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Using sensor-based, geochemical measurements from autonomous platforms to estimate biological production and export of carbon during the 2008 North Atlantic Spring Bloom

Matthew B. Alkire[1], Mary Jane Perry[2], Eric D'Asaro[1], and Craig M. Lee[2]
[1]University of Washington, [2]University of Maine

Net community production and the spring bloom

Each year an explosion of green highlights the North Atlantic between late March and early May. This event, known as the spring phytoplankton bloom, has interested researchers for decades (Sverdrup, 1953) due to its important role in the Earth's carbon cycle. Despite their relatively small size, the rapid bloom of these microscopic plants is an important part of the global oceanic uptake of carbon dioxide (CO_2) from the atmosphere (Takahashi *et al.*, 2009). Through physical processes such as deep mixing and air-sea exchange as well as the biological uptake exemplified by the spring bloom, the world oceans have absorbed approximately half of the total CO_2 released to the atmosphere through the burning of fossil fuels since the Industrial Revolution (Sabine *et al.*, 2004). Regulation of this important greenhouse gas by oceanic uptake moderates the potential for climate warming since CO_2 absorbs long wave radiation emitted by the Earth's surface and reflects it back (i.e. the greenhouse effect). As anthropogenic influences continue to impact the oceans, the processes responsible for this CO_2 regulation may change; however, detecting such change via oceanographic monitoring using traditional techniques requires exorbitant sums of both time and money. The primary objective of the 2008 North Atlantic Bloom (NAB) experiment was to test whether or not automated platforms could be relied upon to obtain the measurements necessary to closely and accurately study large and complex biological processes in remote areas of the ocean. Previous *OCB News* articles have introduced NAB (Perry *et al.*, 2012) and discussed how eddies can stratify the water column and initiate blooms (Mahadevan, 2013; also Mahadevan et al., 2012). This article focuses on the biogeochemical measurements col-

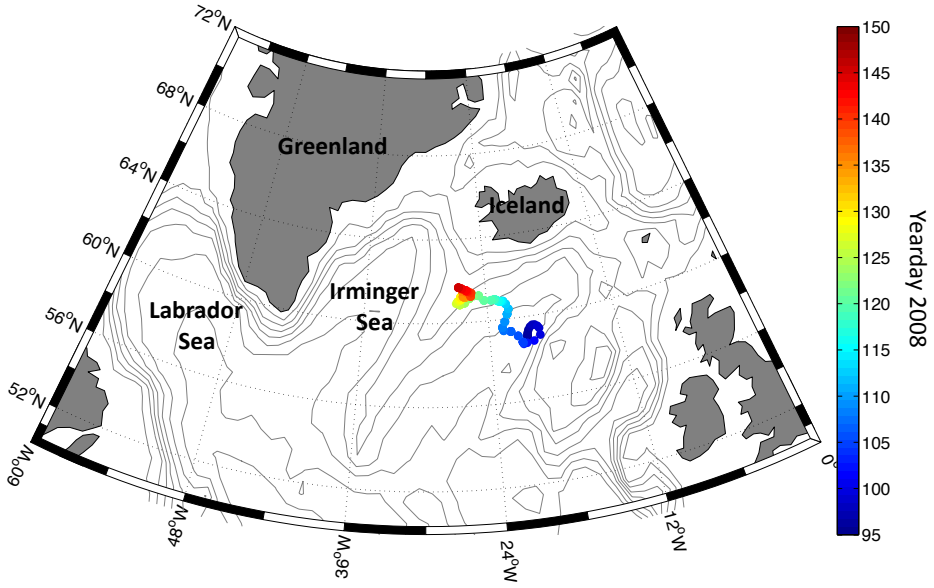


Figure 1. Track of the Lagrangian float during the 2008 North Atlantic Bloom Experiment. Colors represent the progression of the float in time (in days) from initial deployment (yearday 95) to recovery (yearday 150).

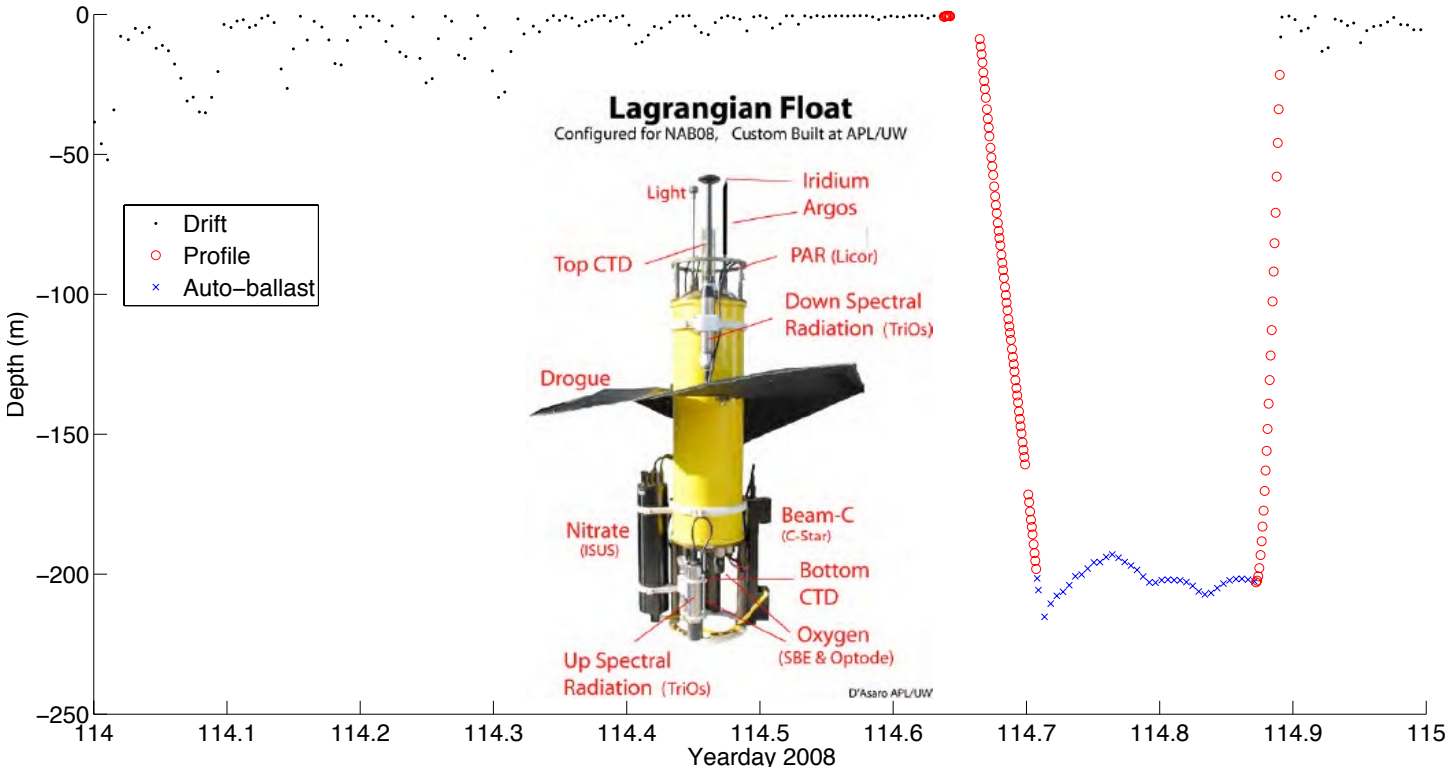


Figure 2. Depth-distribution of measurements collected by the Lagrangian float (schematic shown as inset) over the daily mission cycle (April 23, 2008). Black dots, red circles, and blue x's indicate measurements collected during the mixed layer drift, vertical profiling, and auto-ballast procedure, respectively. Redrawn from Alkire et al. (2012).

lected from Lagrangian floats during the experiment and the application of these data to estimate rates of the biological uptake of CO_2 and vertical export of this carbon to the deep ocean.

