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HOT turns 25: A quarter century of Hawaii Ocean Time-series measurements in the North Pacific Subtropical Gyre

Matthew J. Church, Karin M. Björkman, David M. Karl
Department of Oceanography, University of Hawaii

In October 2013, the Hawaii Ocean Time-series (HOT) program celebrated its 25th anniversary. Through sustained support from the U.S. National Science Foundation (NSF), HOT has become one of the longest running, U.S.-led ocean time-series programs in the world. Over the past quarter century, HOT has maintained near-monthly shipboard and laboratory measurements to quantify the biogeochemical and hydrographic state of the North Pacific Subtropical Gyre (NPSG). The primary study site for HOT, Station ALOHA (A Long-term Oligotrophic Habitat Assessment, 21° 45´N, 158° W), now serves as a vibrant outpost for numerous research projects. The resulting HOT measurements provide insight into the time-varying interactions among ocean-climate, elemental cycling, and plankton ecology across seasonal to subdecadal scales. Moreover, the long-term record on time-varying change in the ocean's carbonate system documents progressive decreases in seawater pH and steady increases in the partial pressure of CO_2 (pCO_2). In this article, we describe a few of the many contributions of HOT science to our understanding of ocean variability, highlighting some of the people that have devoted a major fraction of their lives over the past quarter century to the program.

From A Need to Action

By the early 1980s, the power of time-series for capturing changes in the climate system had already been established. Decadal-scale measurements of UV radiation impinging on the surface of the Earth had been instrumental to attributing depletion in stratospheric ozone to emissions of chlorofluorocarbons. Time-resolved measurements from the Hubbard Brook Experimental Forest were used to demonstrate linkages between wet deposition of atmospheric pollutants and long-term alteration of terrestrial soils and streams in the northeastern United States. By 1983, Keeling's measurement program of atmospheric CO_2 at the Mauna Loa Observatory in Hawaii was celebrating its silver anniversary, focusing attention on the rapid rate of anthropogenic perturbation of the global carbon system. In the

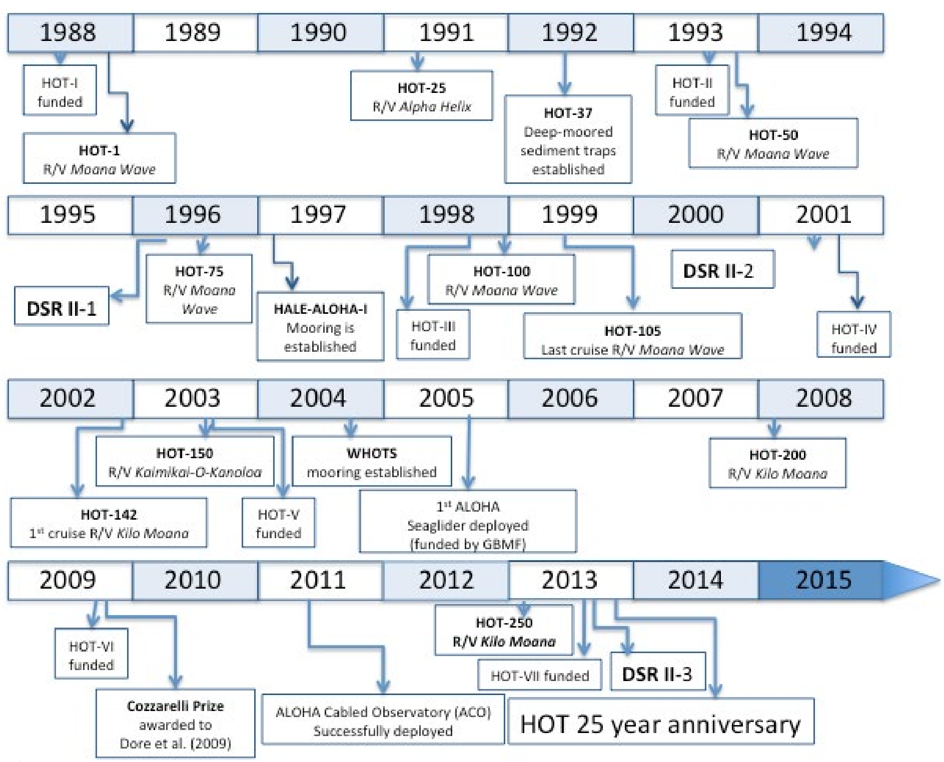

Figure 1. Timeline of major milestones and events in the 25-year history of the HOT program.

oceans, Henry Stommel's measurements at Hydrostation S, together with Werner Deuser's sediment trap record of sinking particles, were increasingly valuable for informing our understanding of the coupling between ocean physics and carbon flux in the open ocean. Such examples, among many others, clearly demonstrated the power of time-series for identifying planetary change. By the mid-1980s, the oceanographic community recognized the need for a comprehensive program(s) to assess ocean change and began formulating plans for the Global Ocean Flux Study (GOFS; later expanded internationally and renamed the Joint Global Ocean Flux Study, JGOFS) and the World Ocean Circulation Experiment (WOCE). Central among the plans for these large, international programs was the recognition that quantifying changes in ocean-climate and carbon cycling would require high-quality, long-term time-series observations.

In 1987, scientists from the University of Hawaii (UH) and the Bermuda Biological Station for Research submitted three separate proposals to the NSF to initiate HOT and BATS in the NPSG and Sargasso Sea, respectively. David Karl (PI) and Chris Winn (co-PI) led the JGOFS-focused biogeochemistry HOT proposal; and Roger Lukas (PI), Steve Chiswell (co-PI), and Eric Firing (co-PI) led a physical oceanography proposal focused on WOCE program objectives. By the summer of 1988, both the JGOFS and WOCE program elements were awarded and the first HOT expedition to Station ALOHA was underway aboard the R/V *Moana Wave* on October 29, 1988 (Figure 1). HOT cruise 1 sailed with a science party of 10 people, several of whom remain actively involved in the program today.

Fast forward to March 9, 2013, a team of 24 scientists led by Fernando Santiago-Mandujano (University of Hawaii) returned aboard the R/V *Kilo Moana* from successful completion of the 250th HOT cruise to Station ALOHA. Over the past quarter century, HOT has grown to become an internationally recognized fixture in the ocean sciences, providing some of the only multi-disciplinary, long-term records of changes in marine biogeochemistry and hydrography in the open sea. Although programmatically, HOT has evolved through time to meet the needs of the oceanographic community, the underlying science objectives and major methodological and sampling approaches have remained largely unchanged since 1988. Foremost among the program's objectives are:

1. Quantify time-varying (seasonal to decadal) changes in reservoirs and fluxes of carbon and associated bioelements
2. Identify processes controlling fluxes and transformation of carbon from the sea surface to the ocean's interior
3. Sustain high-quality measurements to elucidate time-varying interactions among ocean-climate, biogeochemistry, and plankton ecology

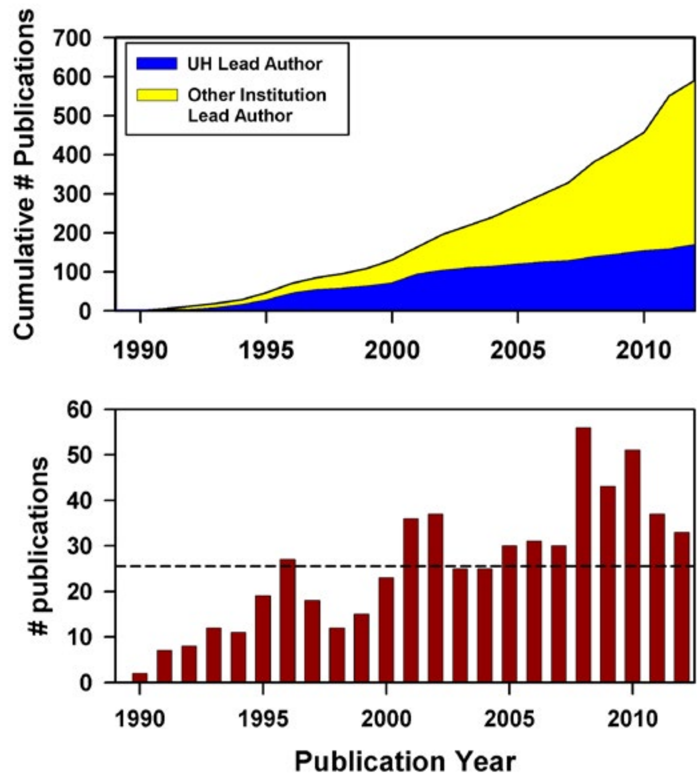

Figure 2. Top: Summary of cumulative HOT publications depicting number of papers led by people from the University of Hawaii relative to those led by people at other institutions. **Bottom:** Total number of HOT publications in each year of the program (1989-2012).

The resulting 25 years of near-monthly observations provide a unique record from which to decipher trends and anomalous behavior in the NPSG habitat. The resulting data have been used in nearly 600 publications, with ~70% of these publications led by scientists outside of UH (Figure 2). Further evidence of the growing value of HOT data can be found in the recently released Intergovernmental Panel on Climate Change (IPCC) Working Group I Assessment Report 5, where the HOT CO_2 and pH time series records are highlighted both in the full report and in the Summary for Policy Makers.

HOT focuses its sampling efforts at Station ALOHA, a site defined as a 10-km radius circle located ~100 km north of the Hawaiian Island Oahu. ALOHA is a deep ocean site (~4750 m), selected in part because it resides more than one Rossby radius (~50 km) north (upwind) of the Hawaiian ridge topography, minimizing the influences of the islands on biogeochemical and physical dynamics at this location (1). Each cruise follows an intensive, routine sampling schedule that includes conducting a "test" station (Station Kahe) in the lee of Oahu to assure the shipboard and laboratory instrumentation are operating properly, and to provide a hands-on training opportunity for novice members of the scientific party to practice deploying and recovering shipboard equipment and to "shadow" the more experienced science party members during sampling. Following a ~10-hour steam to ALOHA, a series of tightly coordinated events follows, including deployment of free-drifting sediment traps to passively collect sinking particles over a ~72-hour period; a series of "burst" CTD hydrocasts (0-1000 m) conducted every three hours over a 36-hour period to resolve the impact of internal tides on the vertical structure of hydrographic and biogeochemical properties; two near-bottom (0-4750 m) CTD hydrocasts; three daytime and three nighttime zooplankton net tows; bio-optical characterization of the upper ocean (0-200 m); and deployment and recovery of free-drifting *in situ* arrays to conduct key plankton rate measurements (*e.g.*, ^{14}C-bicarbonate assimilation). The core suite of sampling on each cruise includes discrete measurements of dissolved inorganic carbon concentrations, total alkalinity, pH, nutrients (using both "standard" auto-analyzer-based methodologies and high-sensitivity techniques), oxygen, total organic carbon, phytoplankton pigments, various measures of cellular biomass, and particulate matter composition (carbon, nitrogen, phosphorus, and silica concentrations). To facilitate distribution and wider public use of program data, HOT has been proactive about developing a user-friendly public database termed HOT-DOGS (Hawaii Ocean Time-series Data Organization and Graphical System), which allows visualization and retrieval of program data. Program data are also available through the NSF-supported Biological and Chemical Oceanography Data Management Office (BCO-DMO).

HOT Science: Plankton, Carbon, and Change

HOT measurements demonstrate that the euphotic zone of the NPSG is a persistently oligotrophic habitat, due in part to weak vertical entrainment of nutrients and rapid plankton growth fueled by perennially abundant solar energy. Microorganisms dominate plankton biomass at Station ALOHA, with picoplankton abundances in the near surface ocean ranging from 4×10^5 to 1×10^6 cells ml^{-1}. HOT has been fortunate to build strong science partnerships that have enabled complementary measurements on the diversity, activities, and dynamics of these microorganisms. These "ancillary" science programs have provided complementary information that has contributed to our understanding of processes underlying time-varying dynamics observed in the HOT record. A major fraction (40-50%) of these cells are cyanobacteria belonging to the genus *Prochlorococcus*. These tiny (<1 mm in diameter), oxygenic, unicellular picoplankton appear responsible for >50% of the daily photosynthetic carbon fixation. However, at the onset of HOT, these abundant organisms were almost wholly unknown to science - their discovery in 1988, the same year HOT began, fundamentally altered our views of ocean ecology and biogeochemistry in the NPSG. Since that discovery, we now recognize multiple co-existing but distinct ecotypes of *Prochlorococcus* as stable inhabitants of the euphotic zone at Station ALOHA.

In addition to *Prochlorococcus*, several genera of non-chlorophyll-containing picoplankton, including members of the Archaea (both Euryarchaea and Thaumarchaea); α-, β-, γ-, and δ-Proteobacteria; Bacteroidetes; Verrucomicrobia; and Actinobacteria are abundant components of the microbial community. When HOT commenced sampling at ALOHA, the paradigm of the microbial loop provided the foundation for our understanding of the ecological interactions of these microorganisms. We now know that broadly lumping these groups of microorganisms together as either "autotrophs" or "heterotrophs" based on the presence or absence of chlorophyll *a* is far too simplistic. These diverse groups of microorganisms rely on equally diverse forms of metabolism that include photoheterotrophy, organoheterotrophy, and chemoautotrophy. Even organisms like *Prochlorococcus*, generally assumed to be a "plant-like photoautotroph", appear to rely on mixotrophic metabolisms, consuming organic matter while actively photosynthesizing. Many of the important discoveries describing previously uncharacterized microbial metabolisms derive from measurements conducted at Station ALOHA (*e.g.*, 2-4).

The time-resolved sampling approach has provided the opportunity to construct annual mass balances of key bioelements, including carbon, oxygen, and nitrogen. As a result, ALOHA has become one of the best characterized open ocean habitats on the planet for quantifying processes influencing inventories and fluxes of bioelements (*e.g.*, net community production, air-sea gas exchange, vertical and lateral entrainment, etc.). Despite the persistent lack of inorganic nutrients, estimates of net community production (NCP) range from 1.1 to 4.0 mol C m^{-2} yr^{-1}, rates comparable to moderately eutrophic aquatic ecosystems. Such measurements imply active supply of nutrients to the euphotic zone waters, and HOT has devoted considerable effort to identifying the source pathways for these nutrients, and how (and why) these pathways vary in time. Among the processes to receive the most attention are nitrogen fixation and vertical entrainment of nitrate into the euphotic zone. Technological advancements have facilitated such studies; profiling floats, gliders, and moorings have been equipped with biogeochemical sensors (pH, nitrate, oxygen, fluorescence) to quantify the impact of high-frequency mesoscale events on carbon, nitrogen, and oxygen budgets at ALOHA (*e.g.*, 5-7).

