO_2 concentrations (2280 ppm), larval recovery was too low to obtain hinge length measurements, but an analysis of the hinge lengths from the other CO_2 treatments revealed a decrease in hinge length with increasing CO_2 concentration.

Sogin (2008) performed a similar experiment, but the larvae were harvested after only 24 hours (Table 2) versus 72 hours in our experiment. Despite the difference in harvest times, the Sogin hinge length data show a trend similar to our data (Fig. 2). Both experiments reveal a significant difference between the 380-ppm and 840-ppm treatments (Fig. 2). As in our experiment, the 2280-ppm treatment yielded insufficient larval recovery for analysis.

Ocean Chemistry

When CO_2 in the atmosphere dissolves in the ocean it combines with water to form carbonic acid (H_2CO_3), a weak acid. This is the reaction we have mimicked in this laboratory experiment. Carbonic acid dissociates, releasing hydrogen (H^+) ions and bicarbonate ions (HCO_3^-), and to a lesser extent, carbonate ions (CO_3^{2-}). Some carbonic acid and CO_2 also remain in solution. This dissolution and dissociation leads to an increase in the H^+ concentration, causing an overall decrease in pH (measure of acidity). A drop of one pH unit corresponds to a 10-fold increase in the H^+ concentration. Seawater pH typically ranges from 8.0-8.3, which is slightly alkaline. However, the absorption of CO_2 has already reduced the pH of modern surface water by ~0.1 pH units relative to pre-industrial times (Doney, 2006).

Implications for Larval Shell Formation by the Bay Scallop

The calcium carbonate in corals and other calcifying marine organisms such as the bay scallop is present in two forms: calcite and aragonite, which is the more soluble form. Exposed aragonite shells dissolve in seawater when carbonate ion concentration drops below 60 µmol/kg. Since the initial shell secreted by the larval bay scallop is made of aragonite, the continued availability of this form of calcium carbonate is important for the survival of the bay scallop. The hinge length data from this and the Sogin (2008) study suggest that elevated CO_2 concentrations affect the formation of the initial D-shell formed during the larval stage (Tables 1 and 2, Fig. 2). These findings collectively underscore the need for further research to explore the sensitivity of shellfish, particularly larval stages, to potential changes in ocean chemistry.

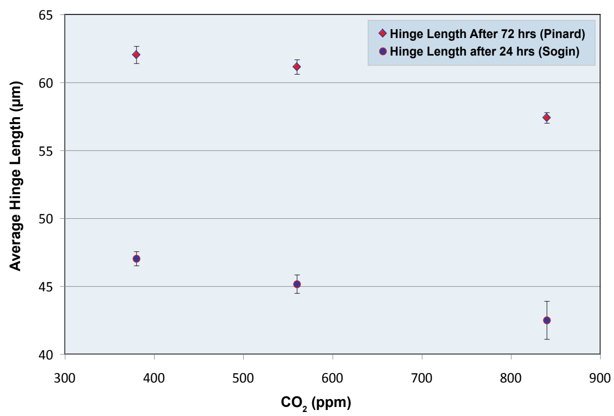


Figure 2: Hinge length data from this study (Table 1) and from Sogin (Table 2). Error bars indicate standard error.

Table 1: Average hinge length after 72 hours (Pinard).

Condition (CO_2 ppm)	*Average Hinge Length (µm)*	*Standard Error*	*Average pH*
380	62.04	0.63	8.108
560	61.15	0.53	7.937
840	57.41	0.39	7.766
2280	-	-	7.306

Table 2: Average hinge length after 24 hours (Sogin).

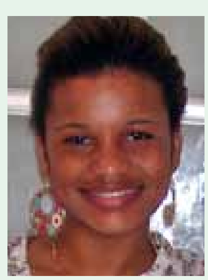
Condition (CO_2 ppm)	*Average Hinge Length (µm)*	*Standard Error*
380	47.04	0.52
560	45.17	0.68
840	42.51	1.4

References

Doney, S.C. (2006). The dangers of ocean acidification. *Scientific American* 294(3), pp. 58-65.

Sogin, E. (2008). Unpublished data.

About the Author



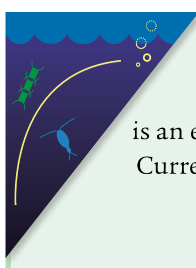
During Summer 2009, the OCB Project Office provided support for Melissa Pinard, a junior chemistry major at Morgan State University in Baltimore, MD, to participate in the Woods Hole Partnership Education Program (PEP) recently established by the Woods Hole Diversity Initiative. PEP brings 12-15 students to Woods Hole each summer for an integrated program of internships and course work. The 2009 PEP course was entitled "Topics in Ocean and Environmental Sciences: Global Climate Change." For her research internship, Melissa worked with two scientists at the Woods Hole Oceanographic Institution (WHOI), Drs. Anne Cohen and Dan McCorkle, on a laboratory-based project to evaluate the sensitivity of larval bay scallops to the changes in seawater saturation state projected over the next century.

OCB Calendar

January 4-February 1:	International Graduate Training Course in Antarctic Marine Biology: Integrative Biology and Adaptation of Antarctic Marine Organisms, McMurdo Station, Antarctica
January 4-23:	Austral Summer Institute X: Ecology and diversity of marine microorganisms (ECODIM), University of Concepcion, Chile
February 22-26:	2010 Ocean Sciences Meeting: From Observation to Prediction in the 21st Century, Portland, OR
February 22-23:	Greenhouse gases in the Earth system: Setting the agenda to 2030, London, UK
March 13-20:	DISCCRS V Interdisciplinary Climate Change Research Symposium, Saguaro Lake Ranch, AZ
April 19-22:	CAMEO Workshop on End-to-End Modeling of Marine Ecosystems, Woods Hole, MA
April 25:	Potential Impacts of Ocean Acidification on Marine Ecosystems and Fisheries, Sendai, Japan
April 26-30:	42nd International Liege Colloquium on Ocean Dynamics Multiparametric observation and analysis of the Sea, Liège, Belgium
May 2-7:	European Geosciences Union General Assembly 2010, Vienna, Austria
May 17-21:	The 6th International Symposium on Gas Transfer at Water Surfaces, Kyoto, Japan
May 19-21:	The Microbial View of Marine Biogeochemical Cycles, Banyuls-sur-Mer, France
May 31-July 10:	2010 Summer Course on Microbial Oceanography, Honolulu, HI
May 31-June 2:	EUR-OCEANS / Europole Mer 2010 Conference: Influence of meso- and submesoscale ocean dynamics on the global carbon cycle and marine ecosystems, Aber Wrac'h, France
June 6-11:	ASLO Summer Meeting, Santa Fe, NM
June 8-12:	2010 International Polar Year Meeting, Oslo, Norway
July 4-9:	Marine Microbes Gordon Research Conference, Tilton, NH
July 19-22:	OCB Summer Workshop, La Jolla, CA
September 21-23:	OCB Scoping Workshop - Sea Change: Charting the course for ecological and biogeochemical ocean time-series research, Honolulu, HI
October 10-14:	IMBER IMBIZO ll - Integrating biogeochemistry and ecosystems in a changing ocean: Regional comparisons, Crete, Greece

Funding Opportunities

- **February 15:** NSF Chemical and Biological Oceanography target dates
- **August 15:** NSF Chemical and Biological Oceanography target dates
- **November 16:** NSF Dynamics of Coupled Natural and Human Systems (CNH) full proposal deadline



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