The biological process responsible for the drawdown of CO_2 is called net community production (NCP), which is defined as the difference between gross photosynthesis by primary producers (i.e., phytoplankton) and total respiration by the resident biological community (phytoplankton, zooplankton, and microbes). Positive values for NCP imply higher net production over respiration whereas negative values suggest community respiration in excess of primary production. NCP can be summarized in chemical terms as follows:

$$106\ CO_2 + 16\ HNO_3 + H_3PO_4 + 78\ H_2O = C_{106}H_{175}O_{42}N_{16}P + 150\ O_2 \qquad (1)$$

Thus, the photosynthetic conversion of CO_2 to organic carbon ($C_{106}H_{175}O_{42}N_{16}P$) utilizes nutrients ($NO_3$ and PO_4) and produces oxygen gas (O_2) in more or less relative proportions called the Redfield ratio. The rapid rise and fall of spring phytoplankton blooms have important implications for the carbon budget because they absorb CO_2 from the atmosphere, convert it to particulate organic carbon (POC), and quickly sink out of the water column, potentially transporting the absorbed CO_2 to depth where it may be sequestered. Hence, it is important to study the spring bloom and how it may respond to ongoing environmental changes such as warming and ocean acidification.

The Redfield ratio from equation (1) allows estimates of NCP from direct oceanographic measurements of change in CO_2, POC, dissolved organic carbon (DOC), O_2, and/or NO_3. However, there are numerous difficulties to consider, including the expense associated with operating a ship in the remote parts of the North Atlantic for a sufficient time to study the bloom, flexibility in scheduling research cruises (as the initiation of the spring bloom varies from year to year), and the exhaustive manual hours associated with sample collection and laboratory analysis.

Measuring the bloom

NAB employed heavily instrumented autonomous platforms (i.e. Lagrangian floats and Seagliders) to collect high-quality physical, chemical, and biological measurements during the bloom. Lagrangian floats are specifically designed to follow water parcels and this frame of reference minimizes advective effects, allowing the resulting measurements to be interpreted as the time-evolution of the water parcel. Seagliders, in contrast, move independently through the water column and can therefore be used to make directed, high-resolution measurements over time and space. For this experiment they provided a larger spatial context for the float measurements. This article focuses on data collected by the Lagrangian float deployed within a phytoplankton patch in the North Atlantic on April 4, 2008 (Fig. 1). The float executed a daily mission cycle wherein it drifted within the mixed layer during most of the day, performed a vertical profile from the surface to ~230 m, conducted an auto-ballasting operation at depth, and profiled back up to the mixed layer and subsequently continued its drift (Fig. 2). The float was outfitted with numerous sensors that allowed continuous measurements of temperature, salinity, pressure (i.e. depth), O_2, NO_3, and optical parameters that were used as proxy measurements of POC through well established linear relationships (Cetinić *et al.*, 2012).

Data collected by the float indicated that the phytoplankton bloom evolved over three distinct phases. A rapid decrease in NO_3 (Fig. 3a) and silicic acid concentrations (Fig. 3d) and a concomitant increase in O_2 (Fig. 3b) and POC (Fig. 3c) in the shallower layers (0-25 and 25-50 m) of the water column between yeardays 114 (April 23) and 118 (April 27) marked the Early Bloom. This short bloom was interspersed with periods of deep mixing, the first of which is reminiscent of winter conditions prior to the onset of the bloom and the second resulting from a brief storm period of high winds. Opposing trends in the biogeochemical measurements were apparent during the storm: NO_3 increased whereas O_2 and POC decreased. The bloom recommenced after the storm passed and the water column re-stratified. The subsequent Main Bloom period (yeardays 127-134) was characterized by a large, near-linear decline in NO_3 and similar increases in O_2 and POC. The Main Bloom was dominated by diatoms and terminated, due most likely to depletion of silicic acid to near zero concentrations, between yeardays 134 and 135. Following bloom termination, the Post Bloom phase (yeardays 141-145) was a period of relatively little NCP, with only small changes in NO_3, O_2, and POC.

Estimating budgets

Measurements of O_2, NO_3, and POC were used to construct a set of coupled budgets, allowing estimates of both NCP and the apparent export of POC. Inventories of O_2, NO_3, and POC within the water column may change over time due to a combination of biological (NCP) and physical processes including mixing, advection, and air-sea exchange (in the case of gases like CO_2 and O_2). The effects of advection and horizontal mixing were minimized by the Lagrangian (i.e. patch-following) reference frame. Since the float drifts within a single patch of water, the flow of "outside water" carrying different O_2, NO_3, and/or POC concentrations past the sensors is minimal. Therefore,

Bloom Phase	NO_3 uptake	O_2 production	ASE	POC production	O_2:NO_3	NCP	POC export	Export ratio
	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}		mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	
Early	16	95	3	43	6	68	23	34%
Main	17	167	83	33	10	119	82	69%
Post	3	3	39	2	1	2	0	0%

Table 1. Estimates of the NO_3 uptake, O_2 production, air-sea exchange (ASE), and POC production over the budget volume, expressed in units of mmol m^{-2} d^{-1}, during each bloom phase. O_2:NO_3 ratios were computed by dividing the O_2 production and NO_3 uptake. Net community production (NCP) was estimated by dividing the O_2 production by the corresponding Redfield ratio (O_2:C ≈ 1.4). The apparent, vertical export of particulate organic carbon (POC) was estimated by subtracting the observed POC production from the NCP. The export ratio refers to the percentage of POC export relative to the NCP. Adapted from Alkire et al. (2012).

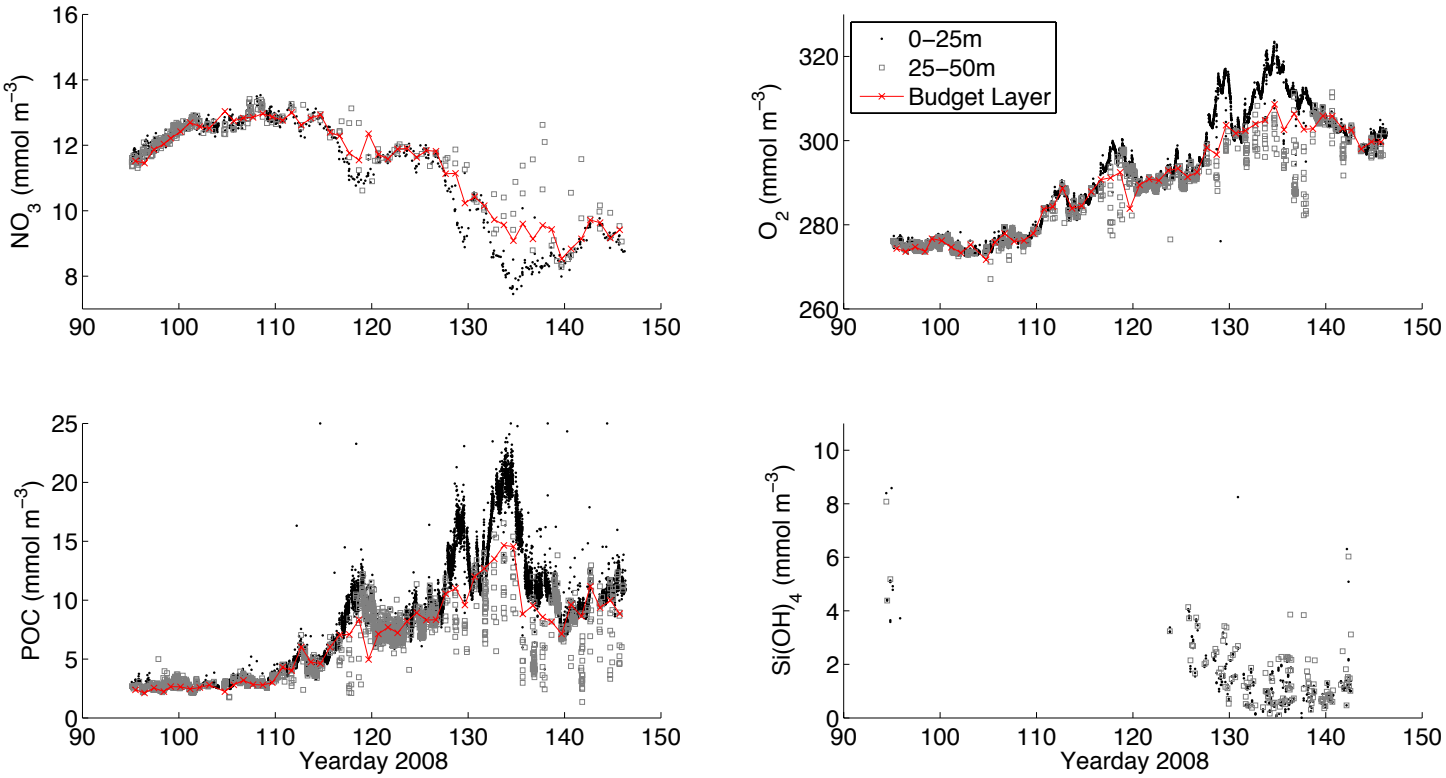


Figure 3. Concentrations of NO_3 (upper left), O_2 (upper right), and POC (lower left) measured by the float between 0-25 m (dots) and 25-50 m (squares) over the experiment period. The red line indicates the mean concentrations over the phytoplankton patch. The lower right-hand panel shows silicic acid concentrations collected from shipboard operations during float deployment, calibration, and recovery exercises. Redrawn from Alkire et al. (2012).

