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A Preliminary Carbon Budget for the Gulf of Mexico

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Introduction

The Gulf of Mexico has been a major source of uncertainty in the North American carbon budget (Chavez et al., 2007). Until recently, it was sparsely sampled and poorly characterized in terms of its air-sea exchange of carbon dioxide, land-to-ocean carbon fluxes, and control mechanisms. It is a large, semi-enclosed water body geopolitically shared almost equally by the U.S. and Mexican governments. The Gulf of Mexico drainage basin extends over roughly 40% of each nation and comprises 33 major river systems. Thus, large-scale changes in land use water management in both countries, as well as changes in temperature and rainfall due to climate change, will profoundly affect Gulf carbon sources and sinks. Nutrient discharge from the Mississippi River has been implicated in widespread hypoxia on the shelf.

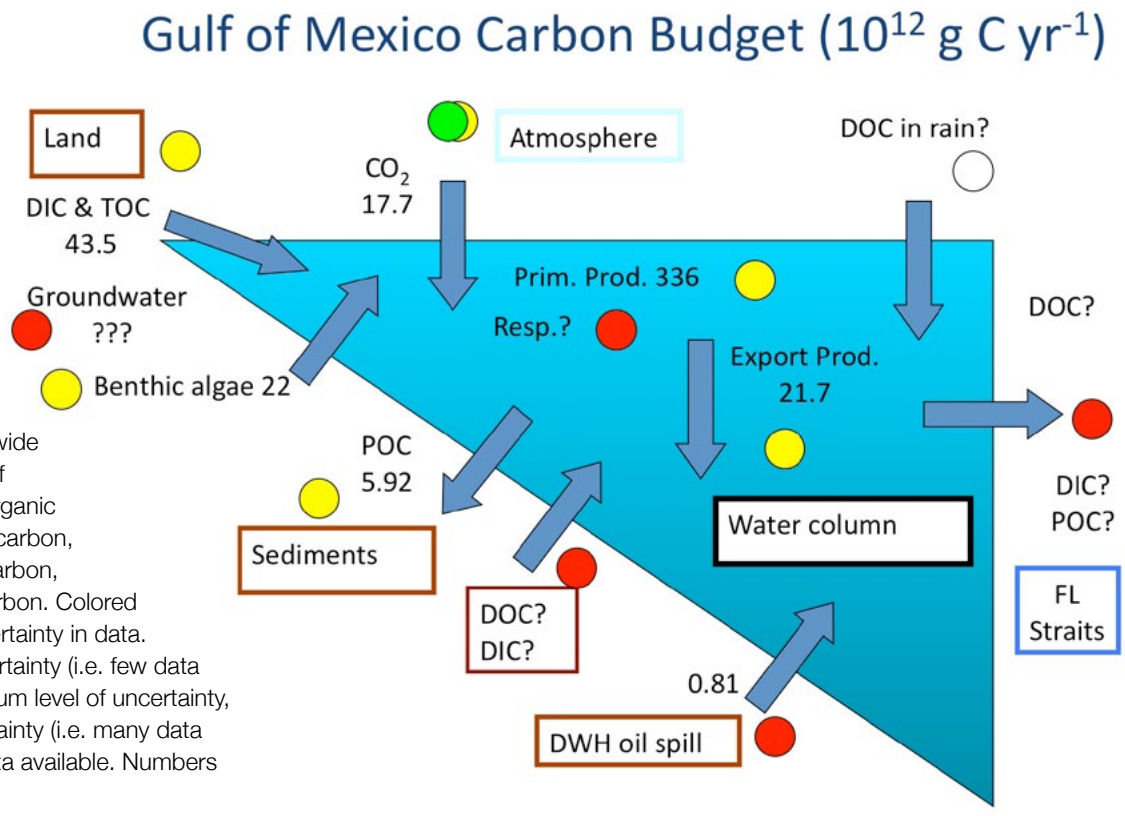

Figure 1. Preliminary shelf-wide carbon budget for the Gulf of Mexico. DIC = dissolved inorganic carbon, TOC= total organic carbon, POC = particulate organic carbon, DOC = dissolved organic carbon. Colored dots represent levels of uncertainty in data. Red dot = High level of uncertainty (i.e. few data available), yellow dot = medium level of uncertainty, blue dot= low level of uncertainty (i.e. many data available), white dot = no data available. Numbers reported in 10^{12} g C yr^{-1}.

There exists no prior carbon budget for the Gulf of Mexico as a whole, although Walsh et al. (1989) presented many elements of a nitrogen budget. We have constructed a carbon budget in part by converting the Walsh et al. (1989) nitrogen and chlorophyll fluxes into carbon units and in part by addition of new observations collected or compiled more recently. Overall, the new data compare well with estimates derived from Walsh et al. (1989).

This paper represents the next installment in a series of reports on coastal carbon budgets currently in preparation as part of the Coastal Carbon Interim Synthesis Activity, a joint endeavor of the Ocean Carbon and Biogeochemistry Program and the North American Carbon Program. The first installment was "Carbon Budget for the Continental Shelf of the Eastern United States: A Preliminary Synthesis" by Najjar et al. (2010) published in the Winter 2010 OCB Newsletter. This was followed by "The Marine Carbon Cycle of the Arctic Ocean: Some Thoughts About the Controls on Air-Sea CO_2 Exchanges and Responses to Ocean Acidification" by Mathis and Bates published in the Spring/Summer 2010 OCB Newsletter. This current installment is still preliminary, with major uncertainties and missing estimates of key fluxes. It is intended as a status report on the activity with the hope that it will stimulate further thought and research.

The domain

The most comprehensive compilation of historical biogeochemical flux data is presented in Walsh et al. (1989). They combined a 2-layered baroclinic circulation model with a 21-layered biochemical model to estimate nitrate input, "new" production, particle export, and remineralization in three coastal areas (west Florida, Louisiana, and Texas) and for the Central Gulf. Seasonal, summer and winter estimates were made with and without including the Mississippi River influence.

Recent work in the Mississippi-Atchafalaya River System (MARS) has provided estimates of key carbon fluxes from land to ocean, primary productivity, and air-sea flux of CO_2 (Cai and Lohrenz, 2010) and also resulted in a preliminary carbon budget limited to the area of the plume (Robbins et al., 2009).

These previous efforts influenced our division of the Gulf into six regions: 1) Texas coast (TX), 2) Louisiana coast (LA), 3) west Florida shelf (WFS), 4) Mexico (MX), 5) Central Gulf, and 6) MARS Plume. The total area of the Gulf of Mexico is 1.6×10^6 km^2 of which the Central Gulf region, with depths greater than 200 m, composes roughly 63%. The remaining area, with depths of 0-200 m, was allocated to the coastal regions as follows: TX - 5%, LA - 11%, WFS - 11%, and MX - 11%, all as % total area and thus adding up to 100%.