With 25 years of sustained observations, HOT data are becoming increasingly useful for examining interannual- to subdecadal-scale changes in ocean biogeochemistry and physics. There are clear examples of natural and anthropogenic changes to the NPSG ecosystem. Mixed layer pCO_2 is increasing at the same rate that atmospheric CO_2 is increasing (~1.8 matm yr^{-1}), with dissolved inorganic carbon concentrations increasing at ~1 µM C yr^{-1}. These long-term trends show no signs of abating. Natural climate processes also impart signatures on ecosystem dynamics at ALOHA and teasing apart the interconnected influences of anthropogenic and natural climate variability remains a central challenge for Earth sciences and demands long-term time-series observations. The HOT record also provides examples of how regional- to basin-scale climate variability influence ecosystem behavior and carbon fluxes. For example, interannual changes in the regional evaporation-precipitation balance partly regulate air-sea CO_2 fluxes (8); seasonal to interannual changes in the positioning of the equatorial currents and the subtropical convergence zone influence ecological and biogeochemical dynamics (9); subdecadal to decadal fluctuations in basin-scale climate patterns (*e.g.*, Pacific Decadal Oscillation, North Pacific Gyre Oscillation, ENSO) appear to alter stratification and nutrient supply with concomitant changes to plankton community structure and material export out of the euphotic zone (10, 11). In the early- and mid-2000s, subdecadal fluctuations in mixed layer temperature and salinity at ALOHA coincided with basin-scale shifts in ocean-climate (as manifest through the North Pacific Gyre Oscillation; Figure 3). Such changes further coincided with a period in the HOT record during which biomass of selected groups of eukaryotic phytoplankton (diatoms, pelagophytes, and prymnesiophytes) and particulate nitrogen export increased. These observations suggest that fluctuations in ocean-climate influence hydrographic properties at ALOHA, altering nutrient supply to the upper ocean with concomitant changes in plankton biomass and community structure. Piecing together the mechanistic connections between these processes in order to understand how future changes might alter these dynamics will require a sustained, time-resolved presence in the sea to inform regional-scale ecosystem models.

Building a Long-Term Program

In retrospect, there are several elements fundamental to HOT that have enabled the program's success. Foremost among these elements are people - people are a time-series program's greatest asset. Knowledgeable, hard working, and dedicated people have provided the program with its core backbone. Many of the HOT staff have been with the program for more than half its existence and a few have been around for more than two decades. Many (26) of

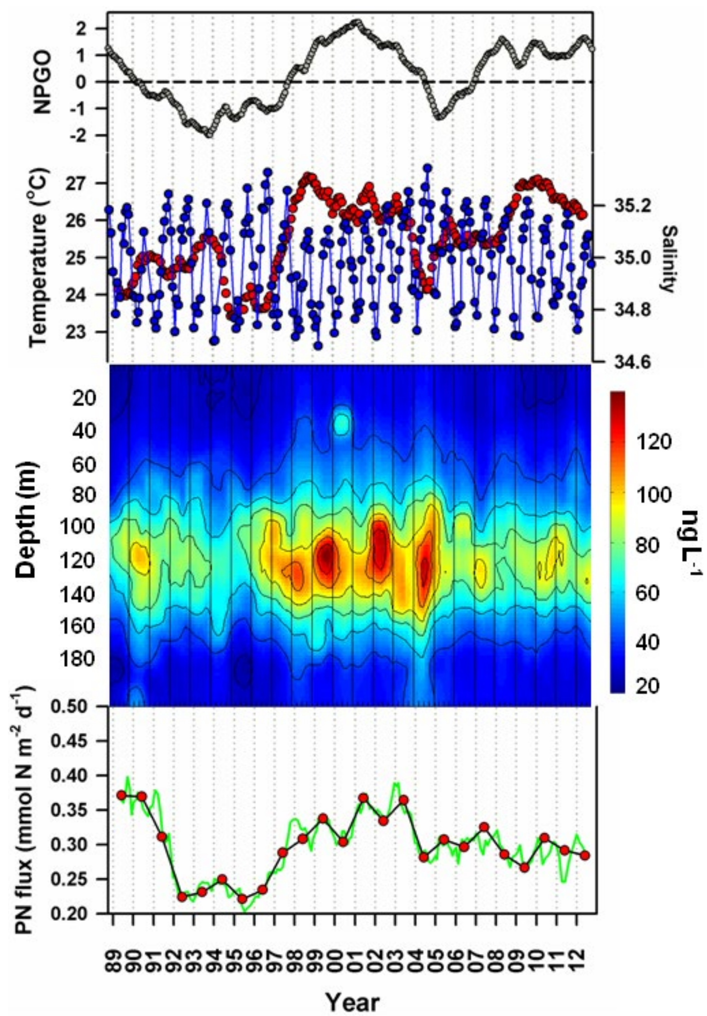

Figure 3. **Top:** HOT program measurements of mixed layer temperature (blue circles) and salinity (red circles); also shown are time-varying changes in North Pacific Gyre Oscillation (NPGO) during the period of HOT program observations. **Middle:** Euphotic zone concentrations of selected phytoplankton pigments; contour plot depicts the sum of upper ocean concentrations of phytoplankton pigments fucoxanthin, 19'-hexanoxyfucoxanthin, and 19'-butanoyloxyfucoxanthin. **Bottom:** Particulate nitrogen flux at 150 m at Station ALOHA; green line depicts 10-point running mean of particulate nitrogen flux while red circles are annual mean flux.

these people have participated in 50 or more HOT cruises, with 7 of these people having participated in more than 100 HOT cruises (Table 1). This dedication to the program provides consistency and continuity in sampling, laboratory analyses, and data management, in addition to providing valuable experience needed to assure that the science is conducted safely and with the utmost attention to quality. HOT has been supported by the NSF since its inception and the program has been fortunate to work with program leaders at NSF committed to seeing the program succeed. In addition to a dedicated workforce, HOT has benefited from continuity in program leadership; many of the scientists currently involved in HOT science have been involved with the program since its beginning (Table 2), providing a resource of people knowledgeable of ecosystem functioning in the NPSG.

Another key element essential to the longevity of a time-series program is prioritization of infrastructure and resources to maximize the quality of the core measurements. High-quality measurements and resulting data are the cornerstone of the program's success, and require constant oversight and investment, from assuring safe and reliable vessels to work from to tracking laboratory methodologies and instrument performance. Throughout the program's history, HOT has utilized standard reference materials (including certified references when available) to track the accuracy of as many of the core measurements as possible. Reference materials are used to track the performance of inorganic carbon system analyses (dissolved inorganic carbon concentrations and alkalinity), nutrients, total organic carbon, particulate matter concentrations, and phytoplankton pigments. In addition, on each cruise, approximately 20% of all samples are collected in triplicate, providing information on analytical and field precision of the core measurements. Finally, HOT has been a regular contributor to community-wide laboratory intercomparison exercises, allowing the program to track the performance of its analyses relative to other oceanographic programs.

The importance of having a reliable and safe vessel from which to conduct HOT cruises has been an essential element of the program's success. Over the course of the program's history, 15

Person	Number HOT cruises (as of October 2013)	Period of program activity
Lance Fujieki	178	1991-present
Daniel Sadler	171	1991-present
Fernando Santiago-Mandujano	170	1991-present
Jefrey Snyder	152	1988-present
Karin Björkman	119	1993-present
Dale Hebel	114	1988-2005
Blake Watkins	96	2003-present
Susan Curless	83	2005-present
Adriana Harlan	80	2005-present
Mark Valenciano	77	1998-2005

Table 1. (above) Top ten most frequent HOT cruise participants.

Table 2. (at right) Current and past HOT program principal investigators and period of activity in the program.

Person	Period of program activity
David Karl	1988-present
Roger Lukas	1988-present
Eric Firing	1988-present
Stephen Chiswell	1988-1993
Christopher Winn	1988-1997
Ricardo Letelier	1988-present
Dale Hebel	1988-2005
John Dore	1989-present
Robert Bidigare	1990-present
Luis Tupas	1991-2000
Michael Landry	1992-present
Fred Bingham	1992-1994
Matthew Church	2009-present

different research platforms, mostly UNOLS vessels, have been utilized for HOT cruises. By far the most heavily utilized vessels have been those operated by the University of Hawaii, including the R/V *Moana Wave* (1988-1999), R/V *Ka`imikai-O-Kanaloa* (1999-2012), and the R/V *Kilo Moana* (2002-present). It is nearly inconceivable to imagine HOT sustaining a near-monthly sampling effort without access to a vessel that calls Honolulu home. HOT has been fortunate to work with conscientious and user-friendly ship operators, crew, and marine center staff.

Since its beginning, HOT has fostered science, education, and outreach programs that rely on the HOT infrastructure, logistical, support, and intellectual resources. In exchange, HOT gains valuable collaborations that strengthen the program and provide new insights into ecosystem processes in the NPSG. HOT cruises are frequently fully subscribed, and over the program's history more than one third of all cruise participants are from universities, institutions, or agencies outside of UH. Many of these cruise participants are "ancillary" scientists who coordinate their science with HOT, providing valuable science leveraged on the core time-series measurements. Many of these "ancillary" scientists have worked with HOT for a decade or more and the resulting collaborations have proved a win-win.

HOT cruises have also provided unique sampling, training, and testing opportunities for students, scientists, and staff. More than 640 different people have participated in HOT cruises. Many of these people have joined for a single cruise – perhaps to gain experience with oceanographic sampling or to learn more about what life is like aboard a research cruise. However, there are also a large number of people that have been on multiple HOT cruises. Students (undergraduate and graduate) are among the most frequent cruise participants (35% of the cruise participants have been students); the relatively short duration (4 days) makes the cruises accessible to students trying to maintain busy academic schedules. Many of these students collect samples or data for their own research projects, while others join cruises to receive training in some specific aspect of HOT core sampling. With more than 30 Ph.D. and M.S. theses deriving from HOT measurements or datasets, students are one of HOT's greatest legacies.

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The CARIACO Ocean Time-Series: 18 years of international collaboration in ocean biogeochemistry and ecological research

F. Muller-Karger[1], L. Lorenzoni[1], E. Montes[1], G. Taylor[2], B. Thunell[3], M. Scranton[2], C. Benitez-Nelson[3], Y. Astor[4], R. Varela[4], L. Troccoli[5] and K. Fanning[1].
[1]College of Marine Science, University of South Florida, St. Petersburg, FL 33701, USA
[2]School of Marine & Atmospheric Sciences, Stony Brook University, Stony Brook, NY 11794-5000 USA.
[3]Department of Earth and Ocean Sciences, University of South Carolina, Columbia, SC 29208 USA
[4]Estación de Investigaciones Marinas de Margarita, Fundación de la Salle de Ciencias Naturales, Punta de Piedras, Nueva Esparta, Venezuela
[5]Universidad de Oriente, Boca de Río, Isla de Margarita, Venezuela

The Cariaco Basin, located in the southern Caribbean Sea, has been a focus of attention for many branches of the scientific community since the early 1950s. The attraction has been its unique geography, biogeochemistry, ecology, and sediments. The Cariaco Basin is a ~1400-m deep tectonic pull-apart basin located on the continental margin of northeastern Venezuela (Figure 1). A shallow sill with two channels that reach depths of ~140 m (Figure 1) isolates the deeper waters of this large basin, while there is a dynamic seasonal exchange of surface waters with the open Caribbean Sea. The basin experiences an upwelling season as Trade Winds intensify between December and May. The rainy season extends from June to November, and surface waters are thermally stratified during this time. The organic matter derived from high surface primary productivity (350-600 gC m^{-2} y^{-1}) decomposes as it sinks, and leads to anoxic conditions below about 250 m (1). Seasonal changes lead to alternating communi-

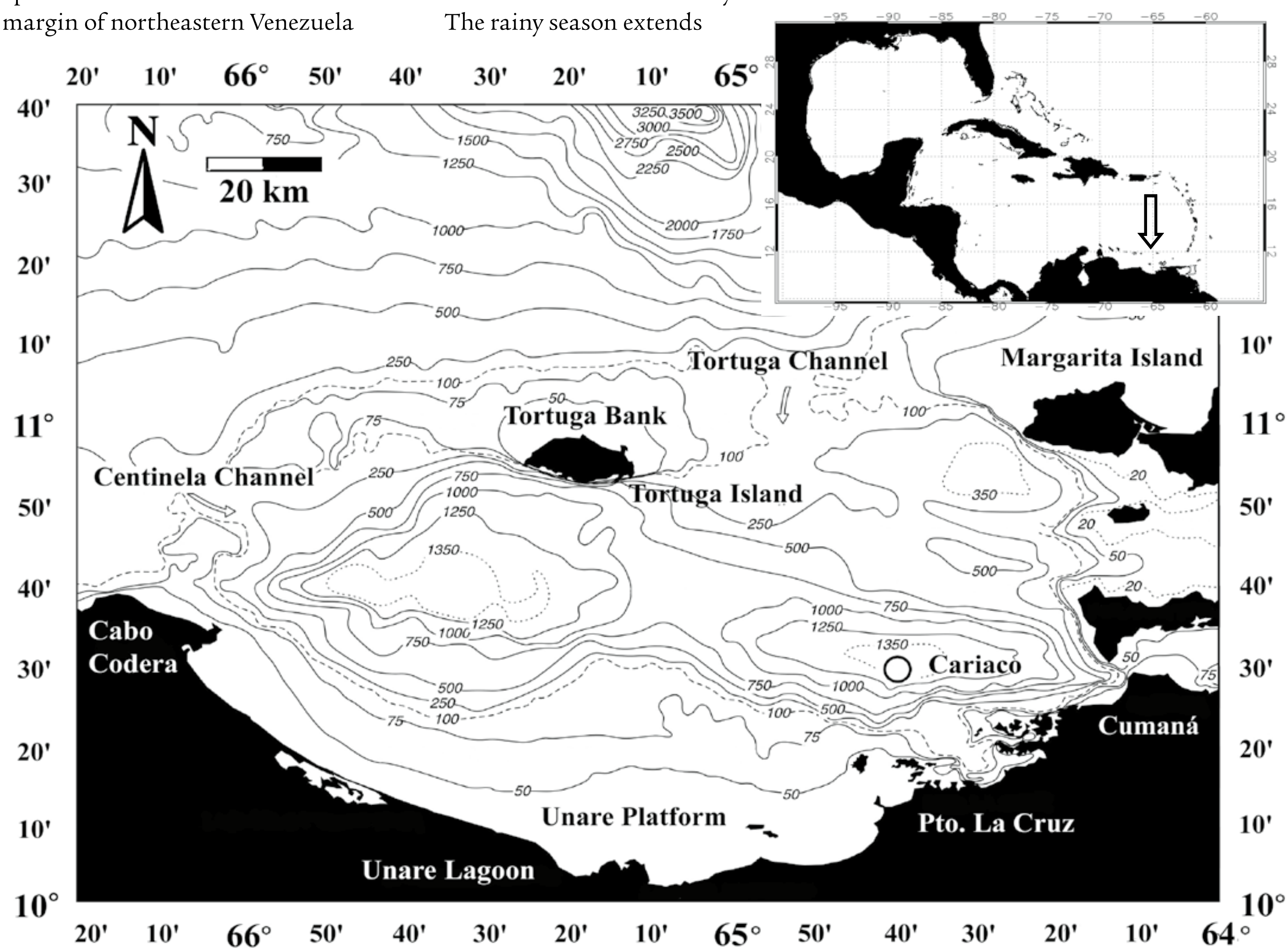

Figure 1. The Cariaco Basin showing the location of the CARIACO Ocean Time-Series station (open circle).

ties of phytoplankton and variation in the composition and amount of particulate matter reaching the bottom of the basin. In Cariaco, diverse microbial communities are vertically separated into habitats that span oxic and anoxic waters of the basin. The cycling of micronutrients and redox-sensitive trace elements has been studied by many chemical, biological, geological and physical oceanographers for over five decades. These studies now reveal long-term changes in the basin that have important ecological consequences.