concentration changes observed by the float are largely "internal" to the phytoplankton patch. Vertical mixing was eliminated from the balance by choosing an isopycnal (a layer of constant density) as the bottom boundary of the patch. Selection of a constant density surface instead of a constant depth surface prevented isopycnal heaving (such as that caused by internal waves) from altering concentrations through vertical advection and obscuring smaller terms. Eliminating these physical processes from the balance allows the observed changes in the O_2 concentration to be interpreted as the sum of air-sea exchange and NCP. Once the air-sea exchange term was estimated from observations of wind speed and surface O_2 concentrations, it was subtracted from the observed change in the O_2 inventory. The remainder is interpreted to be the NCP. During the Early and Main Bloom phases, the change in O_2 was significantly positive (Table 1), indicating net production exceeded respiration during each of the two periods. For the Post-Bloom phase, little net oxygen production was observed, suggesting a close balance between production and respiration.

The POC budget is somewhat more complicated than the O_2 budget due to the production of both particulate and dissolved pools of organic carbon (unfortunately, the latter could not be measured autonomously):

$$NCP = \Delta POC/\Delta t + \Delta DOC/\Delta t - S \quad (2)$$

The "S" term in equation (2) represents vertical export (i.e., sinking) of POC from the patch. In order to calculate export, NCP, $\Delta POC/\Delta t$, and $\Delta DOC/\Delta T$ must be known. First of all, the estimate of NCP derived from the O_2 balance was converted to units of carbon by dividing the biological O_2 production by the Redfield ratio (150:106 ≈ 1.4) given in equation (1). This yields rates of carbon production for the Early, Main, and Post Bloom periods of 68, 119, and 2 mmol C m^{-2} d^{-1}, respectively (Table 1). Next, rates of change in POC inventory within the patch were estimated from optical parameters measured from float-borne sensors. The observations indicated similar changes in POC over the Early and Main Blooms, but little change during the Post Bloom period. The final term, DOC concentration, was not measured during the experiment. Instead, O_2:NO_3 ratios constrained the potential accumulation of DOC during each bloom phase.

Since air-sea processes do not influence NO_3 concentrations and the

observational approach minimizes the impact of physical processes such as vertical mixing and advection, changes in NO_3 inventories are due entirely to biological processes. Using Redfield ratios, we can predict the changes in the NO_3 inventory from our measurements of the biological production of O_2. According to equation (1), the uptake of 16 moles of NO_3 should result in the production of 150 moles of O_2, a ratio of 150:16 ≈ 9.4. Therefore, we can combine our estimates of O_2 production and NO_3 uptake from the float measurements and compare the resulting ratios with the Redfield ratio. Positive deviations from the Redfield ratio are possible when DOC production is significant. Dissolved organic carbon is relatively poor in nitrogen; therefore its production is relatively NO_3-deficient, resulting in O_2:NO_3 ratios of 22 and higher. During the Main Bloom, the O_2:NO_3 ratio was quite close to that expected for Redfield production (Table 1). In contrast, the O_2:NO_3 ratio was relatively low during the Early Bloom, indicating "overconsumption" of NO_3. Overconsumption of NO_3 has been previously observed in the North Atlantic prior to the onset of the spring bloom and has been attributed to protein synthesis during early growth stages (Bury *et al*., 2001). The Post Bloom period is ignored since the changes in O_2 and NO_3 are very close to zero. Consequently, these observations suggest little DOC accumulation during the experiment and we can reasonably assume $\Delta DOC/\Delta t = 0$. Thus, the apparent vertical export of POC from the patch can be estimated from the difference between NCP and $\Delta POC/\Delta t$.

Vertical export and recycling of carbon

During the Early and Main Bloom periods, the apparent POC export was estimated to be 23 and 82 mmol C m^{-2} d^{-1}, respectively. In other words, 69 % of the carbon produced within the patch during the Main Bloom sunk out, versus only 34 % during the Early Bloom. This comparison suggests vertical export was greatest during the Main Bloom period. Elevated export was likely due to limitation of diatom production by the rapidly decreasing concentrations of silicic acid indicated in Fig 3d. Diatoms need silicic acid to build and maintain their frustules. Previous work has shown that diatoms will aggregate and sink out of the water column once silicic acid is depleted below a certain threshold concentration (~2 µM) and form cysts that will allow them to "hibernate" until environmental conditions are once again favorable for growth (Smetacek, 1985; Rynearson *et al*., submitted). Nutrient limitation has also been associated with the production of a form of DOC known as transparent exopolymer particles (TEP). The production of TEP to aid diatoms in aggregation and sinking has led to the idea that this process may result in an enhanced vertical export of carbon, significantly increasing the importance of spring diatom blooms in the sequestration of carbon in the deep ocean (Engel and Passow, 2001). However, this process should result in C:N ratios (or O_2:NO_3 ratios) that exceed the Redfield ratio. Recent studies have suggested that high C:N ratios in the North Atlantic are restricted to summer months and therefore do not occur during the spring bloom (KÖrtzinger *et al*., 2001). The O_2:NO_3 ratio reported here seems to agree with this assessment.

What is happening at the end of the bloom? We may shed some light on this question by comparing independent estimates of the POC flux at different depths. Martin *et al.* (2011) used a different chemical method called ^{234}Th disequilibria to calculate the flux of POC below 100 m depth in the same general area of the float and over a period synonymous with the Main Bloom (yeardays 128-134). Martin *et al.* (2011) estimated a POC flux of 30-50 mmol C m^{-2} d^{-1}, much less than the 82 mmol C m^{-2} d^{-1} calculated using the coupled budgets. One possible explanation for this discrepancy is the difference in the depths of the associated estimates. While Martin *et al*.'s lower estimate applies to export below ~100 m, our higher estimate is associated with a shallower depth of ~60 m (the mean depth of the isopycnal). We hypothesize that rapid and efficient remineralization of carbon in the upper water column drives the decrease in POC export between these two depths. This process could also explain the general lack of DOC (i.e., TEP) in the patch during this large export event. As the material sinks, it is rapidly remineralized at depths < 100 m by bacteria and zooplankton taking advantage of the large groups of stressed diatom cells. Carbon-rich TEP is preferentially (and therefore quickly) recycled, leaving little left behind to enhance export. Material reaching 100 m depth will likely encounter fewer grazers and/or be more resistant to remineralization, as the efficient recycling between 60 and 100 m has removed the labile materials.

Summary

The North Atlantic spring bloom is a regular, large-scale phenomenon that has interested researchers for decades due to the rapid uptake of atmospheric CO_2 from the atmosphere and its potential sequestration via vertical export of phytoplankton cells to depth. Geochemical sensors deployed on autonomous platforms such as Lagrangian floats and Seagliders provide a new and innovative way to gather accurate, high-resolution data in which to study the evolution of this event as various environmental changes such as warming sea surface temperatures and ocean acidification continue to impact biological processes.

Budgets of O_2, NO_3, and POC were derived from data collected by a Lagrangian float deployed in the North Atlantic prior to the onset of the spring diatom bloom. These budgets suggested the bloom progressed in three distinct stages (Early, Main, and Post Blooms) interspersed with wind-driven mixing events before eventually terminating due to silicate limitation. Differences between independent estimates of POC export suggest that TEP may in fact be produced near the surface of the water column during the spring bloom to aid in diatom aggregation and export, but is rapidly remineralized in the upper water column. This hypothesis could explain both the general lack of DOC production measured in the North Atlantic during the spring bloom, as well as C:N ratios resembling the Redfield ratio at depth.