Carbon fluxes of interest

We considered the following fluxes across three of the four key interfaces: land-ocean, air-sea, and sediment-water. No estimates are yet available for fluxes across the shelf break. Inputs from land are dissolved organic carbon (DOC), particulate organic carbon (POC), and dissolved inorganic carbon (DIC). Air-sea fluxes are CO_2 exchange and input of rainwater DOC (not included). Sedimentary fluxes are POC deposition, DOC and DIC exchange across the sediment-water interface (not included), benthic productivity, groundwater inputs of DOC and DIC (not included), and hydrocarbon seeps. Shelf break fluxes are those for DIC, DOC, and POC (none are included). Internal fluxes are primary production, respiration (not included), net community production (not included), and export from the upper (euphotic) layer.

Fluxes were calculated as rates multiplied by the area in each region.

Fluxes from land

Riverine inputs are only from data collected in the U.S.. Cai and Lohrenz (2010) estimated inputs from MARS to be 21, 2.5, and 2.5 Tg C yr^{-1} for DIC, DOC, and POC, respectively. A recent compilation of USGS and EPA STORET data for LA rivers (Robbins et al., in prep.) reported a much lower DIC (0.06 Tg C yr^{-1}) but higher DOC and POC inputs of 8.9 Tg C yr^{-1} for each component. Inputs for all other U.S. Gulf Coast rivers combined are 0.86, 2.65, and 1.11 Tg C yr^{-1} for DIC, DOC, and POC, respectively. The compiled data set suffers from discontinuous time-series, a range of methods used in studies, as well as from a dearth of records for which all carbon system data were collected. It is likely that the DIC estimates compiled from these existing data sets are too low, considering the reports of high DIC from agricultural liming practices influencing Mississippi River discharge (Raymond et al., 2008). We have used values of 22, 11.5, and 10 Tg C yr^{-1}, respectively for DIC, DOC, and POC to obtain a total input from land of 43.5 Tg C yr^{-1}.

Air-sea fluxes

A recent synthesis (Chavez et al., 2007) suggests that the Gulf of Mexico is a major source for CO_2 to the atmosphere ("+" flux) and may dominate the net flux of the entire North American margin because of the Gulf's large size and strong observed fluxes, both positive and negative. However, these conclusions were based on a very limited data set. Several projects in the last three years have greatly increased the number of observations and led to the development of a model incorporating satellite imagery for sea surface temperature and salinity. However, there are still not enough data available to reliably estimate fluxes in the six regions used

for the other processes. Lohrenz et al. (2010a) measured both positive and negative fluxes in the northern shelf region during three seasons, ranging from -1.18 to -0.97 mmol m^{-2} d^{-1} for April 2006, and from 2.71 to 3.22 mmol m^{-2} d^{-1} for October 2005. Values for August 2004 were slightly positive. Robbins et al. (2010a-c) measured over 5100 underway data points of pCO_2, TCO_2, and pH on the west Florida shelf (WFS). These data were used to calculate pCO_2 fluxes, showing generally positive fluxes (source) in the summer and negative fluxes (sink) in the winter. Data from 2009 cruises indicate that the WFS was generally a weak source of CO_2 to the atmosphere (Robbins, unpub.).

Data from nine cruises and more than 64,000 underway data points have been used to develop an algorithm to calculate pCO_2 fluxes (Wanninkhof et al., unpub.). Their estimates indicate that coastal waters of the NW Gulf are a very strong CO_2 sink year-round, and coastal waters of the NE Gulf are a moderate sink year round due to high primary productivity stimulated by input of anthropogenic nutrients from the Mississippi River. The open waters of the Gulf are a source in late summer, but a sink at all other times of the year. The fact that pCO_2 is well correlated with temperature in the open Gulf makes these estimates more reliable than those in coastal waters. Their overall average flux estimate for Gulf waters north of 24° N is -11.8 Tg C yr^{-1} from air to sea (i.e., a net sink).

Taken as a whole, there is still much uncertainty in air-sea flux estimates for the Gulf of Mexico. In consideration of the synoptic aspects of the Wanninkhof et al. (unpub.) model results, we have chosen to use their value of -11.8 Tg C yr^{-1} for the northern Gulf. Since the net result from open waters indicates a slight sink, and any riverine inputs from coastal Mexico would also be expected to have a negative sign, we have increased the flux for the entire Gulf by 50% to include the influence of the southern Gulf.

Carbon fluxes from the upper layer

The model of Walsh et al. (1989) calculates particle export from the upper layer of the water column and from the lower layer (i.e., to the sediment) in units of mg chl m^{-2} yr^{-1}. These were converted to carbon using a C/Chl ratio of 50:1. Values from Redalje et al. (1994) are available only for the LA and MARS Plume regions, and are roughly six times higher than the Walsh et al. model results. We used the average value from Walsh et al. (1989) of 15.1 g C m^{-2} yr^{-1} for the coastal areas and a value of 12.7 g C m^{-2} yr^{-1} for the Central Gulf to obtain a total value of 21.7 Tg C yr^{-1}, or roughly 6.4% of the total primary production. Since actual measured values (Redalje et al., 1994) are much higher, this is probably an underestimate.

Carbon fluxes at the sediment water interface

The Walsh et al. (1989) model results compare more favorably with measured values of carbon flux to the sediment (Rowe et al., 2008; Eadie et al., 1994; Cai and Lohrenz, 2010). Estimates range from 7 to 30 g C m^{-2} yr^{-1} for coastal areas, 1 to 50 g C m^{-2} yr^{-1} for the Plume, and 0.5 to 1.4 g C m^{-2} yr^{-1} for the Central Gulf. A range of 1 to 2 g C m^{-2} yr^{-1} was obtained for the MX slope/rise region from sediment traps by Escobar-Briones (personal communication). We used average rates to compute 0.83, 0.26, and 4.83 Tg C yr^{-1} for Central, slope/rise, and coastal regions, respectively, yielding a total sediment flux of 5.92 Tg C yr^{-1}. This is in reasonable agreement with the estimate from Walsh et al. (1989) of 2.06 Tg C yr^{-1} based on 1.7% of primary productivity.

Primary production

Water Column Primary Production

Phytoplankton primary production rates from three sources (Walsh et al., 1989; Cai and Lohrenz, 2010; Lohrenz and Verity, 2006) ranged from 30 to 3060 g C m^{-2} yr^{-1} for the Central Gulf and the Plume regions, respectively. Values from Walsh et al. (1989) were converted from "new" production to net production using an f value (ratio of "new" production to total production) of 0.1. These values agreed well with those of Lohrenz and Verity (2006) for the Central Gulf and TX, but were 2 to 3 times higher for the WFS and MX regions. Values for the plume obtained by Cai and Lohrenz (2010) were also lower than those calculated by Walsh et al. (1989) by a factor of six. Total Gulf water column productivity was therefore estimated using the lower end of the range of values provided by Walsh et al. (1989) (105 to 210 g C m^{-2} yr^{-1}) to be 336 Tg C yr^{-1}. This may be somewhat of an underestimate.