The CARIACO Ocean Time-Series program established a sampling station in November 1995 at 10° 30'N, 64° 40'W (Figure 1) with support from the Venezuelan Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICIT; now the Fondo Nacional de Ciencia, Tecnología e Investigación or FONACIT) and the U.S. National Science Foundation (NSF). The scientific goal of the program is to understand the relationship between processes that modulate the hydrography, community composition, primary production, microbial activity, terrigenous inputs, particle fluxes, and element cycling in the water column, and to quantify how variations in these processes are preserved in sediments accumulating on the seafloor. Because of the anoxic nature of the water and slow circulation, sediments accumulate in layers undisturbed by bioturbation. Over time, these layers form a detailed sedimentary archive of past climate changes in the Atlantic. This record has been sampled numerous times since the 1950s, most notably by the Ocean Drilling Program and

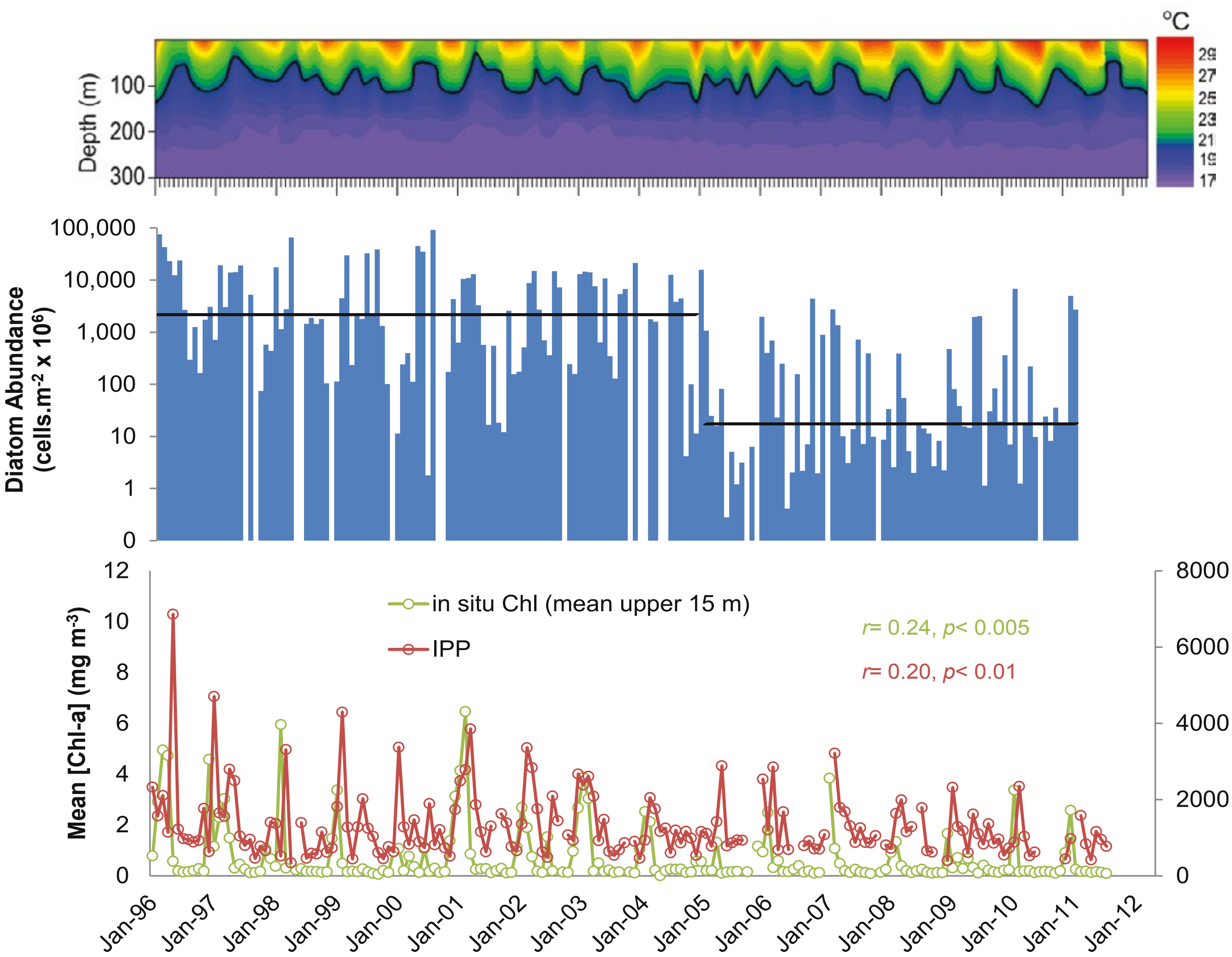

Figure 2. Top: Seasonal upwelling and relaxation cycle typical of the Cariaco Basin. Note the increasing upper water column temperature (visible as warmer colors) in recent years. **Middle:** Shown also are trends in integrated diatom abundance (0-100 m), with medians for 1996-2004 and 2005-2011 in black lines. **Bottom:** [Chl-a] and integrated PP (IPP, 0-100 m); r and p-values for Chl-a and IPP are shown with colored text for the corresponding trend line.

previously by the Deep Sea Drilling Program to obtain detailed paleoclimate records spanning the past 600,000 years.

The CARIACO time-series focuses on collecting modern long-term ocean biogeochemistry and ecology observations and to make these available to the public quickly and openly. Since 1995, CARIACO has provided a platform for the scientific community to conduct over 200 core oceanographic cruises to the time-series station, over 35 sediment trap deployments and 36 microbial-biogeochemistry process-study expeditions. Additional oceanographic cruises have addressed spatial and seasonal variability in many key environmental variables, including coastal and riverine sediment inputs. The time-series program collects data on hydrography and meteorology, nutrient and carbonate chemistry, phyto- and zoo- and bacterioplankton standing stocks, primary production, sinking and suspended particulate matter, dissolved organic matter, and bio-optical characteristics of the water (2). Most sampling is conducted monthly, with sediment traps integrating sinking particulate fluxes over consecutive two-week intervals since the inception of the CARIACO program in 1995. All of these data are processed and made publicly available within weeks. Hundreds of investigators around the world have requested samples or directly participated in cruises or other aspects of the program, gaining access to this unique site through the CARIACO Ocean Time-Series program.

The importance of long time-series: Distinguishing signal from noise

The ocean changes continuously and biogeochemical processes take place over a variety of temporal scales. Time-series that span years to decades allow us to observe interconnections among many of these processes that are otherwise difficult to detect due to high seasonal variability and poor sampling resolution (3). They are an important tool to help discern and understand the impacts of anthropogenic and natural perturbations on ocean ecosystems. Long-term marine biogeochemistry and ecological time-series are particularly important in tropical regions, where small changes in climate can result in major losses in biodiversity (4).

CARIACO is an excellent example of how a biogeochemical time-series is used to detect and study changes in the ocean that are not discernible with traditional methods, by conducting single expeditions, or through irregular sampling. In the early years of the CARIACO program (1995-1999), the southern Caribbean Sea was considered to be very stable, with a regular annual cycle of upwelling along its southern continental margin driven by intensification of the Trade Winds (Figure 2). This process drives ~70% of the annual net primary production (NPP). Phytoplankton production takes place in the upper 50 m of the water column, where chlorophyll-a (Chl-a) concentrations have averaged about 56 mg m^{-2} during the most productive months (December through April) and <27 mg m^{-2} otherwise. Since the early 2000s, major changes have been observed during the CARIACO expeditions. For example, Chl-a concentrations and NPP have steadily decreased since 1995 (ΔChl-a = -2.8 ± 0.5% yr^{-1} and ΔNPP = -1.5 ± 0.3% yr^{-1}; Figure 2; see (5)). A marked decrease in larger phytoplankton such as diatoms has been observed (Figure 2), and in general, phytoplankton taxon dominance has shifted from diatoms, dinoflagellates, and coccolithophorids to smaller taxa (6). There has been a concomitant increase in zooplankton biomass in the upper 200 m, from <500 mg m^{-3} dry weight in 2002-2005 to nearly 700 mg m^{-3} in 2006-2011. This is also consistent with an upward trend in the phaeopigment/Chl-a ratio (+1.1% yr^{-1}; (5)). Coming into 2013, annual average sea surface temperatures (SST) are >1.0°C higher than those measured in 1995 (Figure 3). All of this appears to be related to a weakening of the

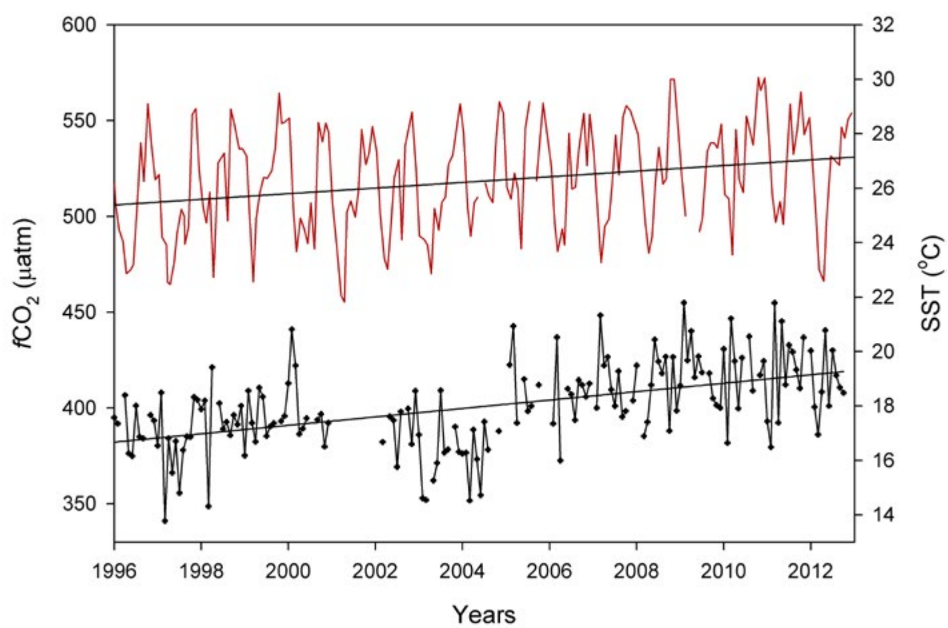

Figure 3. Time-series of sea surface temperature (SST, red line) and deseasonalized fCO_2 concentration (black cross symbols joined by black line) at the CARIACO Ocean Time-Series station.

Trade Winds in the southern Caribbean since 1995, estimated at -1.9% yr^{-1} in wind speed.

Physical changes (temperature, wind speed, etc.) that have resulted in regional ecological shifts have also affected ocean chemistry and vice versa. For example, fCO_2 has increased by ~2.2 matm ($p < 0.05$) (Figure 3; (7)) in response to warming of Caribbean surface waters, accentuated by decreased trade wind strength and subsequently reduced upwelling along the continental margin. An increase in dissolved inorganic carbon is also due to a decrease in primary production, which reduces CO_2 drawdown, and perhaps also to the marked increase in zooplankton biomass. Of additional note was the collapse of the Caribbean Spanish sardine fishery in 2004 and the failed recovery of the fish stocks. This is very likely the collective result of overfishing pressures, declining primary productivity, and the observed warming trends; during CARIACO studies we have found that sardines tend to move offshore when upwelling decreases. The decrease in predation by sardines is further hypothesized to have contributed to the observed increase in zooplankton biomass, which in turn led to higher grazing pressures on phytoplankton.

What are the combined impacts of such bottom-up and top-down pressures on ocean ecosystems? What causes the large-scale, long-term changes in the tropical Atlantic Ocean? Taylor et al. (2012, ref. 5) reported that the seasonal excursions of the Intertropical Convergence Zone (ITCZ) have increased in latitudinal range since 1995. This is accompanied by an increase in average annual precipitation over northern South America (m = +0.04 mm yr^{-1}). In turn, these changes have had many societally relevant impacts, including disastrous precipitation events and changes in the economic structure of coastal fishing communities. Are these changes part of climate-scale fluctuations? Are we observing a “state shift” in the biosphere driven by these physical and chemical changes? CARIACO time-series observations have captured these regional variations and enabled us to study how they are linked.

A key to the past and a tool to understand our future

The local shifts observed in the Cariaco Basin reflect large-scale fluctuations of both short- and long-term climatic states. The instrumental record of the last century is too brief to quantify long-term trends with any certainty. In contrast, the varved sediments of the Cariaco Basin provide a rich record of interannual-to-millennial-scale variability in the tropical and extratropical regions of the Atlantic Ocean. These sediments provide some of the highest-resolution records of abrupt climate events during the Holocene and spanning glacial-interglacial cycles (e.g. 8, 9). The paleoclimate records of the Cariaco Basin offer insight into how long-term change in environmental variables has led to regional shifts in terrestrial and marine ecosystems.