Although there are some disadvantages to the use of autonomous platforms for studying ocean processes (e.g., limited number and type of variables measured, sensor drift, and calibration uncertainty), many of these hurdles can be overcome through careful experimental planning, intense calibration activities, and sensor redundancy. While ship operations remain essential to ongoing oceanographic study, autonomous platforms can be used to collect high-quality data over a variety of temporal and spatial scales that can be used to expand data sets, augment ship-based operations, and/or collect measurements in hazardous environments or those that pose expensive logistical challenges.

References

Alkire, M. B. *et al.*, 2012, *Deep-Sea Res. I* **64**, 157-174.

Bury, S. J. *et al.*, 2001, *Deep-Sea Res. I* **48**, 689-720.

Cetinić I. *et al.*, 2012, *J. Geophys. Res.* **117**, doi:10.1029/2011JC007771.

Engel, A., Passow, U., 2001, *Marine Ecol. Prog. Ser.* **219**, 1-10.

Körtzinger, A. *et al.*, 2001, *Deep-Sea Res. I* **48**, 661-688.

Mahadevan, A. et al., 2012, *Science* **337** (6090), 54-58, DOI:10.1126/science.1218740.

Mahadevan, A., 2013, *OCB News* **6(1)**, 5-8.

Martin, P. *et al.,* 2011, *Deep-Sea Res. I* **58**, 338-349.

Perry, M. J. *et al.*, 2012, *OCB News* **5(3)**, 1-5.

Rynearson, T. *et al.,* submitted, *Deep-Sea Res.*

Smetacek, V., 1985, *Mar. Biol.* **84**, 239–251.

Sverdrup, H. U., 1953, *J. Conseil Internat. pour l'Exploration de la Mer* **18**, 287-295.

Takahashi, T. *et al.,* 2002, *Deep-Sea Res. II* **49**, 1601-1622.

The Bermuda Atlantic Time-series Study (BATS) enters its twenty-fifth year of ocean observations in the North Atlantic that illustrate changes in ocean carbon

Nicholas R. Bates[1], Michael W. Lomas[2], Rodney J. Johnson[1]

Bermuda Institute of Ocean Sciences (BIOS)[1], Bigelow Laboratory for Ocean Sciences (BLOS)[2]

Introduction

The Bermuda Atlantic Time-series Study (BATS; 31°40′N, 64°10′W) project has entered its twenty-fifth year of ocean time-series observations in the subtropical North Atlantic Ocean southeast of Bermuda (Fig. 1). This milestone in ocean observation is shared with its sister time-series off Hawaii (Hawaii Ocean Time-series; HOT or station ALOHA; A Long-term Oligotrophic Habitat Assessment; 22°45′N, 158°00′W); with both ocean time-series providing a wealth of hydrographic and biogeochemical data that have been used to examine, test, and refine many oceanographic paradigms and hypotheses. Since the inception of the BATS project in 1988, more than 450 peer-reviewed journal articles, numerous book chapters, and other documents have been published using BATS data.

In this article, we briefly review the history of the time-series, and the types of sampling and data this oceanographic time-series continues to generate. The BATS project benefits from synergies and connectivity with complementary ocean time-series off Bermuda, including Hydrostation S (32°10′, 64°30′W; started in 1954 by Hank Stommel of Woods Hole Oceanographic Institution (WHOI) and continued at BIOS), the Ocean Flux Program (OFP; started in 1978 by Dr. Werner Deuser and continued today by Dr. Maureen Conte), and associated projects that have used BATS as the context for improving scientific understanding of ocean chemistry and biogeochemistry. "The sum is greater than the individual parts" is an apt phrase for this nexus of scientific time-series endeavors.

Secondly, we focus on the long-term changes in the inorganic carbon cycle in the North Atlantic Ocean off Bermuda, its importance for understanding the uptake of anthropogenic carbon dioxide (CO_2) by the ocean, and the impact of ocean acidification on seawater CO_2-carbonate chemistry. This is one of the many scientific highlights and insights associated with the BATS project, and the reader is directed to an upcoming special volume in *Deep-Sea Research II* for a more in-depth treatment of ocean time-series research (Church et al., In press). Many of these insights have included numerous studies on the physical environment of the oligotrophic gyre (e.g., changes in temperature, salinity, water mass properties, and the role of mesoscale eddies), nutrient cycles and dynamics, and changes in ecosystem structure and paradigms for understanding processes that influence the biology and biogeochemical cycles of the North Atlantic Ocean (Church et

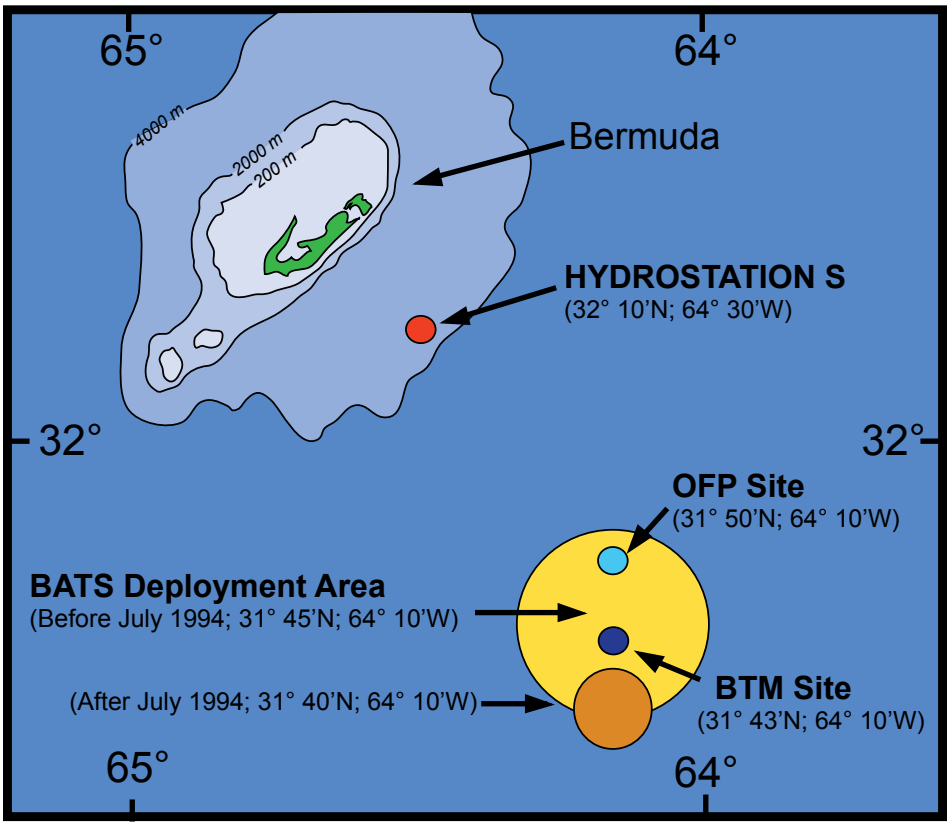


Figure 1. Location map of the Bermuda Atlantic Time-series Study (BATS) site off Bermuda (yellow and orange symbols; 1988-present). The locations of Hydrostation S (red symbol; 1954-present), the OFP site (cyan symbol; 1978-present), and the Bermuda Testbed Mooring (BTM; blue symbol; 1994-2004) are also shown.

al., In press).

Finally, we briefly discuss the involvement of key scientists who have profoundly influenced the BATS project and for a generation of scientists, technicians and engineers, and students, the legacy of training and educational experiences that the project has provided. Sustained shipboard observation of the ocean is not without difficulty due to many factors, and the success of BATS, HOT, and other ocean time-series owes much to the dedication of many scientists and technicians.