Benthic Primary Production

Many coastal regions of the Gulf of Mexico are shallow and the water has sufficient clarity that sunlight penetrates to the sediment surface. These areas support highly productive submerged aquatic vegetation (SAV), which has a significant influence on the overall productivity of the region. The Mid-Atlantic Bight was used as a proxy for these SAV communities. Estimates of 146 g C m^{-2} yr^{-1} from Jahnke et al. (2000) resulted in an areal estimate of 25.7 Tg C yr^{-1} for shelf areas between 0 and 20 m depth. This compares well with estimates from a recent study conducted in the northern Gulf by Murrell et al. (2009) of 109.5 g C m^{-2} yr^{-1} and 19 Tg C yr^{-1}. The average value was added to the water column value to obtain a total primary production of 358 Tg C yr^{-1}.

Hydrocarbon inputs from natural seeps and Deepwater Horizon accident

There are hundreds, if not thousands, of natural hydrocarbon seeps on the seafloor of the Gulf of Mexico, as well as an unknown number of

leaking "capped" oil and natural gas wells. Estimates of how much oil naturally seeps into the environment range from 1,500 to 3,850 barrels per day, or 0.06 – 0.15 Tg C yr^{-1}, not including the input of methane and other volatile organic carbon compounds. The total crude oil from the Deepwater Horizon leak was roughly 4.9 M barrels, or 0.54 Tg C yr^{-1}. Release of gases associated with the leak was about half this amount, or 0.27 Tg C yr^{-1}.

Summary and Outlook

Values in this paper should be considered a preliminary carbon budget because some of the key fluxes are missing, either due to lack of data, existing data that are contradictory, or to the fact that we have not yet incorporated existing data and estimates into our budget. These missing fluxes include respiration, rain, and cross-shelf exchange. However since the Gulf is an enclosed basin, cross-shelf exchange is less important in this case than along the other U.S. margins. Data for export fluxes through the Florida Straits are also missing from this preliminary budget.

Measurements and models of air-sea flux show the greatest progress and potential for increasing certainty in the near future. In addition, many thousands of new data sets were collected during the *Deepwater Horizon* leak response by both U.S. federal and academic researchers. Many research efforts for this response will continue over the next few years, and combined, will likely double or triple the data available from U.S. Gulf waters. Additional effort is needed to gather data from the southern Gulf, including coastal, open ocean, and riverine fluxes.

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SIBER

Sustained Indian Ocean Biogeochemistry and Ecosystem Research

A New Basin-wide, International Program in the Indian Ocean

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Introduction to SIBER

Although there have been significant advances in our ability to describe and model the oceanic environment, our understanding of the physical, biogeochemical and ecological dynamics of the Indian Ocean is still rudimentary in many respects. This is partly due to the fact that the Indian Ocean remains substantially under-sampled in both space and time, especially compared to the Atlantic and Pacific Oceans. The situation is compounded by the Indian Ocean being a dynamically complex and highly variable system under monsoonal influence. The biogeochemical and ecological impacts of this complex physical forcing are not yet fully understood (Hood et al. 2008, Hood et al. 2009).

The Indian Ocean is also warming rapidly (Alory et al. 2007, Alory & Meyers 2009), but the impacts of this warming on the biota, carbon uptake, and nitrogen cycling have not been quantified. The increasing population density and rapid economic growth of many of the countries surrounding the Indian Ocean make the coastal environments particularly vulnerable to anthropogenic influences. Warming and anthropogenic effects are also impacting valuable fish species. These influences and their socioeconomic impacts need to be quantified. Understanding the processes that drive biogeochemical and ecological responses to anthropogenic effects is necessary to provide a sound basis for the sustainable management of this globally important ocean. An understanding of these processes is also necessary to predict the impacts and feedbacks of the Indian Ocean as part of the Earth System.

The Sustained Indian Ocean Biogeochemistry and Ecosystem Research (SIBER) program is an emerging basin-wide research initiative sponsored jointly by the Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) program and Indian Ocean GOOS (IOGOOS) with close ties to CLIVAR's Indian Ocean Panel (IOP). The long-term goal of SIBER is to understand the role of the Indian Ocean in global biogeochemical cycles and the interaction between these cycles and marine ecosystem dynamics. This understanding will be required in order to predict the impacts of climate change, eutrophication, and harvesting on the global oceans and the Earth System, and it is fundamental to policy makers in the development of management strategies for the Indian Ocean. To address this goal, emphasis will be given to the analysis required to predict and evaluate the impacts of physical and anthropogenic forcing on biogeochemical cycles and ecosystem dynamics in the Indian Ocean.

SIBER has been motivated by the deployment of new coastal and open-ocean observing systems in the Indian Ocean that have created new opportunities for carrying out biogeochemical and ecological research. The IOP is coordinating the deployment of a basin-wide observ-

ing system in the Indian Ocean (the Indian Ocean Observing System, IndOOS, which includes the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction, RAMA) (International_CLIVAR_Project_Office 2006, McPhaden et al. 2009). Although there are significant challenges, deployment of an array of more 30 buoys is planned in the open ocean between 20° N and 20° S spanning the entire basin. These deployments, which are already well underway, are accompanied by Argo floats and a variety of physical oceanographic survey and mooring support cruises. In addition, several nations in the Indian Ocean are deploying coastal observing systems. All of these programs provide a unique opportunity for staging international, interdisciplinary research. SIBER will leverage these sampling and monitoring activities and it will provide the basin-wide scientific coordination and communication required to predict Indian Ocean biogeochemical cycles and ecosystem dynamics in the context of climate change and other anthropogenic influences.

The SIBER Program reflects the importance placed on these issues by the International Geosphere-Biosphere Program (IGBP), the Scientific Committee on Oceanic Research (SCOR) and the Global Earth Observing System of Systems (GEOSS). SIBER, which has been developed with the guidance and endorsement of the IMBER and IOGOOS Programs, is ambitious and very broad. It is basin-wide, encompasses biogeochemical research from the continental margins to the deep sea and tropic levels ranging from phytoplankton to top predators including fish and humans. SIBER is intended to provide scientific guidance and potential research foci to accommodate the broad (and often regional) interests of many countries that are interested in pursuing research in the Indian Ocean. For more information on SIBER see http://www.imber.info/siber.html.

Recent developments

The draft SIBER Science Plan and Implementation strategy was submitted to IMBER and IOGOOS in January 2010 (Hood et al. 2010). Following peer review, the plan has been given preliminary approval by the IMBER and IOGOOS steering committees, and is now undergoing final editing and revision. The draft plan is available upon request from the first author. Additional comments and input are encouraged and welcome. The final plan is slated for publication in late Fall 2010. The first national SIBER program was recently established in India with funding provided by India's Ministry of Earth Sciences (MoES). Proposals that have been submitted and reviewed include 6 open ocean and 8 coastal/estuarine projects in the northern Indian Ocean.