The CARIACO Ocean Time-Series continues to measure the quantity and composition of particles settling to the bottom. The project includes detailed geochemical studies paired with efforts to understand changes in rivers and local catchment basins, including near-shore and bottom sediments. These efforts will help develop more accurate interpretations of natural paleoclimate variability and refine predictions of future change that now include strong human drivers. For example, carbon isotope composition of planktonic foraminifera captured in sediment traps and sediment cores have helped resolve the timing and magnitude of the Suess effect, a progressive decrease in the carbon isotope composition of CO_2 in both the atmosphere and ocean since the onset of the Industrial Revolution due to fossil fuel combustion (Figure 4; (10)). Scientists are using a

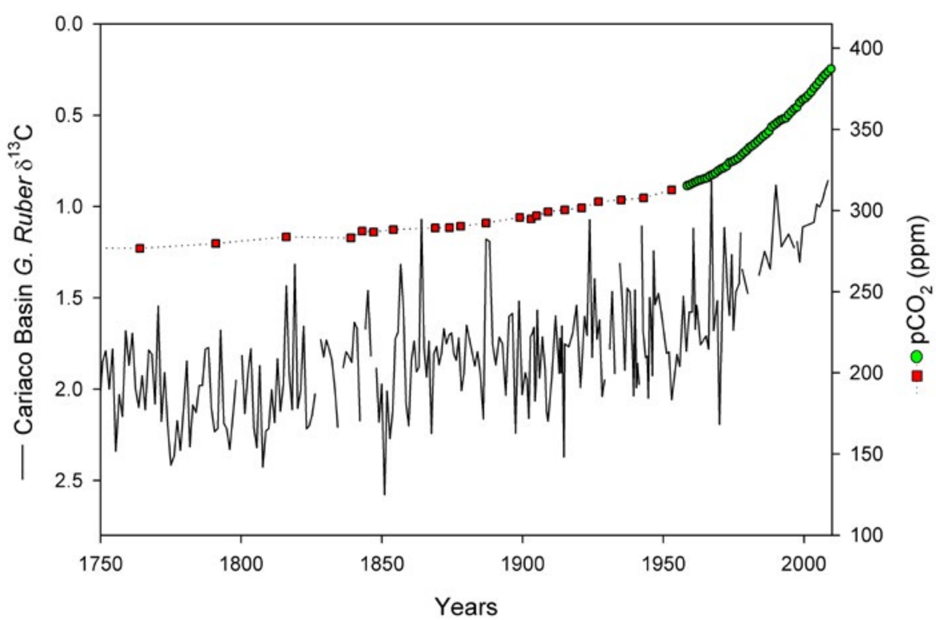

Figure 4. Time-series of pCO_2 records at Mauna Loa (green circles) and in the Siple ice core (red squares) compared with Cariaco Basin planktonic foraminifera $\delta^{13}C$ (black line) from 1750 to present. A significant depletion in $\delta^{13}C$ of foraminifera is observed over the last 50 years, concurrent with the increase in atmospheric pCO_2. Figure modified from (10).

broad range of data from CARIACO to better characterize climate modes and their impacts on ecosystems.

Open international collaboration and teamwork: The basis of success

The CARIACO Ocean Time-Series owes its success to the strong collaborations among scientists in Venezuela, the U.S., and other countries. This collegial collaboration has persevered and ensured the continuation of this important scientific facility. In Venezuela, the Fundación La Salle/FLASA leads the effort, together with four other institutions (Univ. Simón Bolívar/USB, Univ. de Oriente/UDO, Univ. Central de Venezuela/UCV, and Instituto Venezolano de Investigaciones Científicas/IVIC). In the U.S., the program is managed by a team of researchers from the University of South Florida, University of South Carolina, and Stony Brook University. Scientific collaborations extend well beyond these institutions, including partners and researchers from around the world.

One of the main legacies of CARIACO is capacity-building, which ensures widespread and proper use of ocean observations and technology. Capacity-building also fosters an understanding and appreciation of marine resources. Many Venezuelan and U.S. students have completed internships and projects linked to the CARIACO Ocean Time-Series program, including six POGO/SCOR fellows (Partnership for Observation of the Global Oceans/Scientific Committee on Oceanic Research), four of whom have participated in the Centre of Excellence (CofE) in Observational Oceanography at the Bermuda Institute of Ocean Sciences (BIOS). CARIACO data have supported the completion of >35 theses and dissertations. Students and members of our technical support team in Venezuela participate in several social media outlets to demonstrate their enthusiasm for the program and help broaden the impacts of the project.

The gateway to ocean observations: Open data access

To stimulate international collaborations and the advancement of science, the CARIACO Program provides open access to all of the data generated by the program. We use several websites, including one in Spanish established through the Universidad Simón Bolívar, Venezuela, and which now includes co-management by the Instituto Venezolano de Investigaciones Cientificas (IVIC). Hydrographic and biogeochemical data are archived at the National Oceanographic Data Center (NODC-NOAA), the Carbon Dioxide Information Analysis Center (CDIAC), the Biological and Chemical Oceanography Data Management Office (BCO-DMO), and also at USF. Sediment trap data are also available through PANGAEA. Bio-optical observations are submitted to NASA (SeaBASS). Data are available upon completion of quality control, which, depending on the variable, can take as little as a few hours (such as satellite observations).

To boldly go where no time-series has gone before

The scientific community depends on the observations made by ship-based ocean biogeochemical and ecological time-series programs around the world to understand our changing ocean over the long term. Much like the Mars rovers and other spacecraft that have surpassed their original life expectancy, oceanographic time-series continue to provide critical observations because of the passion of groups of investigators that believe in providing such information to the scientific community. Anyone who has worked with an ocean biogeochemistry time-series program knows the difficulties associated with maintaining the high quality and frequency of measurements, let alone equipment maintenance and staff enthusiasm. With a strongly committed and capable team and a wealth of valuable observations, the CARIACO Ocean Time-Series program is continually improving our understanding of how the ocean functions and how it is changing, including critical questions related to:

- particle decomposition and recycling
- quantifying the biological pump
- oxygen minimum zone development
- the interplay between bottom-up and top-down ecological processes
- the impacts of ecological processes on biogeochemical cycles
- past climate and ocean changes deciphered from uniquely valuable paleoclimate records

The CARIACO Program is part of the growing global time-series network focused on studying biogeochemical and ecological processes and on understanding feedbacks of large-scale changes on the earth system (11). In the face of the current global economic crisis and future climate change, strong support by the scientific community and long-term commitment by nations is required to maintain these critical marine biogeochemical and ecological time-series.

Acknowledgments

We are indebted to the personnel of the Fundación La Salle de Ciencias Naturales, Estación de Investigaciones Marinas, Isla Margarita (FLASA/EDIMAR), who have been responsible for the collection of samples and analyses of some of the data presented here, and to the crew of the R/V *Hermano Ginés* for their enthusiasm and professional support. This work was funded by the Consejo Nacional de Investigaciones Cientificas y Tecnológicas (CONICIT, Venezuela, Grant 96280221) and Fondo Nacional de Ciencia y Tecnología (FONACIT, Venezuela, Grant 2000001702 to RV and 2011000353 to YA), the National Science Foundation, Ocean Sciences Division, Chemical Oceanography Program (NSF, Grants OCE-0752139, OCE-9216626, OCE-9729284, OCE-9401537, OCE-9729697, OCE-9415790, OCE-9711318, and OCE-0963028 to FMK; OCE-9415790, OCE-9711318, OCE-9730278 and OCE-0118491, OCE-0326175, and OCE-0752014 to MIS and GTT; OCE-0752037 and OCE-1039503 to RT), and NASA (NASA Grants NAG5-6448 and NAS5-97128 to FMK).

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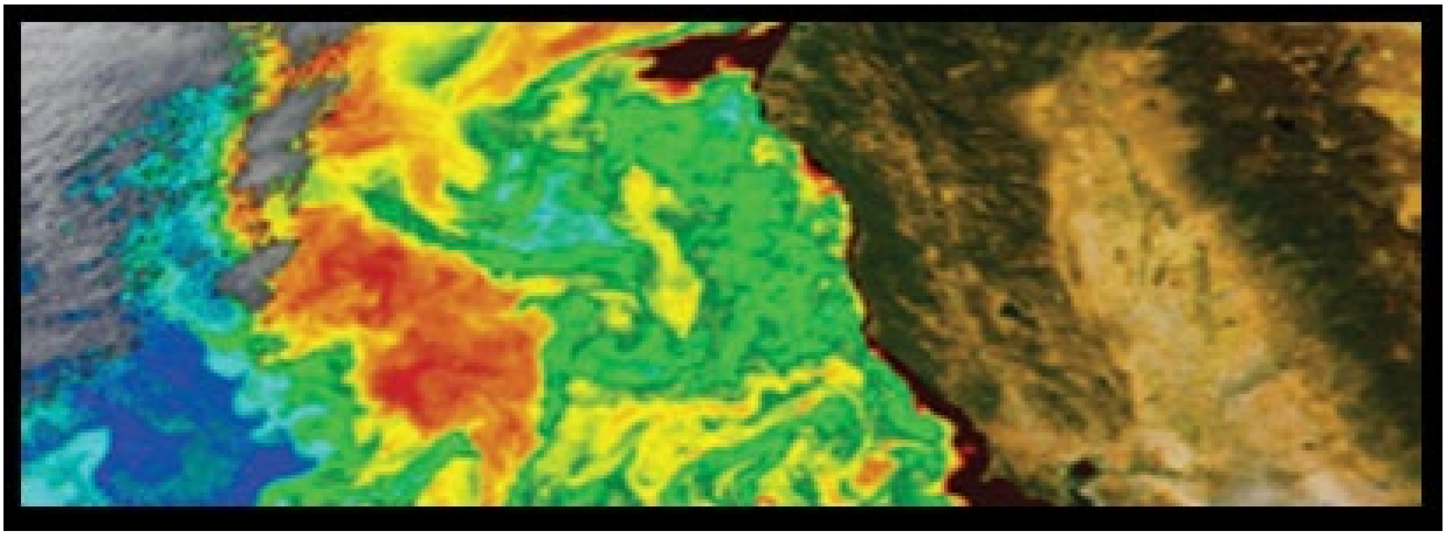
Satellite Remote Sensing for Biogeochemistry and Ecology: The Next Decade

This editorial was submitted by Frank Muller-Karger and Laura Lorenzoni and is based on a letter in support of the PACE mission that was submitted to NASA officials in early November 2013 by concerned members of the OCB community, including J. Yoder, F. Muller-Karger, D. Siegel, S. Doney, S.Dutkiewicz, P. Falkowski, M. Follows, E. Hofmann, M. Kahru, D. Karl, A. Mahadevan, G. Mitchell, S. Murawski, M. J. Perry, J. Sarmiento, and H. Sosik.



Sweet 16 - this is how many years we have had uninterrupted, high-quality bio-optical observations from space, starting with SeaWiFS on the SeaStar satellite (1997-2010), followed by NASA MODIS on the Aqua satellite (2002-present), and then VIIRS on the NOAA Suomi NPP satellite (2011-present). These measurements are now pervasive in our biological and chemical oceanographic research. Some of the more common applications of these data by the OCB community include:

- » Pinpointing phytoplankton blooms
- » Measuring changes in phytoplankton biomass that accompany temperature and wind anomalies over large areas of the ocean
- » Quantifying uncertainty in global estimates of particulate and dissolved organic carbon fluxes

These measurements have been critical in demonstrating that, even within our own life spans, changing climate is having measurable impacts on marine ecosystems. With regard to data quality, we hold SeaWiFS and MODIS data as the minimum standard necessary to conduct large-scale marine biogeochemistry studies.

MODIS Aqua is now entering its second decade of operation. As we saw with SeaWiFS, MERIS, OCTS, and other sensors, including CZCS in the 1980s, these satellites and their sensors are not built to last even this long. Soon, the oceanographic community will be contemplating a significantly reduced satellite data stream, with VIIRS hopefully surviving after MODIS stops transmitting data. VIIRS will continue to provide a robust dataset to estimate chlorophyll concentrations, but at a reduced spectral resolution relative to MODIS.

In October 2012, a group of nearly 30 U.S. and international scientists released a final report to sketch the type of instrument that would be required to conduct advanced biogeochemistry and ecological ocean research and operations. This report defined the requirements for the NASA Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) mission. The team worked for a year with a very broad disciplinary range of international ocean and atmosphere researchers, experts in terrestrial ecology, and practitioners in industry and operations, to define a forward-thinking mission that would fit the limited budget constraints imposed by modern realities.

The sensors and associated capabilities of the PACE mission will be required to significantly advance ocean and ecosystem science and applications within the five topical areas listed below (details are provided in the PACE mission Science Definition Team report):

1. ***Ocean Biodiversity*** –PACE's higher spectral resolution will reveal signatures of phytoplankton taxonomic diversity and particle size distributions, enabling

us to quantify global ocean ecosystem structure and biodiversity from space for the very first time. Ecosystem structure affects the efficiency of energy transfer through marine food webs, ultimately determining fish production. PACE will also provide critical information on phytoplankton physiology and ocean health. The key to these observations is to complement higher-spectral-resolution observations in the blue to yellow wavelengths with very sensitive bands to measure solar-stimulated fluorescence in the red. These fluorescence bands help to distinguish phytoplankton blooms from river plumes in coastal zones and shelf environments. In the open ocean, fluorescence measurements will enable scientists to study the physiological state of phytoplankton. PACE observations will also support and advance research on water quality and habitat variability in estuarine and coastal systems.

2. ***Ocean Carbon Cycling*** –PACE observations will help quantify key carbon concentrations and biogeochemical fluxes in the global ocean, including net primary production (NPP), net community (or ecosystem) production (NCP), and carbon export from surface waters to the deep sea, thus providing the opportunity to quantify links between ocean ecology and the biological pump, a key unknown in the global carbon cycle. The key to resolving the colored dissolved organic matter (CDOM) interference problem in current satellite measurements is to extend measurements to shorter wavelengths, allowing improved separation of phytoplankton pigment concentration and achieving more accurate atmospheric corrections.

3. ***Complex Aerosol and Ocean Properties in the Coastal Ocean*** - PACE's enhanced capabilities for quantifying aerosol optical properties, including aerosol absorption, will greatly improve our ability to quantify oceanic constituents in coastal waters that lie beneath complex coastal atmospheres. This capability will also support water quality monitoring efforts in inland environments.

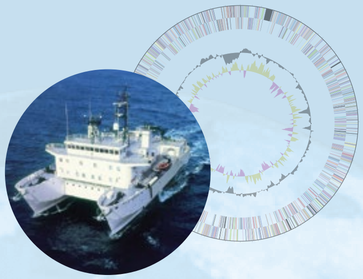
4. ***Understanding Change*** – PACE includes many technology improvements over heritage instruments, leading to superior precision and accuracy in orbit. This inherent stability and fidelity will result in improved insights into processes regulating marine ecosystems and the global ocean carbon cycle spanning weekly to decadal time scales.