A brief history of the BATS project

One of the earliest and most well known time-series is the continuous plankton recorder (CPR) surveys of ocean phytoplankton communities started in 1931 by Sir Alistair Hardy. Subsequently, ocean time-series research began in earnest during the 1950s with the initiation of Hydrostation S in the open ocean (known as the *Panularis* site in its early days) and other coastal time-series, such as the Helgoland Roads time-series in the North Sea started in the early 1960s. Oceanographic time-series such as BATS and HOT owe their initiation to these earlier efforts (Church et al., In press). For studies of the ocean carbon cycle, the first comprehensive survey and collection of inorganic carbon samples in the open ocean occurred as part of the Geochemical Ocean Sections Study (GEOSECS) between 1971 and 1978. GEOSECS laid the foundation for subsequent scientific expeditions, with the Transient Tracers in the Ocean (TTO) expedition of the North and tropical Atlantic Oceans following in the early 1980s (Sabine and Tanhua, 2010). In the early and mid-1980s, two major global ocean survey programs began, namely the World Ocean Circulation Experiment (WOCE) and Joint Global Ocean Flux Study (JGOFS). Early in the planning stages of JGOFS, a need for more comprehensive time-series sampling of ocean biogeochemistry and biology was recognized and two U.S. ocean time-series, BATS and HOT, were initiated in 1988 with funding from the U.S. National Science Foundation (NSF). The primary goals of BATS (and HOT) have been and continue to be improving scientific understanding of the "time-varying" components of the ocean carbon cycle and related biogenic elements of interest (e.g., nitrogen, phosphorus, and silica); and identifying the relevant physical, chemical, and ecosystem processes responsible for the observed variability.

Oceanographic sampling at BATS

Over the past twenty-five years, there have been sustained repeat occupations of the BATS site via monthly "core" cruises. As many oceanographers can attest, shipboard sampling in the winter, even in the subtropical North Atlantic Ocean, can be difficult due to weather and sea conditions, but despite this, the longest interval between sampling is ~6 weeks, apart from an 11-week hiatus in 2006 marking the transition from the older ship R/V *Weatherbird II* to the R/V *Atlantic Explorer*. Each year, three additional BATS "bloom" cruises are undertaken to increase sampling frequency during the spring period of elevated phytoplankton primary production and biomass accumulation, while an annual BATS "validation" cruise allows assessment of the broader spatial variability of hydrography, biology, and biogeochemistry in this region of the ocean. These BATS cruises collectively provide the necessary spatiotemporal coverage to observe and document variations in the plankton community, elemental cycles (carbon, nitrogen, phosphorus, etc.) and associated physical and biogeochemical processes, and coupling of atmospheric forcing and ocean physics over a range of time and space scales.

Since the inception of the BATS project, we have completed over 400 cruises, including 293 core cruises, 71 bloom cruises, and 47 validation cruises. Each cruise includes CTD profiles, hydrocast water sampling through the water column to 4,500 m, rate measurements, and associated ancillary sampling for a variety of biological and biogeochemical parameters. Since 1988, more than 4,000 CTD casts have been conducted, not including physical and bio-optical measurements from separate bio-optical instrument package casts. Discrete samples (Knap et al., 1997) from 37 depths (0-4,500 m) include the following: Dissolved oxygen (DO), salinity, dissolved inorganic carbon (DIC = $CO_2 + HCO_3^- + CO_3^{2-}$), total alkalinity (TA), nutrients (NO_3, NO_2, PO_4, $SiOH_4$), total organic carbon (TOC), total dissolved nitrogen (TDN) and phosphorus (TDP), soluble reactive phosphorus (SRP), particulate organic carbon (POC), nitrogen (PON), silica (BioSi), and phosphorus (POP), and a suite of HPLC phytoplankton pigments, bacterial abundance and picoplankton abundance by flow cytometry, and day and night zooplankton and phytoplankton net tows. The associated NASA project, Bermuda Bio-optical Program (BBOP), has collected upper ocean optical properties on each cruise. On every BATS core and bloom cruise, rate measurements include dawn to dusk *in-situ* primary production and short, four-hour on-deck bacterial production incubations. During core BATS cruises, a MultiPITS sediment trap is deployed for ~72 hours (trap depths of 150, 200, and 300 m), and retrieved samples are analyzed for total mass, total C (and by subtraction, inorganic C), POC, PON, and total P fluxes. Core BATS cruises also include underway measurements of temperature, salinity, ADCP/meteorological

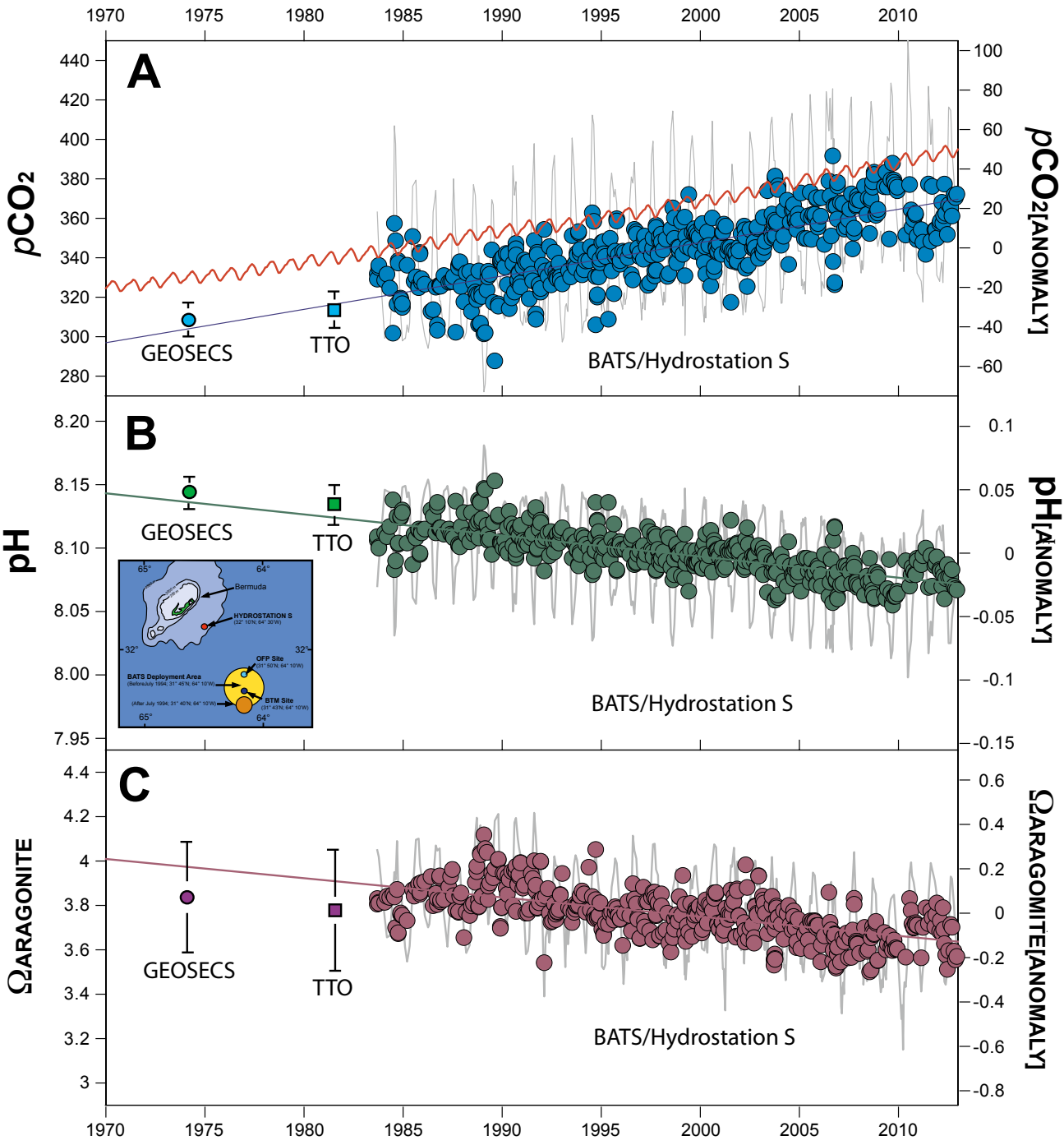


Figure 2. Time-series of atmospheric and oceanic pCO_2, pH, and aragonite saturation states (Waragonite) from 1970-2013 near Bermuda. Seawater CO_2-carbonate chemistry parameters were calculated from observed DIC and total alkalinity according to Bates et al. (2012). In each of the panels, observed pCO_2, pH, and Waragonite data are shown by the grey lines and compared with seasonally detrended data that accounts for seasonality at BATS according the method of Bates et al., 2012. (A) Atmospheric pCO_2 (ppm) from Mauna Loa, Hawaii (red line; NOAA ERSL data courtesy of Pieter Tans), and surface ocean seawater pCO_2 (µatm) at the BATS site off Bermuda. Observed (grey line) and seasonally detrended (blue line and symbols) surface ocean seawater pCO_2 levels are shown. Earlier seawater data from GEOSECS (stations 67°58'W, 33°59'N; 56°33'W, 33°20'N) and TTO (stations 67°21'W, 34°41'N; 61°20'W, 34°42'N; 56°11'W, 32°08'N) expeditions in the North Atlantic Ocean are also shown in this and following panels. (B) Surface ocean seawater pH at the BATS site off Bermuda. Observed (grey line) and seasonally detrended (green line and symbols) seawater pH are shown. (C) Surface ocean Waragonite at the BATS site off Bermuda. Observed (grey line) and seasonally detrended (deep pink line and symbols) seawater Waragonite are shown. Modified from Bates et al. (2012).

data, chlorophyll biomass, and partial pressure of CO_2 (pCO_2).