The timeline for SIBER meetings and symposia that have been convened to date and that are planned for the future are detailed in Figure 1. SIBER convened its first official Scientific Steering Committee (SSC*) meeting (SIBER-1) July 12-15, 2010 in Perth, Australia in a joint meeting with IOGOOS, IOP, and the newly formed Indian Ocean Resources Forum (IRF). This joint meeting brought together leaders in the Indian Ocean research community

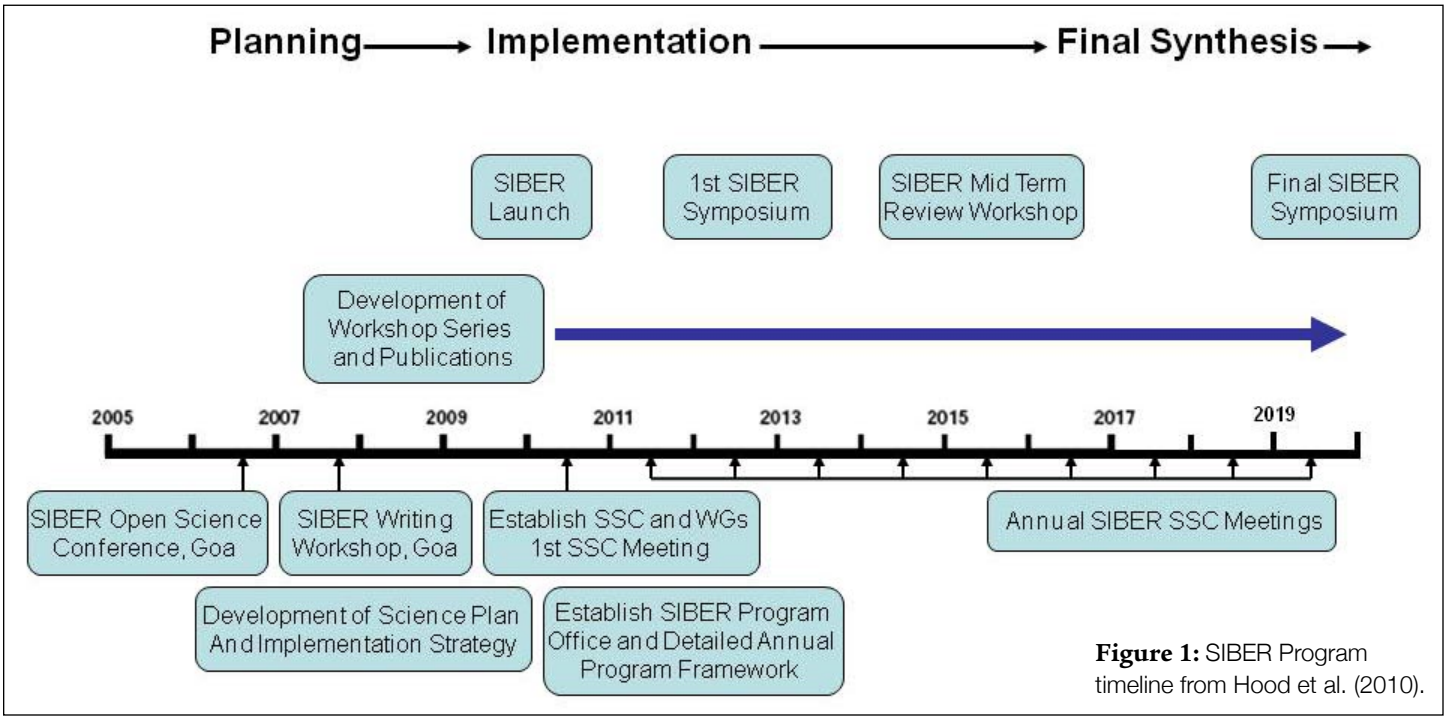

Figure 1: SIBER Program timeline from Hood et al. (2010).

from many Indian Ocean rim nations and from all over the world. The goal of this meeting was to coordinate and facilitate international research efforts in the Indian Ocean.

For SIBER, the major accomplishments and action items from this meeting include:

- Election of officers and establishment of a time frame for SSC member rotations.
- Addition of four new SSC members** recommended by the IMBER and IOGOOS steering committees.
- Review of scientific work, plans and priorities of countries doing biogeochemical and ecological research in the Indian Ocean.
- Development of a strategy for tying SIBER into global carbon cycle research programs.
- Establishment of working groups dedicated to promoting SIBER in the EU, USA, Australia, Africa, Oman/Kuwait/Pakistan, Indonesia/Thailand and Japan/China.
- Establishment of working groups dedicated to updating the SIBER Science Plan scientific themes and questions to ensure that SIBER will continue to focus on the most important scientific questions in the Indian Ocean in the coming years.
- Development of plans to convene a joint SIBER/IOP workshop on biogeochemical sensor requirements for deployment on moorings and Argo floats.

Perhaps the most significant achievement of this meeting was the identification of resources for establishing a SIBER International Project office (IPO). The Secretary of India's Ministry of Earth Sciences (Dr. Shailesh Nayak) and the Director of the Indian National Centre for Ocean Information Services in Hyderabad (INCOIS, Dr. Satheesh Shenoi) have invited the SIBER SSC to develop a proposal for submission to MoES/INCOIS for the establishment of a SIBER IPO in Hyderabad, India. The SIBER SSC is in the process of developing this proposal that will provide specifications and resource needs to establish the IPO. A schematic diagram illustrating the relationships between the proposed SIBER IPO and the IMBER and IOGOOS IPOs, along with oversight and responsibilities, is shown in Figure 2.

*This meeting was attended by Interim SSC members: Raleigh Hood (USA), Wajih Naqvi (India), Jerry Wiggert (USA), Catherine Goyet (France),