5. ***Biogeochemical and Ecosystem Models*** – Many marine biogeochemical and ecosystem models already include multiple functional groups, but the traditional satellite ocean color band-set does not provide the necessary taxonomic discrimination to support these models. The higher spectral resolution and improved accuracy of PACE measurements will provide the necessary observational support for developing and validating these models.

In summary, the PACE mission directly addresses many strategic priorities of the earth science community that are currently embraced by NASA, NOAA, and many other U.S. and international agencies and programs. The capabilities of PACE will lead to new and exciting scientific discoveries and societal applications far beyond what has been or could be achieved with VIIRS, heritage ocean color sensors, or missions being planned by foreign space agencies. This mission has the potential to move the field of ocean color remote sensing to the next level of scientific sophistication, which is essential to addressing key outstanding science questions with which the oceanographic community has been grappling for decades! Furthermore, the unique data sets and products emerging from the PACE mission will provide opportunities for the broader public in the form of jobs and enhanced commerce. It is important for the OCB community to recognize both the scientific value and broader importance of PACE, and to discuss and plan for the advanced science programs that this mission would enable.

center for microbial oceanography: research and education

C-MORE *linking genomes to biomes*



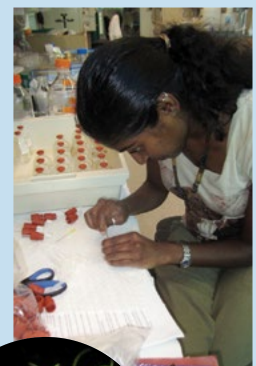
A laboratory-field training course at the University of Hawai'i at Mānoa

2013 Summer Course participants on board R/V *Kilo Moana*

Microbial Oceanography: Genomes to Biomes

May 27 to June 28, 2014

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 2014 summer course is offered to graduate students, postdoctoral scholars, and early career faculty with interests in marine microbiology and biological oceanography.

For course information, please visit

cmore.soest.hawaii.edu/summercourse

AGOURON INSTITUTE · NSF · SCHOOL OF OCEAN AND EARTH SCIENCE AND TECHNOLOGY, UNIVERSITY OF HAWAI'I AT MĀNOA · C-MORE

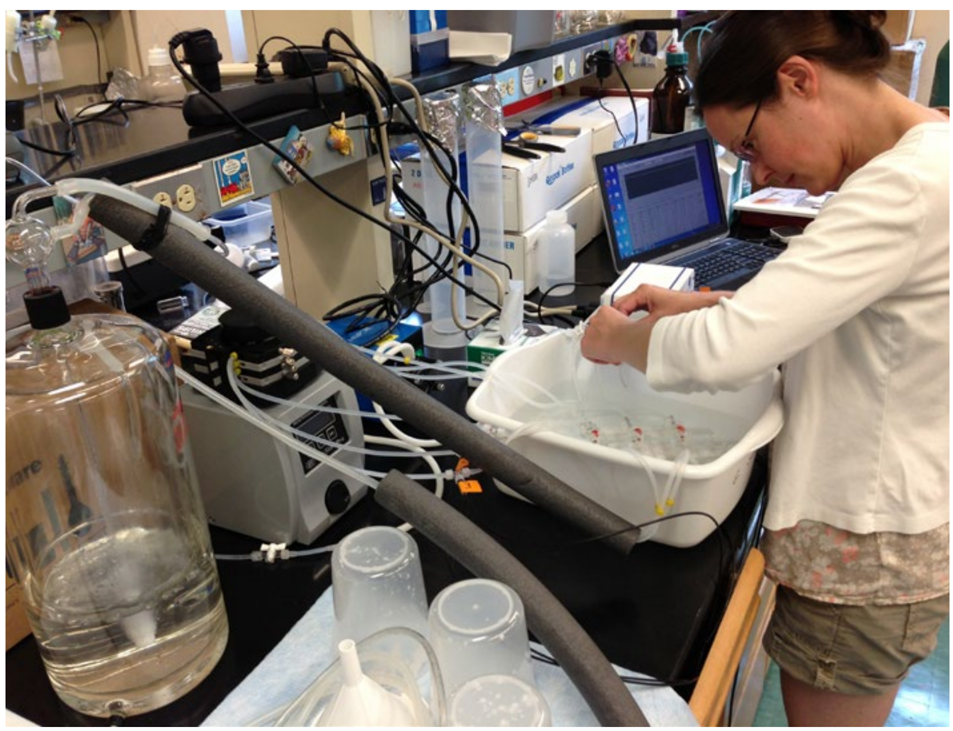
OCB hosts three C-MORE Science Kits in Woods Hole

OCB hosts three C-MORE Science Kits: Ocean acidification, marine mystery, and ocean conveyor belt. The ocean acidification kit (two lessons, grades 6-12) familiarizes students with the causes and consequences of ocean acidification. The ocean conveyor belt kit (four lessons, grades 8-12) introduces students to some fundamental concepts in oceanography, including ocean circulation, nutrient cycling, and variations in the chemical, biological, and physical properties of seawater through hands-on and computer-based experiments. With the marine mystery kit (grades 3-8) students learn about the causes of coral reef destruction by assuming various character roles in this marine murder-mystery. Teachers along the eastern seaboard may use these kits for free. To reserve a kit, please submit a request.

A New Education and Outreach Project: Planting AntaRctica in KAnsas (Project PARKA)

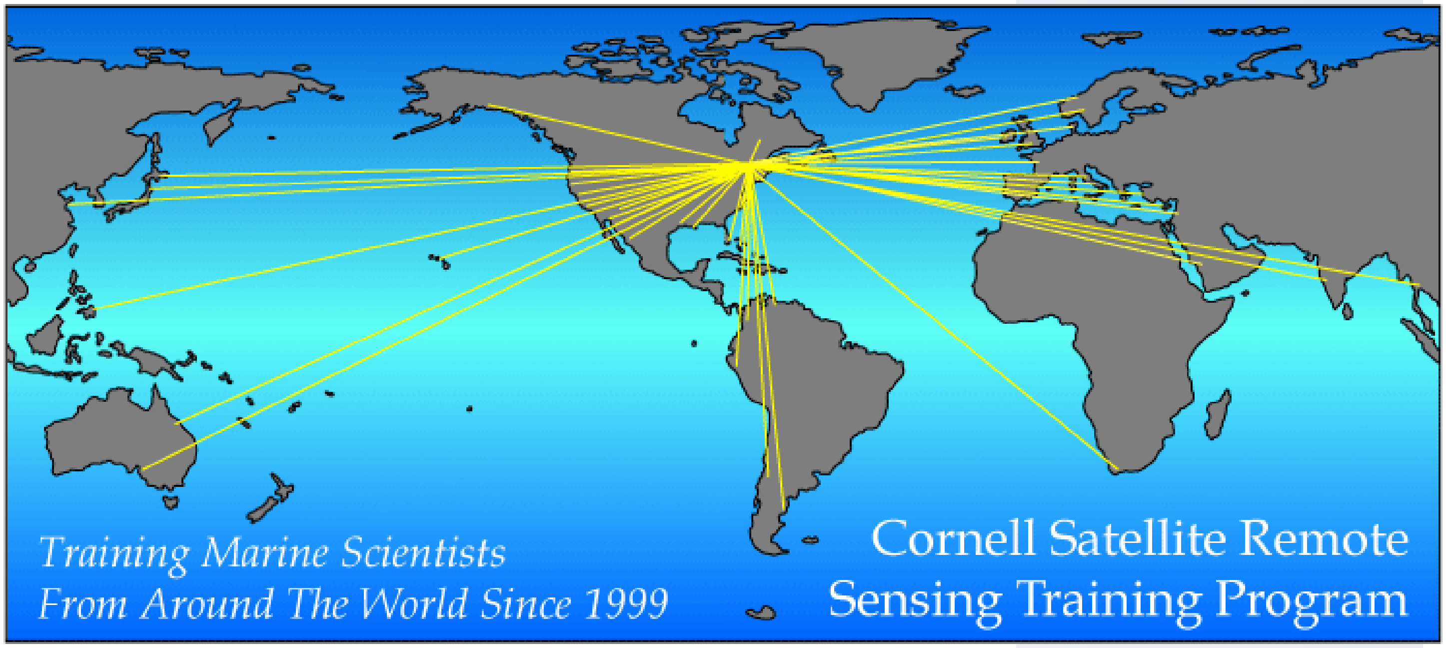
Dr. Grace Saba at the Institute of Marine and Coastal Sciences at Rutgers University in New Jersey, is leading a yearlong marine science program for 9-12th grade Kansas science teachers and students (2013-14) called Planting AntaRctica in KAnsas (Project PARKA). This outreach and education project is supported by Rutgers University and COSEE Networked Ocean World and funded by NSF Office of Polar Programs (Grant #1246293) as part of a larger project entitled "Synergistic effects of Elevated Carbon Dioxide (CO_2) and Temperature on the Metabolism, Growth, and Reproduction of Antarctic Krill (*Euphausia superba*)" (Dr. Saba, lead PI; Dr. Brad Seibel, University of Rhode Island, co-PI). Participants of the program will work with research scientists to learn about interdisciplinary oceanographic research taking place at the West Antarctic Peninsula in January 2014. This exciting research mission will characterize the connection between ocean chemistry, climate change, and Antarctic food webs. During the year, students will learn the research mission science through participating in classroom activities, following mission blogs, talking with scientists at Palmer Station, Antarctica via Live Video Broadcasts, meeting the research scientists, and presenting their own research at a spring 2014 Student Research Symposium. Participating teachers (21 teachers from 16 Kansas high schools) attended a summer workshop (July 2013) to meet Dr. Saba and learn about the science and project. Learn more about Project PARKA and follow the scientist and student blogs here: http://coseenow.net/project-parka/

At the July 2013 workshop, the Kansas high school teachers learned a lot of background information about oceanography, Antarctic food webs, climate change, and ocean acidification. Here they are having a group discussion about how ocean acidification affects marine organisms. Photo by Grace Saba



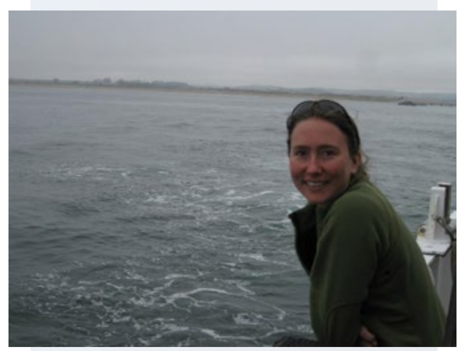
Dr. Grace Saba testing equipment for the upcoming Antarctic field season, during which she will measure oxygen consumption (breathing) rates in krill. Kansas students will be able to see the experiments and ask questions during live calls to Palmer Station this January.

OCB supports student participation in the Cornell Satellite Remote Sensing Training Program



Every year at Cornell University, Dr. Bruce Monger and colleagues coordinate and run an intensive 2-week summer training course on satellite remote sensing techniques. In an effort to promote more widespread and effective use of satellite remote sensing data in OCB research and offer more hands-on training opportunities for early career scientists in the OCB community, the OCB Project Office provided tuition, housing, and travel support for 8 scientists, including graduate students and postdocs, to take the course, which was offered May 31-June 14, 2013. Below are some of their reflections on the training program.

Claire Parker (Univ. of California, Santa Cruz)



Claire has a B.S. in Chemistry from Bates College (Lewiston, Maine), and is currently a Ph.D. student at the University of California, Santa Cruz working with Professor Kenneth Bruland. She is studying biologically and environmentally relevant trace metals in the California Current System, through which she is involved with the GEOTRACES program.

"Being able to view satellite data quickly and easily is valuable in my field. We often use satellite data as soon as it becomes available to decide on our cruise track for the day, and getting an understanding of the biological and physical processes happening in the region at the time of sampling is very helpful in our data analysis. Taking this course with Bruce Monger gave me the perfect fundamental understanding and practical skills to be able to make use of these data."

Tihomir Kostadinov (Univ. of Richmond, Virginia)

While Tihomir's primary training is in bio-optical modeling (Ph.D. program at Univ. of California, Santa Barbara working with Prof. David Siegel), his research interests also span various other aspects of Earth System Science. His dissertation highlight was the development of a novel algorithm for the retrieval of particle size distributions from satellite ocean color data. He is just about to complete a two-year position as an Andrew Mellon Foundation/American Colleges of the South postdoctoral fellow at the University of Richmond (UR) in Virginia.

During the fellowship, he has focused his research efforts on ocean color and bio-optics, snow remote sensing and forest ecology, and Milankovitch cycles. He also taught physical geography and climate change to undergraduates at UR and directed student research. He will continue at UR as a researcher funded by the NASA Ocean Biology and Biogeochemistry program, focusing on phytoplankton functional types (PFTs) from space and in ecosystem models.

"I am very grateful to OCB for the support it provided for me to attend Bruce Monger's ocean color remote sensing course at Cornell. The course topics were well chosen and the course was well structured. While some of the course material was review for me, I learned valuable new skills, especially related to the processing steps of raw satellite swath data, temporal and spatial binning algorithms. I was introduced to IDL, Python and SeaDAS. I also gained new skills in processing and interpreting SST, wind and sea level height data. Importantly, I gained valuable experience in application of EOFs to analyze time-series of imagery. I gained further understanding of binned vs. mapped data. I am planning to apply the Level 2 --> Level 3 binned and mapped data processing skills I learned and the EOF analysis techniques to my research very soon in order to merge several sensors' data into one seamless product of PFTs, ideally with error estimates."

Yang Feng (Virginia Institute of Marine Science)

Yang Feng is currently a postdoctoral research associate in the Biological Sciences Department of the Virginia Institute of Marine Science. Her research focuses on how anthropogenic activities impact marine environments, primarily through the use of coupled physical-biogeochemical models.

"The Cornell Satellite Course was very helpful for my research. The material was very practical and easy to learn. As a modeler for years, I have faced the situation of using observational data to validate model simulation results many times. The course taught me how to retrieve satellite data and process them to different levels, spatial, and temporal resolutions to meet the research requirements. In addition, the course included many great social activities between lectures, allowing me to interact with many young scientists in the field. In all, the whole experience was really awesome!"

Emma Wear (University of California, Santa Barbara)

Emma is a Ph.D. student in Craig Carlson's lab at the University of California, Santa Barbara. She is working on a project funded by a NASA Earth and Space Science Fellowship to examine the effects of CDOM photobleaching on interactions between heterotrophic bacterioplankton and DOM. This work is based on the Plumes & Blooms cruise program in the upwelling-driven Santa Barbara Channel. One of the goals of her project is to place traditional bottle experiments in their broader environmental context using satellite data.