Importantly, BATS CTD, bottle, and rate measurement data, as well as science event logs and preliminary release CTD data for the most recent cruises are available at http://bats.bios.edu/ and via anonymous ftp (ftp://ftp.bios.edu). The data are also archived at the U.S. National Oceanographic Data Center (NODC) and, in the near future, at the Biological and Chemical Oceanography Data Management Office (BCO-DMO), the CLIVAR/Carbon Hydrographic Data Office (CCHDO), and OceanSITES.

Ocean carbon cycle and ocean acidification variations at BATS

The time-varying dynamics of vertical mixing and marine biogeochemical cycling in the upper ocean controls primary production, net air-sea exchange of CO_2, and distribution of many biologically important elements in the sea. Understanding controls on the ocean carbon cycle in the North Atlantic subtropical gyre requires that we not only examine variations in ocean carbon chemistry (TA, DIC, pCO_2, pH, etc.), but also how they interact with physical and biological processes. Two recent papers (Bates et al., 2012; Bates, 2012) indicate that primary production, warming/cooling, air-sea CO_2 gas exchange, and natural modes of climate variability such as the North Atlantic Oscillation (NAO), Atlantic Multidecadal Variability (AMV), and El Niño-Southern Oscillation (ENSO) are important drivers of the inorganic carbon system.

On socially relevant time scales (i.e. decades to centuries), biological processes sequester large quantities of atmospheric carbon (including anthropogenic CO_2) in the ocean, modulating the concentrations of CO_2 in the lower atmosphere. Several indirect methods exist to determine the rates of uptake and cumulative inventories of anthropogenic CO_2 in the global ocean, including back calculation (e.g., ΔC*, MIX, TrOCA) and tracer-based (e.g., transit-time distributions (TTDs)) estimates (Sabine and Tanhua, 2010), but rate and inventory estimates are accompanied by significant uncertainties and caveats. Direct observations of DIC or pCO_2 changes over time from open-ocean, regional sea, and coastal sea time-series are thus important to validate these indirect approaches. Such direct observations include repeat monthly or seasonal sampling at a fixed ocean time-series location (e.g., BATS - Bates et al., 2012; HOT - Dore et al., 2009; Canary Islands - Gonzalez-Davila et al. 2010), annual reoccupation of a fixed location or ocean section (e.g., Iceland and Irminger Seas - Olafsson et al., 2010), long-term opportunistic surface sampling that is irregular in time and space but sufficient to establish long-term regional trends (e.g., surface pCO_2, Takahashi et al., 2009; McKinley et al., 2011), or lower-frequency repeat sampling along an ocean section via large hydrographic survey programs like WOCE and CLIVAR/CO_2 Repeat Hydrography.

Direct observations of seawater CO_2-carbonate chemistry off Bermuda since 1983 at Hydrostation S and 1988 at BATS (the combined BATS/Hydrostation S CO_2 time-series) represent the longest continuous record of contemporary ocean carbon cycle changes, including oceanic anthropogenic CO_2 uptake and associated changes in ocean CO_2 inventory and acidity (Fig. 2). Earlier inorganic carbon data sets from GEOSECS and TTO extend the time-series back to the early 1970s (Fig. 2). At the BATS site, surface water DIC increased by 1.53±0.12 µmoles $kg^{-1}yr^{-1}$, and pCO_2 increased at a rate of 1.62±0.12 µatm yr^{-1} (Bates et al., 2012; Fig. 2a). Since 1983, DIC and pCO_2 have increased by ~40 µmol kg^{-1} (~3%) and ~50 µatm (~20%), respectively, due to uptake of anthropogenic CO_2.

As a comparison to the observed changes at the BATS site, the increase in surface/mixed layer DIC in the Atlantic Ocean has ranged from 0.85-1.53 µmol kg^{-1} yr^{-1} (Knap et al., 1997; Olafsson et al., 2010; Sabine and Tanhua, 2010; Bates et al., 2012). Estimates at the higher end of this range are observed in the longest (>20 years) time-series (e.g., Sargasso and Iceland Seas), and are consistent with expected DIC increases due to oceanic anthropogenic CO_2 uptake. Increases in Atlantic seawater pCO_2 have ranged from 1.62-2.60 µatm yr^{-1} (Gonzalez-Davila et al., 2010; Olafsson et al., 2010; Bates et al., 2012), similar to those obtained from the longest spatio-temporal records of seawater pCO_2 (Takahashi et al., 2009; McKinley et al., 2011). These seawater pCO_2 changes are also consistent with rates of atmospheric pCO_2 increase at the longest time-series sites (Bates et al., 2012; Bates, 2012). Over the last 30 years, North Atlantic surface seawater DIC and pCO_2 have increased by ~1.5-2% and ~12-18%, respectively, indicating that surface seawater DIC and pCO_2 have kept pace with contemporaneous atmospheric pCO_2 increase over the last few decades. The concentration gradient between oceanic and atmospheric pCO_2 (i.e., ΔpCO_2), a primary forcing for air-sea CO_2 gas exchange, has remained fairly constant over time.

Observations at BATS indicate that the Revelle Factor (β) values have also increased (Bates et al., 2012), suggesting that the capacity of North Atlantic Ocean surface waters to absorb CO_2 has diminished, even though seawater pCO_2 has kept pace with increasing atmospheric pCO_2. The sink of CO_2 into subtropical mode water (STMW) in the North Atlantic has been estimated at 0.985 ±0.018 Pg C (Pg = 10^{15} g C)

between 1988 and 2011 (70±1.8% of which is due to uptake of C_{ant}).

The sink of CO_2 into the STMW is 20% of the CO_2 uptake in the North Atlantic Ocean between 14-50°N (Bates, 2012). However, the STMW sink of CO_2 was strongly coupled to the North Atlantic Oscillation (NAO), with greater uptake of anthropogenic carbon, or CO_2 into STMW during the 1990s (NAO positive phase; Bates, 2012). In contrast, uptake of CO_2 into STMW was much reduced in the 2000s during the NAO neutral/negative phase. Thus, NAO-induced variability of the STMW CO_2 sink is important when evaluating multi-decadal changes in North Atlantic Ocean CO_2 sinks.

The gradual acidification of the surface ocean is also evident at BATS. Surface water pH, carbonate ion concentration [CO_3^{2-}], and saturation state for calcium carbonate ($CaCO_3$) minerals such as aragonite ($\Omega_{aragonite}$) have also decreased over the last three decades (Fig. 2b, c). Surface seawater pH has declined at a rate of 0.0017 ± 0.0002 yr^{-1}, while $\Omega_{aragonite}$ has decreased by 0.009 yr^{-1}. Ocean time-series seawater CO_2-carbonate chemistry data collected at BATS and other sites are thus important for quantifying ocean CO_2 uptake and associated changes in ocean chemistry, validating indirect assessments of anthropogenic CO_2 (C*) uptake and inventories, and studying ocean acidification impacts over time (Tanhua et al., 2013).