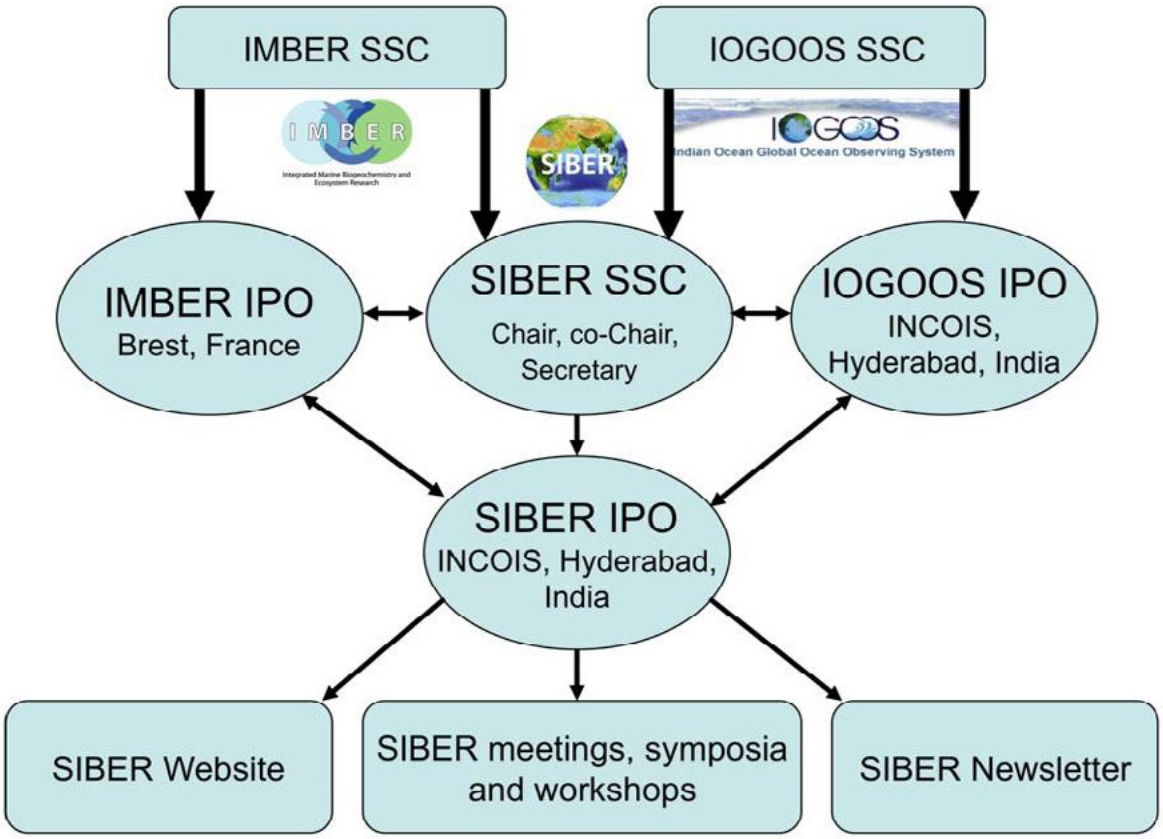

Figure 2: A schematic diagram illustrating the relationships between the proposed SIBER IPO and the IMBER and IOGOOS IPOs along with oversight and responsibilities.

Richard Matear (for Lynnath Beckley, Australia), Greg Cowie (UK), Dwi Susanto (USA/Indonesia), Adnan Al-Azri (Oman), Hiroshi Kitazato (Japan), and Tim Rixen (Germany). Interim SSC members Mike Landry (USA) and David Vousden (South Africa) were unable to attend.

**New SSC members: M. Ravichandran (India), Mitrasen Bhikajee (Mauritius), Shiham Adam (Maldives) and Somkiat Khokiattiwong (Thailand).

Legacy

The coordination and integration of Indian Ocean biogeochemical and ecosystem research through SIBER will advance our knowledge of this under-sampled basin and provide a major contribution to the understanding of how regional and global change may impact biogeochemical cycles and ecosystem function, not only in the Indian Ocean, but in the Earth System, creating a lasting legacy upon which future research can be built. The scientific findings will inform scientists in the international community and provide a focus for future research on important regional, basin-wide, and global issues. These findings will also provide policy makers with the sound scientific basis upon which to make decisions on the management of Indian Ocean ecosystems. SIBER will leverage and strengthen GOOS and IMBER by promoting coordinated international, multidisciplinary research in developed countries, and also human resources and infrastructure development in many developing Indian Ocean rim countries.

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Reflections of an MBARI 2010 Summer Intern

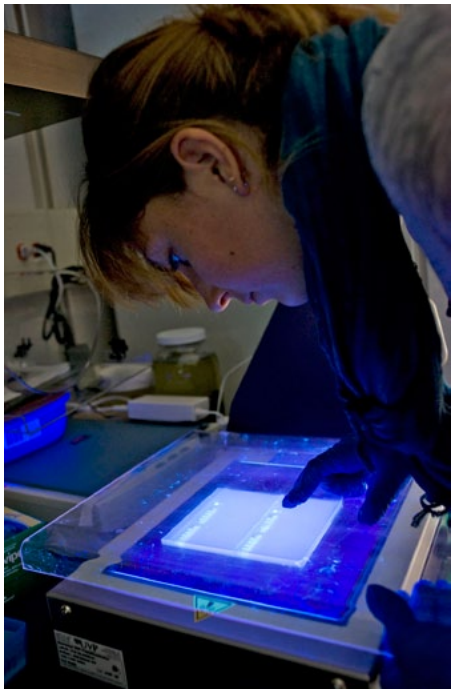
by Sara Thomas, University of Hawai'i

The summer of 2010 was when I stepped away from my familiar playing grounds and entered an unexplored science, microbial oceanography. I was leaving my University of Hawai'i (UH) home base and entering a new playing field, the Monterey Bay Aquarium Research Institute (MBARI). Having earned my Bachelor of Science in Global Environmental Science and completed an undergraduate thesis project in terrestrial geochemistry, the MBARI summer internship program would be my first opportunity to be part of a marine science research team. This was the field I want to practice in graduate school but I did not have a specific research topic in mind that I knew I wanted to pursue. I was interested in multiple disciplines of oceanography so I applied to my top three choices of research projects offered by the internship program with faith that MBARI would coach me into discovering a specific research topic to pursue in graduate school.

When I received my acceptance into the summer internship program I was ecstatic and honored to be one of the 17 chosen for the 2010 MBARI summer internship team. The program only had funding for 12 interns but was able to accommodate additional interns who were sponsored by other institutions. The Center for Microbial Oceanography: Research and Education (C-MORE) supported my spot on the intern team. This was my chance to not only step out onto a new research field but to do so at a leading oceanographic institution with an experienced C-MORE post-doc from the University of California at Santa Cruz to coach me one-on-one for 10 weeks.

I was selected to work on the Environmental Sample Processor (ESP) project. On this project I practiced the process of designing and optimizing molecular assays for the ESP. The ESP is a revolutionary electromechanical fluidic machine that collects discrete sub-surface water samples and applies molecular probes to identify microbes and their functional gene expressions, all *in-situ.* The instrument also archives samples that can be analyzed after a maximum deployment of approximately 30 days. The ESP is a big upcoming player for microbial oceanography and marine biogeochemistry. My internship at MBARI was an opportunity to learn how this instrument works. I attempted to design molecular assays to target the functional gene expression *idiA* in the species *Synechococcus,* and optimize the *nifH* assays developed by Matt Church at UH for future implementation on the ESP at station ALOHA. But more importantly, this was the summer that would entice me to the microbial and biogeochemistry disciplines of oceanography, fields I honestly never thought I would pursue.

It was a challenging summer. I was on unfamiliar turf as a new player on the well-established ESP team, stepping into not only a completely new lab at a different institution, but in an untried field too. I didn't have prior microbiology training, in a classroom or in research, or an engineering background. Yet there I was at MBARI, taking a swing at a research project that directly dealt with microorganisms and advanced micro fluidics technology.