"My prior experience with remote sensing data was in the context of terrestrial GIS analyses, so this class was an excellent opportunity to get up to speed on the practical aspects of using remote sensing in oceanography and of working up large quantities of data through a command-line interface. I have a much better understanding of the pros and cons of various data types and much more confidence in my ability to get good results. Bruce does a great job of distilling these complex subjects, and I'm grateful to OCB for this incredibly helpful experience.

Nicolas Van Oostende, Princeton Univ.

Nicolas Van Oostende is pursuing postdoctoral research in Prof. Bess Ward's laboratory in the Department of Geosciences at Princeton University. He earned his Ph.D. in biology at Ghent University in Belgium, where he studied microbial ecological dynamics during coccolithophorid blooms and interactions between bacteria and the production of transparent exopolymer particles by the coccolithophore *Emiliania huxleyi*. His research interests have led him from the study of bee pollination behavior by means of artificial flowers, to diversity-productivity relationships in benthic diatoms and to the study of marine planktonic microbial food webs. He is currently interested in phytoplankton functional diversity as it relates to their biogeochemical role in the ocean.

Van Oostende recently returned from an oceanographic cruise crossing the North Atlantic Ocean. The project uses natural abundance signatures and tracer stable isotope incubations to investigate nitrogen utilization and primary production, along with flow cytometry and molecular biological methods to explore the diversity of the phytoplankton assemblage. He intends to use the results of this and previous cruises to inform ecological models through his collaboration with Dr. John Dunne at the Geophysical Fluid Dynamics Laboratory.

"I was honored to receive funding from OCB to participate in the remote sensing summer course led by Dr. Bruce Monger at Cornell University. This course gave me the opportunity to familiarize myself with a variety of ocean sciences remote sensing techniques. Bruce Monger's charisma and his hands-on approach to remote sensing data processing, backed by two dedicated teaching assistants, were the highlight of this two-week summer session. The North Atlantic project has already benefited from my recent learning experience, and the remote sensing approach will be further integrated into my ecological modeling research in the future."

Xiao Liu, University of Southern California

Xiao Liu obtained her B.S. from Ocean University of China in Qingdao, China and then her M.S. from Virginia Institute of Marine Science, College of William and Mary in Gloucester Point, Virginia. Xiao is currently a Ph.D. student enrolled in the program of Ocean Sciences at University of Southern California, working with Dr. Burton Jones and Dr. Naomi Levine on integrated ocean observing and ecosystem modeling. Xiao is particularly interested in applying data obtained from satellite and autonomous platforms to coupled physical-plankton models in order to understand physical-biological interactions in the ocean.

"The satellite remote sensing training course provided at Cornell University was an excellent learning experience for me and I was immediately able to use what I learned from the course in my research. Dr. Bruce Monger's "hands-on" approach turned out to be very effective and informative, and within only two weeks I was taught a variety of skills that are needed to acquire global data from satellite sensors. I was particularly interested in the central Red Sea, an area that is historically under-investigated. With the skills and methods learned from this course, I managed to extract more than a decade's worth of ocean color data and obtain interesting results from EOF analysis. I have submitted an abstract to the 2014 Ocean Sciences Meeting, which includes some of this work. I am excited to present my data and looking forward to the reunion of the 2013 Cornell Remote Sensing Summer Group at the meeting!"

Maria Herrmann (NASA/GSFC)

Maria received her Ph.D. in Meteorology from the Pennsylvania State University, where she studied ocean biogeochemistry and physics with Prof. Raymond Najjar. She is currently a support scientist with Sigma Space/NASA GSFC, studying the coastal carbon cycle.

"I would like to thank OCB for supporting my participation in the Summer 2013 Satellite Remote Sensing Training Course at Cornell University. The course by Bruce Monger was packed with useful information and hands-on exercises, and at the same times was fun

and interesting and enlightening. Thanks to Bruce for the great experience! I learned about a variety of remotely sensed data and data products and, most importantly, about various ways to access and process the data efficiently. I am directly involved in the Coastal Carbon Synthesis Activity, coordinated jointly by OCB and the North American Carbon Program (NACP). The near-shore systems are highly heterogeneous, which complicates temporal and spatial averaging of carbon fluxes and the construction of regional budgets. The use of remotely sensed data provides a tremendous opportunity to develop systematic methods for scaling up the local flux estimates to regional scales, which is vital to the synthesis work we are doing. The Cornell class gave me the necessary tools to incorporate remotely sensed ocean color and temperature data into my work in the most efficient way, rather than relying on "brute force" computing."

Annie Bourbonnais (Univ. of Massachusetts, Dartmouth)

Annie is currently a postdoctoral fellow at the School for Marine Science and Technology at University of Massachusetts Dartmouth. She primarily studies the role of eddies in nitrogen loss in oxygen minimum zones off Peru and Mexico. During her Ph.D. and M.Sc. projects, she studied nitrogen elimination processes in hydrothermal vent systems of the Juan de Fuca Ridge in the northeast Pacific Ocean and nitrogen fixation in the oligotrophic subtropical northeast Atlantic Ocean. Nitrogen is an essential macronutrient that affects primary productivity in most of the ocean.

"The Cornell satellite remote sensing course was a great experience that taught me more about programming (i.e. IDL, Python), which is an essential skill that can be easily used for other applications (e.g. sequence processing in microbiological work) and overall, will improve my productivity at work. The class provided essential remote sensing background that will allow me to better identify and study mesoscale eddies and produce high-quality figures for publications on the subject. Overall, the course was a wonderful experience. Bruce Monger is an expert in the field and one of the best instructors I know."

OCB provides travel support for U.S. students to attend 2013 SOLAS Summer School

Every two years, SOLAS (Surface Ocean Lower Atmosphere Study) coordinates and runs an international summer school that brings together >70 students and 15 world-class instructors for a combination of lectures and hands-on activities to provide exposure to the numerous disciplines involved in conducting research on ocean-atmosphere interactions. In an effort to promote collaborative opportunities and enrich the quality of research on air-sea interactions, OCB provided travel support for 9 early career scientists from the U.S. to participate in this year's Summer School in Xiamen, China, which took place August 23-September 2, 2013. Below are some of their reflections on the summer school.

Natalie Freeman, Univ. of Colorado, Boulder

Natalie Freeman has a B.S. in Mathematics with an applied concentration in Statistics from the University of Kansas in Lawrence, KS. During the summer of her junior year, she did an internship with the SMART (Summer Multicultural Access to Research Training) Program at the University of Colorado at Boulder, during which she analyzed Southern Ocean hydrographic data in order to quantify and understand Southern Ocean deoxygenation. This being her first hands-on research experience with a climate change-related topic she realized not only that this was the kind of work she wanted to pursue, but also where she wanted and needed to be. Natalie is currently a graduate student, research assistant, and National Science Foundation Graduate Research Fellow pursuing a Ph.D. in Atmospheric and Oceanic Science at the University of Colorado at Boulder. Her current project with Dr. Nicole Lovenduski involves using satellite estimates to assess the variable and changing calcification in the Southern Ocean.

"I consider it a great honor to have participated in the 6th International SOLAS Summer School in Xiamen, China. In addition to the lectures on various SOLAS themes, the hands-on workshops given by many esteemed research scientists in attendance catered to our specific research interests and also provided a more enriching experience. These lectures had just the right balance of background information, present-day research and events, and correlation to the future to keep everyone engaged, either by learning something new or digging deeper and adding to or expanding current knowledge. I experienced many "firsts" during this school, such as my first (short) cruise, which focused on investigating biological, physical, and chemical properties throughout a local estuary.

Presenting my current research, both by poster and orally in a professional setting, while receiving feedback from my peers and the scientists, was one of the major takeaways of the program that will carry on into my career. SOLAS gives young scientists the opportunity to find a place in the community, reminding us that we are the next generation of scientists. I left with greater confidence, great experience, broader knowledge of the field I'm pursuing, new and more finely tuned skills, great contacts, and many new friends."

Brian Butterworth (State Univ. of New York, Albany)

Brian is a doctoral student at the Atmospheric Sciences Research Center at SUNY Albany. He works with Dr. Scott Miller researching the relationship between wind speed and carbon dioxide gas exchange across the ocean surface. As part of his work, he assembled and installed an eddy covariance system on the bow mast of the research vessel *Nathaniel B. Palmer* in the Southern Ocean. Prior to his work at SUNY, he did Master's research at University of Colorado at Boulder focused on thermally driven upslope winds in the Rocky Mountains.

"Attendance at the SOLAS Summer School in Xiamen, China was an invaluable opportunity to connect with the scientific community in my field of research. One major benefit from the experience was the research advice I received from the organizing faculty. Through the conversations I had, I came home with better direction and specific 'next step' ideas on which I have been working. In addition, the opportunity to develop relationships with peers at a program like SOLAS allowed me to see my research in a global context and gain an appreciation for the value of an international scientific community. I was grateful to be invited (and supported) to participate in such a program."

Joanna Kinsey, State Univ. of New York, ESF

Joanna Kinsey is currently a Ph.D. candidate in the Department of Chemistry at the State University of New York, College of Environmental Science and Forestry. She works with Dr. David Kieber examining how changes in irradiance intensity and spectral quality affect the production of organosulfur compounds and acrylate in the polar phytoplankton *Phaeocystis antarctica*. In addition to her dissertation research, Joanna has participated in studies investigating aerosol production from bubble bursting, dimethylsulfide photochemistry, and biological consumption of dimethylsulfoxide and acrylate. While attending the University of San Diego for her bachelor's degree, Joanna examined anthropogenic impacts of a fish cannery on the Magdalena Bay ecosystem and participated in an Antarctic cruise studying the effect of free-floating icebergs on the surrounding chemistry and ecology.

"The 6th International SOLAS Summer School program in Xiamen, China was an invaluable opportunity to expand my understanding of the complex processes and interactions occurring in the surface ocean and lower atmosphere. Through the use of both lectures and lab practicals, we covered a wide range of topics from marine ecology to atmospheric photochemistry. These lectures provided me with additional context for my own research and affirmed my observations and conclusions. The laboratory practicals offered hands-on experience to areas outside of my own research, including marine genomics and modeling. The modeling practical was especially informative, demonstrating the attention to detail required and the importance of obtaining good field data to develop robust models. The SOLAS Summer School also stressed the importance of effective communication. Poster sessions, communication practicals, and oral presentations allowed us to critically evaluate our communication styles and gain feedback from our instructors and peers. In addition to the educational value and experience, it was incredible to explore such a vibrant city with an international group of my future colleagues and make connections that will last the rest of my career."

Cristina Romera-Castillo, Florida International Univ.

Cristina is a Postdoctoral Associate at the Florida International University, working in Rudolf Jaffé's Lab. She is studying the composition and size of dissolved organic matter using techniques such as preparative HPLC, solid phase extraction, ultrafiltration, optical measurements, and NMR. She received her Bachelor's degree in Chemistry from Universidad de Jaén (Spain) and her Ph.D. in Chemical Oceanography at the Instituto de Ciencias del Mar (ICM)-CSIC in Barcelona in collaboration with the Instituto de Investigaciones Marinas (IIM)-CSIC in Vigo. Her dissertation focused on the colored and fluorescent fraction of dissolved organic matter in the ocean and its links to microorganisms. Throughout the course of her Ph.D. program, she completed two graduate internships, one at the Wood Hole Oceanographic Institution (USA) and one at the Alfred-Wegener-Institut für Polar- und Meeresforschung (Germany). She has participated in multiple oceanographic cruises aboard national and international vessels.

"Last August, I participated in the SOLAS Summer School organized in Xiamen (China), thanks to the sponsorship of the Ocean Carbon and Biogeochemistry Program and SOLAS. It was a great experience. We had many lectures about different topics related to the oceanic and atmospheric sciences. I particularly liked the lectures and practicals about modeling, since this is not the focus of my current work but it would be a perfect complement to it. Having participated in this summer school, I am interested in learning more about carbon cycle modeling and its applications to my research. We also had other interesting lectures, some of which provided tips on writing papers and preparing posters for conferences, ethics in science, and other important topics that are not always covered in graduate courses. It was a great opportunity to meet and interact with other marine scientists and develop a professional network of colleagues that will remain in touch for years to come."

Oluwaseun Ogunro, New Mexico Institute of Mining and Technology

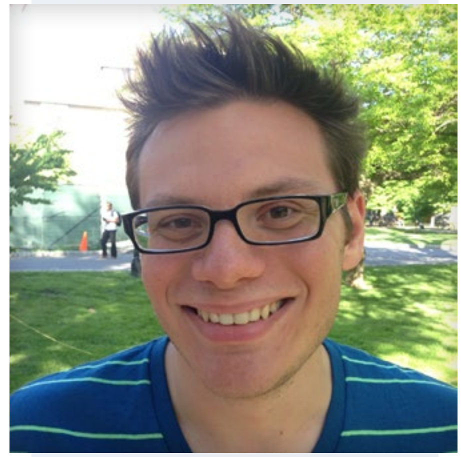
Oluwaseun O. Ogunro was born in Nigeria. He received a B.S. in Chemistry from Obafemi Awolowo University in 2008 and graduated in the top 5% of his class. He matriculated at the New Mexico Institute of Mining and Technology (NMT) in Fall 2011 as a Ph.D. student in ocean and atmospheric chemistry. He is working with Prof. Oliver Wingenter (NMT) and Dr. Scott Elliott (Los Alamo National Laboratory). Their research focuses on categorizing dissolved organic carbon in the global ocean into different marine macromolecules. This work is also in collaboration with Dr. Susannah Burrows, at Pacific Northwest National Laboratory, with the aim to estimate the mass fraction of different macromolecules in sub-micron sea spray aerosols.

"I was selected to attend the 6th International Surface Ocean Lower Atmosphere Study (SOLAS) summer school in China. My expenses were co-funded by NMT and OCB. The SOLAS workshop taught skills and theory of the many disciplines necessary to understand the nature of ocean-atmosphere interactions and their impacts on climate. I presented my research at the workshop, and it was beneficial for me to get feedback from the young and experienced scientists there.

The summer school included lectures and practical exercises that focused on several ocean and atmospheric processes. I participated in a cruise (along with other workshop colleagues) aboard the Xiamen University's Research Vessel OCEAN II to the Jiulong River Estuary to measure physical, chemical, and biological features of the estuary. As a modeler, I found this to be quite exciting.

Lectures and practicals were given by distinguished lecturers, including Peter Liss, Roland von Glasow, Phil Boyd, Laurent Bopp, Maurice Levasseur, David Kieber, Eric Saltzman, and others. It was a valuable opportunity for me to develop contacts, which promise to be *fruitful in the future. I am grateful to OCB and look forward to a rewarding career doing SOLAS- and OCB-relevant research."*

Andrew Babbin, Princeton Univ.