People and education

As the current stewards of the BATS project, we are keenly aware that the success of BATS (and other time-series for that matter) depends on the dedication of many scientists, technicians and students who are and have been involved with the ocean time-series over the last few decades. In the 1980s, both BATS and HOT were initiated with the commitment of the Ocean Sciences division at NSF and this continued. For the first 23 years of the BATS project, Anthony H. Knap served as Principal Investigator for the project. Tony's vision and commitment to ocean observation and ocean time-series shaped the BATS project into the successful scientific endeavor it is at present, and his stewardship of ocean observation continues in his current role at the Geochemical and Environmental Research Group (GERG; Texas A&M University). Other scientists have also contributed greatly to the BATS project as co-investigators, including Anthony F. Michaels (USC; University of Southern California), Dennis A. Hansell (RSMAS; Rosenstiel School of Marine and Atmospheric Sciences), Deborah K. Steinberg (VIMS; Virginia Institute of Marine Sciences), and Craig A. Carlson (UCSB; University of California, Santa Barbara). Over the last 25 years, the expertise and dedication of more than 40 other scientists and technicians have contributed to sustained high-quality ocean observations off Bermuda.

Through interests of prior and current scientists and technicians, BATS has maintained an active and diverse educational component throughout its existence. This has included a broad demographic of U.S. and international undergraduate research interns and graduate students, as well as graduate-level international scholars in the POGO/Nippon Foundation Centre of Excellence in Observational Oceanography program. Many of the students and interns that have been involved with BATS early in their scientific careers continue to interact with BATS, but now in the role of research colleagues.

References

Bates, N.R. et al., 2012, *Biogeosci.* **9**, 2509-2522, doi: 10.10.5194/bg-9-2509-2012.

Bates, N.R., 2012, *Biogeosci.* **9**, 2649-2659, doi: 10.10.5194/bg-9-2649-2012.

Church, M.J. et al., In press, *Deep-Sea Res. II*, http://dx.doi.org/10.1016/j.dsr2.2013.01.035.

Dore, J.E. et al., 2009, *Proc. Natl. Acad. Sci. U. S. A.* **106**, 12235-12240, doi: 10.1073/pnas.0906044106.

Gonzalez-Davila, M. et al., 2010, *Biogeosci.* **7**, 3067-3081, doi:10.5194/bg-7-3067-2010.

Knap, A.H. et al., Eds., *BATS Methods Manual, Version 4*, (U.S. JGOFS Planning Office, Woods Hole, MA, 1997), 136 pp.

McKinley, G.A. et al., 2011, *Nature Geosci.* **4**, 606-610, doi:10.1038/Ngeo1193.

Olafsson, J. et al., 2010, *Earth Syst. Sci. Data* **2**, 99-104, www.earth-syst-sci-data.net/2/99/2010/.

Sabine, C.L., Tanhua, T., 2010. *Ann. Rev. Marine Sci.* 2, 175-198, doi:10.1146/annurev-marine-120308-080947.

Takahashi, T. et al., 2009, *Deep-Sea Res. I* **56**, 2075-2076, doi:10.1016/j.dsr2.2008.12.009.

Tanhua, T. et al., 2013. *The marine carbon cycle and ocean carbon inventories* (and references therein). J. Church, G. Seidler, Eds. (Springer-Verlag, New York), submitted.

Ocean TECH – A new project to inspire middle and high school students to pursue STEM careers

By Johanna Wren and Barbara Bruno (C-MORE Education Office)

The Center for Microbial Oceanography: Research and Education (C-MORE) is starting a new two-year project funded by NSF/GeoEd to stimulate interest in ocean, earth and environmental science careers among underrepresented middle and high school students. This "Ocean TECH" project features a series of events that emphasize hands-on ocean science and technology and interactions with career professionals.

The first Ocean TECH event was held in February as part of the University of Hawai'i's "Mānoa Experience" college preview day. The event consisted of two parts. Middle school students participated in a "fast and furious" program of hands-on activities that stimulated scientific thinking and creativity, based on the Ocean FEST model but adapted for 6th-8th graders. High school and community college students conducted lab investigations on global change that utilized Hawai'i Ocean Time series (HOT) data based on the C-MORE Science Kits. Both programs drew direct links between the hands-on science activities, research currently being conducted at C-MORE and the School of Ocean and Earth Science and Technology (SOEST), and careers that benefit Hawai'i.

An integral part of Ocean TECH is near-peer teaching. Graduate students serve as instructors and undergraduates serve as teaching assistants, through which they convey their enthusiasm for their chosen field of study. Middle and high school students can more easily relate to these young role models, which can make pursuing an ocean or earth science career seem more attainable. This program also provides outreach and science communication training for the student instructors.

The goal of Ocean TECH is to inspire underrepresented pre-college students, such as Native Hawaiians and Pacific Islanders, to pursue a career in the geosciences. Through partnerships with GEAR-UP (Gaining Early Awareness and Readiness for Undergraduate Programs) and the Office of Multicultural Student Services, we have reached students from underserved communities in Hawai'i and throughout the Pacific.

Providing a strong connection between science activities and career options is vital. In an effort to connect post-high school students with professionals in the STEM field, C-MORE organized a career mixer in partnership with the Kamehameha Schools Bishop Estates, entitled Mālama i ka 'āina, Mālama i ke kai, (Caring for the Land, Caring for the Ocean). This March 2013 event was organized by Jessica Ayau and provided 25 post-high school students the opportunity to interact and network with 25 professionals in various careers in the ocean and earth sciences. Building on the success of this event, we are planning future career events that reach more students.

If you are interested in learning more about Ocean TECH please contact Johanna Wren (jwren@hawaii.edu) or Barbara Bruno (barb@hawaii.edu) in the C-MORE Education office.

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.

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

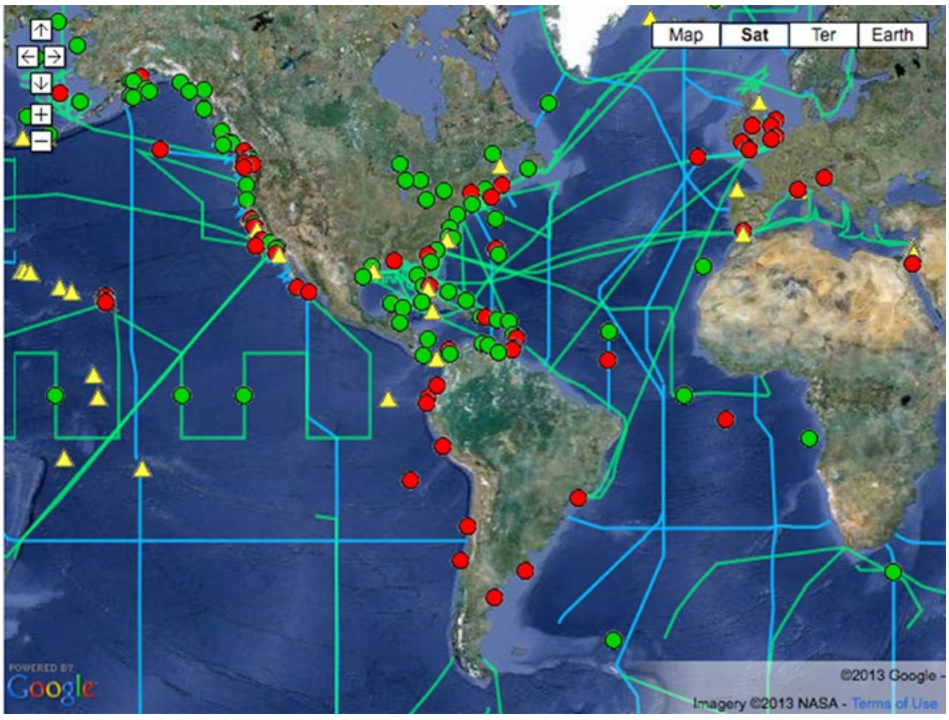
St. Andrews, UK, 24-26 July 2013

To continue the progress started by last year's Seattle workshop on developing an ocean acidification observing network, a second gathering will be held in Scotland in July by UKOA, the OA-ICC, IOCCP, GOOS, and NOAA OAP. This workshop intends to design the components and locations of a global ocean acidification observing network; identify measurement parameters and procedures for major components; and develop the strategy for data management.

The meeting will also devote particular attention to improving the comparability of coastal/shelf sea ocean acidification observations; bringing together national and regional components into a global whole; creating linkages with ongoing time series and biological monitoring; and synthesizing existing data.