My mentor, Julie Robidart, was my MVP throughout the summer. Her passion for microbial oceanography made her more than willing to teach me everything I needed to know to make it to home base on the ESP project. When I first stepped onto the MBARI field she coached me every step of the way, and before we knew it, her expertise gave me the confidence I needed to round all the bases of the ESP lab on my own. It was a rewarding experience for both of us. My experience at MBARI was further enhanced by the program coordinators George Matsumoto and Linda Kuhnz, who did an excellent job organizing the program and providing interns with support and encouragement throughout the ten weeks. Together we all made a great team!

Important OCB Dates

- **December 11–12, 2010:** Coastal Synthesis Workshop (San Francisco, CA)
- **March 22–24, 2010:** 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)

OCB Summer Workshop Report

Ecosystems and biogeochemical cycling in a changing ocean

July 19–22, 2010 (La Jolla, CA)

by Heather Benway

The 5th annual OCB summer workshop, co-sponsored by the NSF, NASA, and NOAA, convened 107 participants at the Scripps Institution of Oceanography in La Jolla, California July 19-22, 2010. The workshop opened with a session on the Arctic, which is undergoing rapid changes in response to warming, accelerated melting of large ice sheets, and reductions in seasonal sea ice cover. This session included two presentations that addressed implications of increasing sea ice melt for sea surface CO_2 and carbonate ion concentrations in the western Arctic Ocean. Another presentation focused on recent observations of seasonally changing aragonite saturation in the northern coastal Gulf of Alaska. Moving into the Bering Sea, a speaker described the impact of decreasing sea ice extent on autotrophs, including primary productivity, export, and community composition.

Many models are predicting a significant expansion of oxygen minimum zones (OMZs) in response to increasing anthropogenic CO_2 emissions, which will affect marine productivity, carbon and nutrient cycling, and food webs. A plenary session on low-oxygen regions opened with a characterization of key features of the biological pump in open-ocean OMZs. Another presentation described the adaptations of and physiological challenges facing benthic organisms in upwelling OMZs. Shifting the focus to coastal regions, one speaker illustrated the increasing incidence of coastal hypoxia related to anthropogenic nutrient loading and subsequent eutrophication, and provided an overview of insights gained from the application of molecular biological and stable isotope techniques to detect and differentiate key transformations in the marine nitrogen cycle. The final speaker in the session described global, regional, and paleo-modeling approaches to explore the implications of expanding OMZs for marine biogeochemical cycles.

Benthic and pelagic ecosystems are inextricably linked by way of biogeochemical cycling and transformation, and benthic-pelagic coupling along continental shelves represents a significant unknown in coastal carbon budgets. A plenary session on benthic-pelagic interactions opened with a presentation on molecular approaches that have improved understanding of marine nitrogen and carbon cycling and community structure in the intermediate nepheloid layer of OMZs. To assess the role of benthic oxygen consumption in seasonal hypoxia on the Oregon Shelf, the next speaker described the application of an eddy correlation method to quantify benthic oxygen exchange rates. Another presentation focused on the application of stable isotope tracers and linear inverse modeling to better understand carbon cycling in benthic marine food webs. Using data from time-series sediment traps in the Gulf of Maine, the final speaker illustrated the importance of benthic nepheloid layer processes to carbon cycling in continental margins.

The meeting also included presentations on the carbon sink potential of vegetated coastal ecosystems; regional updates on the North American coastal synthesis activities; overviews of recent ocean acidification, ocean fertilization, and Gulf of Mexico oil spill activities; community discussions of the next U.S. Carbon Cycle Science Plan; and partner program and agency updates. For further information, including access to archived webcasts and presentations given at the workshop, please visit the workshop website.

OCB Scoping Workshop Report

Sea change: Charting the course for ecological and biogeochemical ocean time-series research

September 21-23, 2010 (Honolulu, HI)

by Heather Benway, Kendra Daly, and Laura Lorenzoni

Apart from the whirlwind of hurricane activity in September that wreaked havoc with several participants' travel plans, the time-series workshop was a great success, thanks to the capable leadership of the workshop steering committee: Matthew Church (University of Hawaii), Frank Muller-Karger (University of South Florida), Mike Lomas (Bermuda Institute of Ocean Sciences), Sue Banahan (Consortium for Ocean Leadership), Ken Johnson (Monterey Bay Aquarium Research Institute), and Laura Lorenzoni (University of South Florida). The workshop convened participants from academia, supporting agencies, and other U.S. and international time-series and observing programs. The goals of this workshop were to:

- synthesize ongoing research at U.S. OCB time-series sites (HOT, BATS, CARIACO);
- identify potential areas of improvement, including strengthened connections to other marine biogeochemical time-series and observing activities; and
- generate a prioritized list for future activities at the sites.

The meeting opened with summaries of scientific highlights by the PIs from each time-series site, which set the stage for an ongoing community discussion of future scientific priorities and activities. Participants identified scientific questions related to ecosystem structure and dynamics driven by spatial (e.g., mesoscale features like eddies) and temporal (e.g., episodic events) scales that could be effectively addressed with the time-series. There was a discussion of current and emerging technologies that could be incorporated at the time-series sites (e.g., moorings), as well as the need to use existing historical data sets from the sites to their fullest potential. Participants recommended that the time-series sites continue ship-based measurements and expressed the need for improved and more extensive modeling efforts and flux estimates, along with better integration and synthesis across the time-series sites. They also highlighted the importance of time-series sites as 'training facilities' for up-and-coming oceanographers.

The presentations and working group discussions on the Ocean Observatories Initiative (OOI), European marine observatories, autonomous platforms, and satellite- and ship-based time-series clarified the role of the OCB time-series sites as part of a global observing system. Participants recommended leveraging and strengthening ties to existing U.S. and international time-series and observing programs to the extent possible. A workshop report is in preparation. For more information, please visit the workshop website.

OCB Website Developments

» NEW OCB Policies and Procedures document available on OCB website: The OCB Project Office and the OCB Scientific Steering Committee (SSC) recently developed a document for the community that describes OCB's programmatic mission, objectives, and operating procedures

» OCB adds expanding low oxygen conditions to its list of scientific priorities

» Submit your peer-reviewed publications to the OCB website

» Informational OCB page on the Gulf Oil Spill

New Community Resources

Research Tools

» Revised GO-SHIP Repeat Hydrography Manual

» Matlab Toolbox to Perform Secondary Quality Control (2nd QC) on Hydrographic Data published at CDIAC

» Alliance for Coastal Technologies (ACT) releases technology evaluations of four pCO_2 analyzers (PMEL MAPCO2/Battelle Seaology pCO2, Contros HydroC/CO2, Sunburst SAMI-CO2, Pro-Oceanus Systems PSI CO2-Pro)

» Regional Carbon Cycle Assessment and Processes (RECCAP)

continued on next page...