Andrew Babbin is a Ph.D. Candidate in the Geosciences Department at Princeton University. With his advisor, Bess Ward, he studies how fixed nitrogen, the limiting nutrient of ocean productivity, is lost from the marine system. His research focuses on two microbially-mediated processes, denitrification and anammox, by using stable isotope tracing techniques in the ocean's oxygen-deficient zones. With labeled tracers, he measures the rates of fixed nitrogen loss, analyzes the controlling effects of various environmental factors on nitrogen gas production, and investigates the balance between nitrous oxide production and consumption in these low-oxygen ocean basins. Prior to his graduate studies, Andrew received his Bachelor's degree in Earth & Environmental Engineering from Columbia University.

"The SOLAS Summer School presented me with the incredible opportunity to develop connections, both within and outside of my specific research area of biogeochemistry. As the field continues to progress toward one of vast collaborations among international scientists with highly varied research specialties, SOLAS was the perfect venue at which to begin my transition from graduate student to researcher. While being able to learn from a number of senior earth scientists will prove invaluable, the collaborations that will develop from having met and discussed research with fellow students will impact the progression of my career. This opportunity will not be wasted, and I am in OCB's debt for having supported my participation in the summer school."

Hilary Palevsky, Univ. of Washington

Hilary Palevsky is currently a 4th year Ph.D. student in the School of Oceanography at the University of Washington. Between earning a B.A. in Geology from Amherst College in 2007 and beginning her graduate studies in 2010, she spent a year traveling and studying the interactions between science and policy in the North Atlantic cod fisheries as a Thomas J. Watson Fellow and two years teaching marine science to K-12 students on traditionally rigged schooners in Long Island Sound. Her current research, advised by Drs. Paul Quay and Ginger Armbrust, uses geochemical tracers to study the rate and efficiency of biological carbon export and the role of the biological pump in oceanic absorption of carbon dioxide. Her region of study is the North Pacific Ocean, which she has crossed three times on Chinese container ships, a great sampling platform and a very different experience from sailing traditionally rigged schooners.

"The SOLAS Summer School in Xiamen, China did a fantastic job of introducing students from a broad array of academic backgrounds to a diverse set of research areas and skills, from atmospheric modeling to molecular analysis of marine microbes. The two-week school mixed lectures, small group hands-on practical sessions with the lecturers, and opportunities for the students to share our research with the lecturers and each other through poster sessions and oral presentations. For me, the opportunity to interact with a diverse group of young scientists from all over the world was the highlight of the experience. My network of peers has broadened significantly, a valuable resource for continued advice as I apply the new data analysis and modeling techniques I was exposed to at the summer school."

An interactive exhibit for demonstrating ocean acidification

Mike DeGrandpre[1], Cory Beatty[1], Holly Truit[1], Jason Blanchard[2] and Doug McIntosh[3]
[1]University of Montana, [2]StageWorx, Inc., [3]JDM Enterprises, Inc.

One of the challenges faced by all researchers when writing a NSF proposal is providing substantive broader impacts beyond the research outcomes themselves. Resisting the expeditious fallbacks of creating a webpage or speaking to community groups, I contemplated developing an ocean acidification exhibit for spectrUM, our on-campus science museum (http://spectrum.umt.edu/). If we can't bring Montana to the ocean why not bring the ocean to Montana? The spectrUM director (Holly) was receptive to the idea and wrote a strong supporting letter. We subsequently proposed the exhibit within the Broader Impacts section of an Arctic Observing Network (NSF-ARC) proposal, with a budget of $10,000. The proposal was funded and the panel and reviewers specifically mentioned the exhibit as one of the proposal's strengths.

With funding in hand, the challenge now was to create a working exhibit from my vague original concept, i.e. to show a pH change in the "ocean" by changing the CO_2 in the "atmosphere". There was no room for trial and error so hedging my bets and crossing my fingers, I chose to use a flowing stream (a river) to enhance gas exchange and have the atmosphere switch from 100% N_2 to 100% CO_2. Additionally, it was important that the ocean basin have a sufficiently small volume to show pH changes over a short time (< 1 minute). Enlisting the help of spectrUM's exhibit craftsman (Jason), a local electronics expert (Doug), and my long-time research technician (Cory), the idea became a reality, complete with sensors for "ocean" pH and "atmospheric" CO_2 and miniature figurines strolling on the ocean beach. Unfortunately, the ocean pH, projected on a large screen using a wireless transmission, did not change with addition of pure CO_2 to the headspace. However, bubbling the CO_2 into the river and placing the pH electrode directly in the river outflow gave measureable pH changes. The kids don't seem to care about these technical inconsistencies, but have focused on the control of the atmosphere by pushing the red (CO_2) or blue (N_2) buttons (see photo) and watching the pH response.

It has been a surprisingly big hit. Through spectrUM's field trips, clubs, camps, public hours, and birthday parties, 4,440 people have viewed the exhibit over the first 8 months. Of those served, approximately 1,000 were adults and the remaining 3,440 were preK-12th grade students. Over 15% of the visitors were Native Americans, Montana's largest minority group. The exhibit continues to have daily visitors. For those interested in building their own Ocean Acidification exhibit, the plans can be found here.

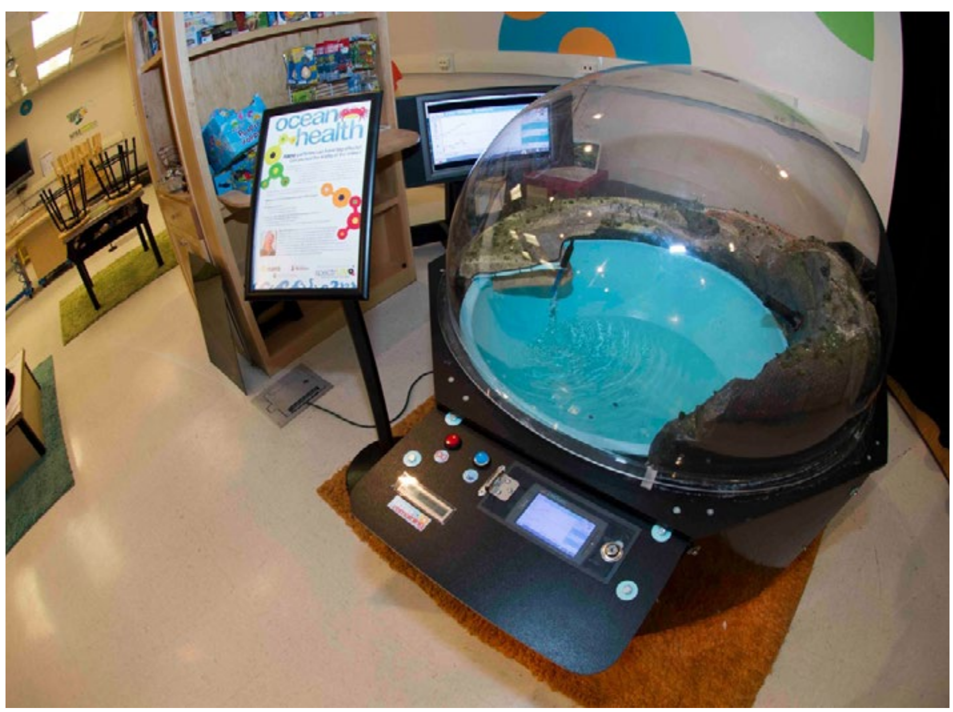


Photo courtesy of Todd Goodrich (University of Montana)

2nd Workshop to develop a Global Ocean Acidification Observing Network (GOA-ON)

St. Andrews, UK, 24-26 July 2013

While OCB was holding its annual summer workshop in Woods Hole, another major ocean-related meeting was taking place in St Andrews, Scotland to continue discussions of building a Global Ocean Acidification Observing Network. Specifically, the meeting focused on developing an integrated implementation and data-sharing infrastructure for the deployment of ocean observing assets. 85 scientists from 28 countries attended the meeting, including participants from UKOA, the OA-ICC, IOCCP, GOOS, and NOAA OAP, and a report will be available in late 2013. More information, including the workshop booklet, agenda, abstracts, and participants, can be found on the meeting website.

OA News Items

» The interim report from the first Global Ocean Acidification Observing Network (GOA-ON) workshop in Seattle, in 2012, is now available for download.

» A new factsheet, "20 Facts about Ocean Acidification," designed to assist scientists in speaking about ocean acidification, is available for download. This was produced by OCB, the OA-ICC, UKOA, NOAA OAP, Washington Sea Grant, and BIOACID. Versions in Spanish, French, and German should be available for download soon.

» Registration opens January 1 for the Wendy Schmidt Ocean Health X Prize for an affordable, reliable pH sensor.

» The Paul G. Allen Family Foundation has announced the winning concept for the the Ocean Challenge: Mitigating Acidification Impacts. The $10,000 prize was awarded to Dr. Ruth D. Gates from the University of Hawaii at Manoa and Dr. Madeleine van Oppen from the Australian Institute of Marine Science for their idea to implant selectively bred coral into existing reefs to help the coral withstand acidified waters. Visit http://www.pgafamilyfoundation.org/oceanchallenge/ for full details.

» Just prior to the OAPI 2013 meeting, NOAA's Ocean Acidification Program convened all of its funded PIs in a two-day meeting September 16 – 17 (Silver Spring, MD) to discuss and plan research priorities for the next 3 - 4 years. The meeting also highlighted accomplishments from the past two years. Most of the NOAA PIs then attended the follow-on OCB OA meeting at Gallaudet.

Ocean Acidification Special Issue in Phil. Trans. Roy. Soc B

http://rstb.royalsocietypublishing.org/content/368/1627.toc

Week of meetings in Washington, DC brings together U.S. ocean acidification research community

Again and again, "communication" was mentioned as one of the strongest needs in ocean acidification (OA) science during the week of the second ocean acidification principal investigators' (OAPI) meeting this September in Washington, DC. But, as Holly Greening (Tampa Bay Estuary Program) pointed out on the meeting's last day, the OA community has already generated so much conversation around the science that big results have already materialized in just a decade or two: major multi-year commitments of research funding by numerous federal and private organizations, national and state policies, discussion about OA at international levels, and early integration of OA science with other earth science issues like warming and deoxygenation. But the OA community isn't stopping there, as proven by recent events in Washington!

Before the OAPI meeting, COMPASS held a two-day training workshop focused on preparing more ocean acidification scientists to communicate publicly about their research with a variety of audiences. Similar in format to the 2012 workshop COMPASS offered before the Ocean in a High-CO_2 World meeting, scientists had opportunities to refine their message, role-play different interview scenarios with professional journalists, then receive feedback from the group.

On Tuesday evening, COMPASS and OCB hosted a panel discussion called "Ocean Acidification Tapas" among the journalists and four of the scientists who attended the communication workshop. Intended to focus on the challenges facing scientists when they discuss their research, the panel provided a light and fun introduction to some very serious issues and served as the kickoff to the OAPI meeting. Panelists also shared some highlights from the communications workshop, fueling much interest in the next one COMPASS plans to host!

The OAPI meeting itself began on Wednesday with a round of short talks by scientists. (Slides and the meeting agenda are available at the meeting website.) These talks highlighted new science and set up the themes of discussion for the breakout sessions later in the meeting. Chris Sabine (NOAA) spoke about developments in observing and measuring ocean acidification, followed by Todd Martz (Scripps) who talked about the state of technical development concerning OA sensors. Bruce Menge (OSU) spoke about ways in which the OMEGAS project was linking measurements to processes, followed by Gretchen Hofmann (UCSB), who spoke about advances in using molecular-to community-level methodologies to examine everything from individual effects to adaptive capacity of organisms to OA. Joan Bernhard (WHOI) then spoke on OA as one of many issues, and how more experiments are looking at OA in combination with temperature, oxygen, and other environmental factors, especially considering

the paleorecord. Finally, Francis Chan (OSU) spoke about uncertainty – not only from scaling up laboratory results, but also concerning using incomplete scientific results to try to inform future planning.

Next, Cheryl Dybas from NSF gave a short talk titled "The Changing Climate in Science Journalism," which focused on the ways in which traditional media and outlets for disseminating research to general audiences are changing. Attendees engaged Cheryl in a lively question-and-answer session afterwards, continuing the discussion around some questions that had cropped up initially at the COMPASS workshop. Some of the discussion addressed how to attribute funding sources, how to mention uncertainty when talking about experimental findings, and how to navigate interviews more effectively.

During lunch, Heather Galindo from COMPASS provided an extremely condensed version of the COMPASS communication training. She provided an overview of things to keep in mind, like: Who is the audience? What are they interested in? Are they used to hearing the conclusions first, or are they content to wait awhile? Then, participants practiced using the "message box" approach outlined in Nancy Baron's book, "Escape from the Ivory Tower", which is a key piece of COMPASS communication training workshops.

In the afternoon, program managers from all the Federal agencies associated with the Interagency Working Group on Ocean Acidification (IWG-OA) provided short overviews of their agency's investments in ocean acidification research, whether as a specific area of interest, or integrated within existing activities (see photo above). Participants included David Garrison (NSF), Paula Bontempi (NASA), Kenli Kim (State Dept.), Mary Boatman (BOEM), Paul Cough (EPA), Susan Russell-Robinson (USGS), Bret Wolfe (FWS), and Libby Jewett (NOAA, IWG-OA chair). Overviews also provided meeting attendees with a window into how some of the agencies less familiar to the ocean acidification research community work. Discussion following the panel focused on how to promote ongoing support for OA monitoring, data management, national and international capacity building, and future research projects.

Data management was the theme of the next session, led by a talk from Krisa Arzayus (NOAA NODC) followed by a panel discussion including Krisa, Cyndy Chandler (BCO-DMO), Hernan Garcia (NODC), and Phil Goldstein (OBIS USA). Discussion focused around programmatic issues such as support for data management, the challenges of linking multiple data repositories, and the DOI system; and around universal issues such as educating scientists on best practices, incentivizing the data management and archiving process, and balancing the need to support good data management with the temptation of using extra funds to collect more information.

The next morning, Paul Bunje from the X Prize Foundation shared details about the Wendy Schmidt Ocean Health Prize that focuses on development of affordable and reliable ocean pH sensors.

Most of Thursday and half of Friday were devoted to breakout sessions focused on discussing overarching issues relevant to OA science. Ten sessions were convened concurrently. Each breakout was designed to consider the state of ocean acidification knowledge in an interdisciplinary context, and then to start synthesizing trends and themes in ocean acidification science across environments. Leaders sought input from participants on how enhanced interdisciplinary activity can address knowledge gaps. Finally, each breakout was charged with identifying logical short-term steps and longer-term goals for the research community. The outcomes of each breakout session were shared with all meeting participants in plenary-session report-back periods, in which meeting participants could provide input to other breakout sessions' proceedings. Ultimately, the breakout leaders plan to assemble a special issue of *Oceanography* magazine containing papers summarizing the findings of each breakout session, as well as other science highlights from the OA community.