Related Project News

IOCCP

- Report from the Southern and Indian Ocean Surface Ocean CO_2 Atlas (SOCAT) Workshop (16-18 June 2010, Hobart, Tasmania) now available

IMBER and SOLAS

- Plenary presentations from the IMBER IMBIZO II to be posted on the meeting website and presentations from the Dry Cruise interactive training workshop on good data management practices are now available here.
- **Upcoming IMBER/SOLAS special joint sessions:**
  - **ASLO 2011 Aquatic Sciences Meeting** (*February 13–18, 2011, San Juan, Puerto Rico*) - S28: Biogeochemical, Ecological and Physical Dynamics of Eastern Boundary Upwelling Systems
  - **European Geosciences Union (EGU) General Assembly 2011** (*April 3–8, 2011, Vienna, Austria*) - Session OS3.1: Sensitivity of marine ecosystems and biogeochemical cycles to global change

NACP

- AmeriFlux Science Meeting & 3rd NACP All-Investigators Meeting (January 31–February 4, 2011, New Orleans, LA) – Pre-registration deadline is **December 10, 2010**!

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

New Community Resources, cont.

White Papers, Articles, and Reports

» U.S. Group on Earth Observations (USGEO) report on earth observations

» *Science Daily* article: Speed installation of system to monitor vital signs of global ocean, scientists urge (Partnership for Observation of the Global Oceans (POGO))

» Report from the CAMEO Workshop on End-to-End Modeling of Marine Ecosystems

» Community White Paper: A Call for a Global Biogeochemical Fluxes Program for the Ocean Observatories Initiative (OOI)

Journal Special Issues

» *Biogeosciences* special issue: Hypoxia

» *Biogeosciences* special issue: The Ocean in the High-CO_2 World II

» Ecological and Biogeochemical Interactions in the Dark Ocean. Edited by D. K. Steinberg and D. A. Hansell, *Deep-Sea Research Part II* 57 (16), 1429-1592 (15 August 2010)

» Special Issue of *Oceanography* "Celebrating 50 Years of the Intergovernmental Oceanographic Commission"

Education and Outreach

» 3rd CarboSchools booklet "Global Change: From research to the classroom" to be released in Dec. 2010

The 2010 USA Science and Engineering Festival OCB & ASLO team up for outreach success

by Sarah Cooley (WHOI)

Nine hundred straws	☑
Slocum glider	☑
Two gallons of red cabbage juice	☑
Zip ties	☑
Plankton net	☑
Granola bars	☑
Go-flo bottle	☑
Duct tape	☑

That's just a sample of the pre-trip supply checklist that helped the ASLO-OCB booth become a smashing success at the October 23-24 USA Science and Engineering Festival in Washington, DC, on and around the National Mall. All types of scientists — cheerleaders with science degrees, science comedians, and many more — spent the weekend educating children and adults about science, technology, engineering, and math.

ASLO and OCB collaborated to host one of the 1500 festival booths that offered hands-on science to visitors of all ages. With the slogan "Watching water to probe the planet" prominently displayed on our booth's banner, we aimed to introduce visitors to several aquatic observing methods and what we have learned from them. We showed off classic and cutting-edge observing technologies such as plankton nets, Go-flo bottles, Argo floats, and Slocum gliders, and we showed examples of their data on a variety of posters. We also used a hands-on activity to introduce visitors to ocean acidification, one of the phenomena uncovered by such observing efforts.

We adapted the hands-on activity from the OCB science lab "Ocean acidification in a cup." Visitors of all ages chose a cup containing fresh water or artificial seawater plus red cabbage juice (a great nontoxic pH indicator) and blew bubbles through the liquid with a straw to see how difficult it is to "acidify" a water sample with carbon dioxide. Most people were surprised at how easily they could change the pH of their liquid samples! To connect this activity to what people already knew about acids and bases, we also displayed examples of household fluids plus cabbage juice that spanned the pH range and invited them to compare their observations to this "standard curve." Even the youngest visitors enjoyed matching up the colors and bubbling into their cups.

H. Benway (left) and S. Cooley (right) teach the masses about ocean acidification.

Throughout the weekend, we found countless ways to connect aquatic science with visitors' interests. With visitors who wanted to compare the acidification responses of the two water types, we talked about differences between lakes and oceans. When experimenters competed to see who could acidify their sample the farthest or the fastest, we'd talk about what model forecasts actually predict, and how carbon dioxide's behavior ultimately limits ocean acidification. When someone asked about the Go-flo bottle, we'd talk about field research. When the Slocum glider caught

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From left to right: H. Benway, A. Sponberg, D. Bronk, and S. Cooley wield Slocum glider shell that Oscar Schofield (Rutgers) generously loaned us for the Festival – a big hit among children and adults!

The 2010 USA Science and Engineering Festival OCB & ASLO team up for outreach success, cont.

someone's eye, we told them a bit about how ocean engineering technologies can be simple and elegant, yet provide more data than thousands of ships combined.

We estimate that 500-600 visitors stopped at our booth over the two-day festival. This meant a very busy two days for the booth's organizers, ASLO's Debbie Bronk and Adrienne Sponberg, and OCB's Heather Benway and Sarah Cooley. We couldn't have done it without the generous participation of Susan Banahan and Marti Snyderwine, who helped us through the midday rush hours. Festival organizers are tentatively planning for a second USA Science and Engineering Festival in 2012, so consider teaming up with us then to highlight your science. You never know—you may just find a future graduate student!

EPOCA, BIOACID and UKOARP 2010 Annual Meeting 2010

Largest Ocean Acidification meeting to date held in Bremerhaven, Germany

by Claudine Hauri, EPOCA student representative

In September 2010, 230 scientists involved in EPOCA (European Project on Ocean Acidification), BIOACID (Biological Impacts of Ocean ACIDification, Germany) and/or UKOARP (UK Ocean Acidification Research Programme) participated in the largest meeting to date on ocean acidification. The meeting provided an opportunity to share the latest research and to bridge interdisciplinary work. A primary focus of the meeting was the physiological response of micro- and macroorganisms exposed to changes in carbon chemistry. Additional topics included observations of local changes in biogeochemistry, paleo-reconstruction of ocean carbon chemistry, and biogeochemical/ecological modeling.

CarboSchools, a program that fosters partnerships between climate researchers and secondary school teachers, is a unique component of all three projects that integrates cutting edge scientific research with education of school children across Europe. Direct interaction between children and scientists, including live documentation of ongoing experiments in Svalbard helped to increase the interest and awareness of rising atmospheric CO_2 and its consequences.

One full day of the meeting was dedicated to Ph.D. students and early career scientists. This gathering attracted 70 students and early career scientists. It was an ideal platform to present preliminary results. The informal setting encouraged open discussions and fostered collaborations among young scientists. As successful as it was, it could be a model for future student meetings.

Please feel free to visit the EPOCA website to read more about the meeting:
http://www.epoca-project.eu/index.php/what-do-we-do/meetings/epoca-2010-meeting.html

Or about CarboSchools:
http://www.carboeurope.org/education/index.php

Claudine Hauri
EPOCA student representative
Ph.D. candidate, ETH Zurich, Switzerland
claudine.hauri@env.ethz.ch

OCB to host Ocean Acidification PI meeting in Spring 2011

The OCB Project Office and OCB ocean acidification subcommittee are planning an invited workshop for lead investigators of funded ocean acidification-related research projects to promote dialogue and build relationships among scientists from all disciplines, agency affiliations, and regions. To aid the development of the national ocean acidification research program, we seek to bring the community together while many ocean acidification research projects in the U.S. are still in their early phases to foster collaborations that will maximize all outcomes of the research: the scientific findings themselves, the associated education and outreach activities, data management efforts, and future research planning. Events will include overview talks, poster sessions, breakout sessions, plenary discussions, and flash introductions. Representatives from international programs will also provide information on collaborative opportunities between U.S. and international researchers. This meeting will be held March 22-24, 2011 at the Woods Hole Oceanographic Institution in Woods Hole, MA.

Ocean Acidification News Headlines

OCB ocean acidification website sees 10- to 20-fold increase in site visits following the release of the ocean acidification FAQs

» **New and improved NOAA Science on a Sphere (SOS) ocean acidification content:** Sarah Cooley (OCB Project Office) has been working to improve the visual presentation of ocean acidification data for NOAA SOS to make it more accessible to a broad range of museum visitors, and she has also developed an accompanying script to help docents explain the concepts behind the datasets that appear on the sphere. These improvements are coming soon to a "sphere" near you.

» The National Science Foundation announces recipients of grants to study ocean acidification

» National Research Council report "Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean" available now

» Third Symposium on the Ocean in a High CO_2 World to take place in Autumn 2012 in Monterey, CA

» Dr. Richard Feely receives Heinz award

» UK Ocean Acidification Research Programme formally launched

» Funding opportunity for US-UK exchange visits

» **Ocean Acidification—A new guide for non-specialists:** The Ocean Acidification Reference User Group (RUG) has released a new document about ocean acidification entitled "Ocean acidification: Questions answered" that is targeted to non-specialists. The document draws from the longer OCB-EPOCA-UKOARP-BIOACID "Frequently Asked Questions about Ocean Acidification," and provides information about some of the more technical questions the public is asking about ocean acidification. It has been translated into 5 languages for wide circulation.

» IMBER/SOLAS Working Group on Ocean Acidification to meet with U.S. program and science managers November 30, 2010 in Washington, DC to explore joint international activities

» **IMBER/SOLAS Working Group on Ocean Acidification invites contributions for a map- and web-based overview of ocean acidification research:** Prior to release of the web site, researchers can contribute ocean acidification research locations for inclusion in the site and send suggestions for web site features to Jim Barry (barry@mbari.org). Please provide the following information:

- project title
- latitude
- longitude (decimal degrees)
- depth (m)
- investigator
- research focus (e.g. physiology, chemical oceanography, growth rates, calcification)
- taxon (taxa)
- start date
- end date
- web link

» **Ocean acidification research cruise opportunities in 2011 and 2012:** Three ocean acidification research cruises will be run as part of the UK Ocean Acidification Research Programme:

- **CRUISE 1:** June–July 2011, around the UK & Ireland including North Sea, Skagerrak, English Channel, Celtic and Irish Seas, NE Atlantic and the Bay of Biscay.
- **CRUISE 2:** July–Aug 2012, Arctic Ocean including Greenland, Iceland & Barents Seas, Fram Strait and vicinity of Svalbard.
- **CRUISE 3:** Jan–Feb 2012, Southern Ocean including across Drake Passage, Scotia Sea, Weddell Sea ice-edge, NW of South Georgia.

Observational measurements of various environmental and response variables will be made on all three cruises, including carbonate chemistry, nutrients, light, etc and biological and biogeochemical properties and rates. Bioassay experiments will be conducted at a range of different CO_2 levels, in a customized laboratory container allowing temperature and light climates to be controlled. Three separate types of bioassay will be conducted in parallel, for bacteria, phytoplankton and zooplankton. We are keen to consider requests from international scientists to participate, although berths will be limited. Spare berths will be allocated based on the interest of the proposed science and how well it fits in with what we are already planning. For more information, please contact Toby Tyrrell (Toby.Tyrrell@soton.ac.uk).

OCB Calendar

2010	
December 7–9:	Second International Symposium on Arctic Research (ISAR-2) — Arctic System in a Changing Earth (Tokyo, Japan)
December 11–12:	Coastal Synthesis Workshop (San Francisco, CA)
December 13–17:	Fall American Geophysical Union Meeting (San Francisco, CA)
2011	
January 10:	NASA Carbon Monitoring System Community Forum (Washington, DC)
January 19–21:	National Council for Science and the Environment (NCSE)'s 11th National Conference on Science, Policy and the Environment: Our Changing Oceans (Washington, DC)
January 31–February 4, 2011:	Ameriflux and NACP All Investigators Meeting (New Orleans, LA)
February 13–18:	ASLO 2011 Winter Meeting: Limnology and Oceanography in a Changing World (San Juan, Puerto Rico)
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 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 3–6:	43rd International Liege colloquium on ocean dynamics (Liege, Belgium)
May 23–25:	OCB Scoping Workshop: "A Biogeochemical Flux program aligned with the Ocean Observatories Initiative" (Woods Hole, MA)
June 20–24:	7th EGU Alexander von Humboldt Conference on "Ocean Acidification: Consequences for marine ecosystems and society" (Penang, Malaysia)
July 3–7:	11th International Conference on the Biogeochemistry of Trace Elements (Florence, Italy)
July 18–21:	Annual OCB Science Workshop (Woods Hole, MA)
July 19–21:	2011 US CLIVAR Summit (Woods Hole, MA)

OCB Calendar (continued)

2011 (continued)	
August 29–September 10:	SOLAS Summer School 2011 (Corsica, France)
September 12–15:	LOICZ Open Science Conference 2011: "Coastal Systems, Global Change and Sustainability" (Yantai, China)
September 26–30:	World Conference on Marine Biodiversity (Aberdeen, Scotland)
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)

2010/2011 Funding Opportunities

- **November 30:** 2010 UK-US collaboration development award program (contact: maike.rentel@fco.gov.uk)
- **December 1:** NASA ROSES 2010 - A4. Land Cover/Land Use Change NOI deadline
- **December 9:** NSF Dynamics of Coupled Natural and Human Systems (CNH) proposal deadline
- **January 7:** Comparative Analysis of Marine Ecosystem Organization (CAMEO) proposal submission deadline
- **January 27:** NSF Major Research Instrumentation proposal deadline
- **February 15:** NSF Biological and Chemical Oceanography proposal targets
- **March 1:** NSF Catalyzing New International Collaborations proposal target
- **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

OCB News

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