Important Dates

- **December 1, 2013:** Deadline for submission of proposals for OCB activities in 2014/2015
- **July 21-24, 2014:** OCB Summer Workshop (Woods Hole, MA)
- **August 19-21, 2014:** NACP/OCB Coastal Synthesis Final Community Workshop (Woods Hole, MA)

Meetings and Activities

Ligands and Eddies and Plasticity, Oh My! A Report from the 2013 OCB Summer Workshop

by Heather Benway, OCB Project Office

The 8th annual Ocean Carbon & Biogeochemistry summer workshop, sponsored by NSF and NASA, convened 173 participants from July 22-25, 2013 at the Woods Hole Oceanographic Institution in Woods Hole, MA.

Plenary sessions

This year's summer workshop included four plenary sessions:

Narrowing in on key biological carbon fluxes: Estimates, approaches, and uncertainties
Evolutionary responses of plankton to climate change
Trace element-biota interactions
Southern Ocean processes

The first plenary session *Narrowing in on key biological carbon fluxes: Estimates, approaches, and uncertainties* included presentations by Ken Johnson (MBARI), Rachel Stanley (WHOI), Paul Quay (UW), Matt Church (Univ. Hawaii), and Dave Siegel (UCSB). Talks in this session showcased various methods and associated data sets from satellites, autonomous platforms, and biogeochemical time-series that are used to calculate important biological carbon fluxes (e.g., net community production, or NCP). Presenters and participants examined discrepancies among flux estimates and discussed potential underlying sources of variability, focusing mostly on the methods themselves. They stressed the importance of 1) understanding the seasonality and the dominant physical and biogeochemical mechanisms at play in a given system, particularly with regard to nutrient supply and bloom dynamics; and 2) knowing exactly what you are measuring with the method(s) you are using. As a first step toward developing a more systematic and universal quantitative approach, participants stressed the need for a detailed assessment and comparison of methodologies, including spatiotemporal application, assumptions, and limitations. As part of this process, participants recommended the use of high-resolution models with constrained physics to place different methods in a common dynamical framework, which would help reveal methodological biases and identify which biogeochemical processes are most critical.

The second plenary session *Evolutionary responses of plankton to climate change* included presentations by Tatiana Rynearson (URI), Elena Litchman (Michigan State Univ.), Dave Hutchins (USC), Sinead Collins (Univ. of Edinburgh), and Carol Lee (Univ. of Wisconsin). Speakers in this session presented examples of evolutionary responses of different marine plankton to changing ocean conditions and described different patterns and mechanisms of adaptation. Throughout the session, presenters and participants discussed the implications of short-term physiological and ecological responses (phenotypic plasticity) for organisms' long-term adaptative potential. They described how evolutionary responses to environmental change are expressed and measured in an experimental setting, and recommended simple, controlled laboratory experiments involving perturbation of only one environmental variable at a time. Mesocosm studies and models were recommended as more effective tools to explore more complex scenarios involving multiple environmental stressors and species interactions. The group also identified examination of standing genetic variation in natural populations as another way to gain insights into the potential of these organisms to adapt to changing environments.

The third plenary session *Trace element-biota interactions* included presentations by C. Mark Moore (Univ. of Southampton), Kathy Barbeau (Scripps), Seth John (Univ. of South Carolina), Mak Saito (WHOI), and Adrian Marchetti (Univ. of North Carolina). Speakers in this session talked about physical and biogeochemical controls on micronutrient distributions in the ocean and explored mechanisms that different organisms use to increase bioavailability of these micronutrients. The presentations addressed an impressive array of chemical, molecular, and modeling approaches for exploring the complex interactions between micronutrients and biota. Discussions among participants and speakers largely focused on the study of iron-limited systems and the origin and roles of ligands in iron availability and uptake. Iron enrichment events typically occur over time scales of minutes to days, which makes it challenging to capture and study them. However, participants agreed that studying these episodic events, preferably in organisms' natural environments, was critical to achieving a better understanding of iron uptake mechanisms and associated physiological responses.

The final plenary session *Southern Ocean processes* included presentations by Michael Meredith (BAS), Hugh Ducklow (LDEO), Kevin Arrigo (Stanford), Nicole Lovenduski (Univ. of Colorado), and Eileen Hofmann (ODU). This comprehensive session featured talks on climate drivers (e.g., Southern Annular Mode, El Niño-Southern Oscillation), ocean circulation, carbon uptake, primary productivity, and ecosystem structure and the complex interactions among these processes in the Southern Ocean. The highlight of the discussion in this session was the importance of a large-scale observing program in the Southern Ocean. Existing measurements are sparse, leaving many parts of the Southern Ocean unstudied, and given the highly dynamic and complex nature of this system, results cannot be extrapolated from one region to another with confidence. Interdisciplinary field programs like Integrating Climate and Ecosystem Dynamics (ICED) have begun to provide tremendous insight into climate, biogeochemistry, and ecosystem dynamics in the Southern Ocean from a coordinated circumpolar perspective. Participants agreed that sustained shipboard and autonomous measurement campaigns represent the critical foundation of an effective observing system (Southern Ocean Observing System (SOOS)) that will support long-term study of these processes, and the implementation of such a system will require international coordination and investment. Cost-effective strategies such as the use of models for data assimilation will provide real-time feedback to help guide and improve autonomous platform design and deployment.

Other meeting highlights

In addition to the stimulating plenary sessions, this year's summer workshop featured reports on recent OCB and partner activities, including the GEOMICS (Genome-Enabled Ocean Microbiology Integrated with Chemical Surveys) workshop in February 2012 and the International Time-Series Methods workshop held in November 2012; a talk by Dave Siegel (UCSB) on EXPORTS, a new NASA field campaign to improve the predictability of the ocean's biological pump; agency updates by program managers from NASA and NSF; a talk by Ken Buesseler on the impacts of the Fukushima Dai-ichi nuclear power plant explosions on the ocean; short presentations by graduate students on their research interests; reports from the joint U.S. CLIVAR/OCB working groups; an overview of an OCB-relevant NSF EarthCube workshop; U.S. and international partner program activities and updates; three hands-on BCO-DMO (Biological and Chemical Oceanography Data Management Office) tutorials; and two interdisciplinary poster sessions.

For more information, including links to the talks and webcast footage, please visit the workshop website or contact Heather Benway.

Publications & Products

- » Benway, H. M., Doney, S. C. (2013). Addressing biogeochemical knowledge gaps. *International Innovation* (North America, June 2013), 12-14.
- » Workshop report from International Time-Series Methods Workshop (*Nov. 2012, BIOS, Bermuda*)
- » Report from Gulf of Mexico Coastal Carbon Synthesis Workshop soon to be released (contact OCB Project Office to view current draft)
- » 20 talking points about ocean acidification – a fact sheet to help scientists communicate ocean acidification to the media and the public (also see Ocean Acidification column)

Community Resources

Data and Research

- » New synthesis of the global methane budget (Global Carbon Project)
- » Updated global carbon budget to be released in November (Global Carbon Project)
- » International biogeochemical time-series network and email list
- » Climate Data Guide seeking data experts for assistance in reviewing strengths and limitations of carbon cycle data sets; if interested, please send email to climatedataguide@cgd.ucar.edu
- » New global plankton atlas (MAREDAT) published in *Earth System Science Data (ESSD)*
- » LDEO (Takahashi) Database V2012 NDP-088 (V2012) now available

Reading

- » IPCC 5th Assessment Report, Working Group I (Physical Science Basis), Summary for Policy Makers
- » 3rd special issue in DSRII on research at BATS, HOT and CARIACO
- » New book Ocean-Atmosphere Interactions of Gases and Particles by P.S. Liss et al.
- » New book Lost Antarctica – Adventures in a Disappearing Land by Jim McClintock
- » Initial design report for Future Earth

Education and outreach

- » Project PARKA (Planting AntaRctica in KAnsas) (also see Education column)
- » New interactive ocean acidification exhibit at Univ. of Montana (also see Ocean Acidification column)

Science Planning

- » National Research Council is conducting a Decadal Survey of Ocean Sciences (DSOS 2015) - provide input on future ocean science research priorities here

OCB Partner Activity

Key uncertainties in the global carbon cycle: Perspectives across terrestrial and ocean ecosystems

August 6-10, 2013 (Boulder, CO)

As part of the NCAR Advanced Studies Program (ASP) Colloquium *Carbon-climate Connections in the Earth System*, a researcher workshop entitled *Key uncertainties in the global carbon cycle: Perspectives across terrestrial and ocean ecosystems* convened an international body of terrestrial and ocean carbon cycle expertise to discuss processes common to both reservoirs that are closely tied to the carbon cycle. The workshop was co-sponsored by the Carbon Cycle Interagency Working Group and its U.S. Carbon Cycle Science Program, USDA, U.S. CLIVAR, NSF, and OCB. The workshop was divided into four themes, including disturbance, remineralization and decomposition, nutrient limitation, and individual organisms/trophic interactions. All workshop presentations and accompanying webcasts are available on the workshop website. Meeting highlights and recommendations will be soon be published in a meeting report in *Eos Trans.* American Geophysical Union.

Partner Program Updates

IMBER

- IMBER Open Science Conference (June 23-27, 2014, Bergen, Norway) (see flyer on next page)
- New IMBER-endorsed projects
  - Sustainability of Marine Ecosystem Production under multi-stressors and Adaptive Management (MEcoPAM)
  - Variability of Ocean Ecosystems around South America (VOCES)
  - BIoGeochemical cycles in the SOUTHern Ocean: Role within the Earth System (BIG-SOUTH)

SOLAS

- SOLAS seeking community feedback on future program directions and research themes
- SOLAS-relevant sessions at upcoming 2014 Ocean Sciences meeting
- Report on your national SOLAS-related projects and research activities here
- New SOLAS-endorsed projects
  - Ocean Atmosphere Sea Ice Snowpack (OASIS) program
  - NETCARE - NETwork on Climate and Aerosols: Addressing Key Uncertainties in Remote Canadian Environments
  - Western Atlantic Climate Study II (WACS II)

U.S. CLIVAR

- New U.S. CLIVAR Science Plan to be released in December
- U.S. CLIVAR Town Hall meetings at 2013 Fall AGU and 2014 Ocean Sciences meetings

IOCCP

- Data submission deadline for SOCAT v3 is December 31, 2013
- Establishment of Biogeochemical Essential Ocean Variables

How Can OCB Help You

- Looking to **publicize a recent paper**? Add it to the OCB peer-reviewed literature list, contact the Project Office about doing a science feature on the OCB website, or submit to the OCB Newsletter
- Want to **share news** about education and outreach resources, jobs, field opportunities, relevant upcoming meetings and special sessions, etc.? Post to the OCB email list
- Looking for **international travel support**? The OCB Project Office has limited funds for U.S. participation in international workshops and meetings that advance the programmatic mission of OCB. The OCB SSC reviews travel support requests three times a year: March, July, and November

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OCB Calendar

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

2013	
November 26-29	Symposium on Integrating New Advances in Mediterranean Oceanography and Marine Biology (Barcelona, Spain)
December 4-6	PMIP Ocean Workshop 2013 Understanding Changes since the Last Glacial Maximum (Corvallis, OR)
December 9-13	Fall American Geophysical Union (AGU) Meeting (San Francisco, CA)
2014	
January 6-25	Austral Summer Institute XIV (ASI XIV) - Coastal and Open Ocean Studies through Multiple Approaches (Concepcion, Chile)
January 26-29	2014 Gulf of Mexico Oil Spill and Ecosystem Science Conference (Mobile, AL)
February 22-23	Bering Sea Project Open Science Meeting (Honolulu, HI)
February 23-28	2014 Ocean Sciences Meeting (Honolulu, HI)
April 15-18	North Pacific Marine Science Organization (PICES) Open Science Meeting Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems (FUTURE) (Kohala coast, Big Island, HI)
April 22-25	WESTPAC 9th International Scientific Symposium (Nha Trang, Vietnam)
April 27-May 2	European Geosciences Union General Assembly 2014 (Vienna, Austria)
May 5-9	46th Liège Colloquium: Low oxygen environments in marine, estuarine and fresh waters (Liège, Belgium)
May 18-23	Joint Aquatic Sciences Meeting (JASM) (Portland, OR)
May 27-June 28	C-MORE Summer Course in Microbial Oceanography (Honolulu, HI)
June 23-27	Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) Open Science Conference: Future Oceans – Research for marine sustainability: multiple stressors, drivers, challenges and solutions (Bergen, Norway)
July 6-11	Gordon Research Conference Ocean Global Change Biology (Waterville Valley, NH)
July 21-24	2014 OCB Summer Workshop (Woods Hole, MA)
August 4-9	IMBER ClimEco4 Summer School - Delineating the issues of climate change and impacts to marine ecosystems: Bridging the gap between research, assessment, policy and management (Shanghai, China)
August 19-21	NACP/OCB Coastal Synthesis Final Community Workshop (Woods Hole, MA)
November 17-21	2nd International Ocean Research Conference: One Planet, One Ocean (Barcelona, Spain)

UPCOMING FUNDING DEADLINES

For a full list of OCB-relevant funding opportunities (including rolling submissions), please visit http://www.us-ocb.org/data/funding.html

2013	
December 3	NSF Ocean Acidification proposal deadline
December 6	Marine Science and Technology Foundation - Expression of Interest deadline
December 6	Schmidt Ocean Institute Expression of Interest deadline for collaborative research cruises on R/V Falkor in 2016
December 6	NSF Arctic Research Opportunities proposal deadline
2014	
January-June	Wendy Schmidt Ocean Health X Prize Registration open (early-bird registration ends in March)
January 13	Partnerships for Enhanced Engagement in Research (PEER) (NSF, USAID) proposal deadline
January 21	NSF Coastal SEES proposal deadlines
February 15	NSF Chemical Oceanography and Biological Oceanography proposal targets
May 16	Marine Science & Technology Foundation full proposal deadline
August 15	NSF Chemical Oceanography and Biological Oceanography proposal targets

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Editor: Heather M. Benway

OCB Project Office, Woods Hole Oceanographic Institution
Dept. of Marine Chemistry and Geochemistry
266 Woods Hole Road, Mail Stop #25
Woods Hole, MA 02543
v 508-289-2838 · f 508-457-2193

We welcome your comments and contributions for publication.
hbenway@whoi.edu