For more information on this invitational workshop, contact workshop co-chairs Jeremy Mathis (NOAA PMEL; also the current OCB-OA subcommittee co-chair) or Phil Williamson (NERC/U. of East Anglia).

Present distribution of ocean acidification observing assets, from the 2012 Seattle GOA-ON workshop website.



Second U.S. Ocean Acidification Principal Investigators' Meeting

Gallaudet University's Kellogg Conference Center, 18-20 September 2013.

The OCB Project Office and Ocean Acidification Subcommittee is hard at work planning the second U.S. OA Principal Investigators' OAPI Meeting in Washington, DC this fall. The meeting goals include strengthening scientific collaboration and minimizing duplication of efforts; synthesizing the current state of knowledge, identifying major uncertainties, and discussing the way forward; promoting effective data management and sharing; exploring how to apply results of OA studies to the world outside the lab; and identifying outstanding research questions.

To achieve these objectives, the organizers have created an agenda full of panel discussions, plenary discussions, and targeted breakout sessions. These will explore how current U.S. ocean acidification research and organizational support fit together, and how the community can encourage greater synergy. Meeting attendees will be able to showcase their own research findings during poster sessions, while plenary sessions are devoted to exploring the overall state of the science and planning future opportunities together.

Participants will include the academic research community, federal agency researchers, program managers, representatives of nongovernmental organizations, and more. Register today!

Ocean Tapas: Small Bites of Big OA Issues

Gallaudet University's Kellogg Conference Center, 17 September 2013, 7:00-8:00 pm

The OAPI meeting kickoff activity on Tuesday evening will be hosted by COMPASS. Similar to the Ocean Tapas panel preceding last year's Ocean in a High-CO_2 World Meeting, this will be a fast-paced discussion among journalists and scientists on the latest findings, thorniest challenges, and social relevance of ocean acidification science. Moderated by Nancy Baron (COMPASS Director of Science Outreach), this panel will highlight the hot topics in the field and jumpstart conversations about communicating your science at the OAPI meeting and beyond. Join us for this lively event and the chance to meet and talk with the journalists at the no-host reception to follow. You will have a chance to make great new connections with the media and each other in this fun kick-off event.

Annual meeting of the SOLAS-IMBER Working Group on Ocean Acidification and the International Coordination Centre on Ocean Acidification Advisory Board, 13-14 May 2013

The advisory board of the newly formed Ocean Acidification International Coordination Centre, based at the International Atomic Energy Agency Laboratory in Monaco, met for the first time this spring. The advisory board includes scientists (many from the SOLAS-IMBER OA WG), representatives from major national and international OA research programs, representatives from international organizations, and government and foundation representatives. The OA-ICC is supported by IAEA Member States and through the Peaceful Uses Initiative.

Topics discussed include initiatives designed to promote international activities that are not currently funded at national or international levels. These include facilitating international observing, developing joint facilities and platforms, promoting collaboration between natural and social scientists, continuing to update the best practices documents presently available, hosting an open-access bibliographic database, facilitating data management, building capacity, and continuing outreach activities.

In the next few months, the OA-ICC will be launching its new website. The site will provide a central source for ocean acidification news and information on international OA-ICC activities.

Paul G. Allen Ocean Challenge: Mitigating acidification impacts

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

Register to participate in the June 17 webinar to learn more about this opportunity.

A Budding International Biogeochemical Time-Series Network

The biogeochemistry of the ocean varies across a range of time and space scales, with anthropogenic forcing contributing an added layer of complexity. In a growing effort to distinguish between natural and human-induced earth system variability, sustained ocean time-series measurements have taken on a renewed importance. Shipboard biogeochemical time-series programs provide the oceanographic community with the multi-year, high-quality data needed for characterizing ocean biogeochemistry and ecosystem variability. They represent one of the most valuable tools scientists have to characterize and quantify ocean carbon fluxes and their associated links to a changing climate.

There is extraordinary, unexploited strength in numbers with respect to ocean time-series. Large spatial-scale analyses using many different time-series will allow us to detect and interpret links between climate variability and ocean biogeochemistry, ultimately improving our understanding of marine ecosystem change. However, in order to bring together datasets from different time-series, it is important that the sampling and analytical protocols used at each site are transparent, consistent, and inter-comparable.

International Time-Series Workshop

In November 2012, an international time-series methods workshop was jointly convened by OCB and the International Ocean Carbon Coordination Project (IOCCP) at the Bermuda Institute for Ocean Sciences (BIOS). A brief synopsis of the workshop was published in the April 23 issue of *Eos*. The full workshop report is in the final stages of review and revision, and will be released to the OCB and IOCCP communities soon. The report includes detailed recommendations on shipboard sampling order, as well as sampling and analytical considerations and tiered method recommendations for nine sets of biogeochemical parameters, including pigments, in line measurements, CTD parameters and discrete calibrations, inorganic macro- and micronutrients, biomass, inorganic carbon parameters, biological rate measurements, trap fluxes, and organic matter. The report also summarizes participant discussions and key issues raised during the workshop, including experiments and intercomparison activities to improve internal consistency and data intercomparability across time-series; metadata documentation; development of a coordinated international network of biogeochemical time-series; and funding and capacity-building issues, including minimum lists of core variables needed to monitor various aspects of global ocean change.

International Time-Series Network website

As one of the key recommendations from the workshop, we have been working on a new, permanent time-series network web presence for global ship-based biogeochemical time-series, including an interactive map of all time-series and downloadable files that include detailed information about their measurements and methods. This website also includes regular science features (great way to increase visibility of new time-series products and publications), time-series reports and products, and more.

Time-Series Network Email List

The international network of shipboard biogeochemical time-series also offers an email list. It represents an opportunity for time-series PIs and staff to communicate and coordinate with one another. The list is used to provide information about:

- previous and upcoming time-series-relevant meetings and workshops
- employment, funding, and cruise opportunities
- scientific publications and outcomes from time-series sites
- time-series experiments and intercomparison activities
- potential "calibrations of opportunity"

If you are interested in subscribing to our growing email list **TS_network@whoi.edu**, please click here.

NACP/OCB Coastal Synthesis Activities The Gulf of Mexico Coastal Carbon Workshop

OCB continues its partnership with the North American Carbon Program (NACP) to coordinate and facilitate research activities to refine carbon budgets for the coastal regions of North America. The Gulf of Mexico Coastal Carbon Workshop was held March 27-28, 2013 in St. Petersburg, FL. The workshop, which convened 37 scientists, opened with an overview presentation on the history of carbon cycle and coastal synthesis activities in the U.S., followed by a presentation on the current state of the Gulf of Mexico carbon budget. Each flux team leader then presented on the work they had done over the past few months to refine their flux estimates, including data synthesis, literature searches, modeling efforts, etc. Flux teams included riverine input, estuarine fluxes, submarine groundwater discharge, air-sea fluxes, primary production, respiration and NCP, and exchange at the ocean boundary. The flux teams then went into breakout sessions to discuss how they could make near-term improvements to their flux estimates, potential near-term outcomes (e.g., peer-reviewed publications), and recommendations for longer-term observational and modeling investments that would require additional funding. The flux team leaders then reported out to the entire group and the meeting closed with an open discussion about workshop outcomes, including a workshop report in the near-term and multiple peer-reviewed publications over the next 12-18 months. We are also exploring the potential for a special journal issue on the coastal synthesis activities. After the meeting ended, flux team leaders met to update the Gulf of Mexico carbon budget numbers and develop a plan for the workshop report. We also followed up on key issues raised for various fluxes during the meeting. When the report is completed, it will be circulated widely via the OCB and NACP email lists, the OCB and NACP websites, and the coastal carbon wiki. In the meantime, the agenda, participant list, and presentations given at the workshop are available on the workshop website.

To view the status of coastal carbon budgets for different North American coastal regions, please view articles published in previous issues of the OCB newsletter (east coast, west coast, Gulf of Mexico, Arctic, Great Lakes). The east coast budget was updated as a result of the east coast team meeting in January 2012. Results are available in the meeting report. To get regular regional updates, please visit the Coastal Synthesis Wiki Site. A final community workshop highlighting the findings and outcomes of the North American coastal synthesis activities is tentatively planned for 2014.

Publications & Products

- Benway, H. M., Doney, S. C. (2013). Addressing biogeochemical knowledge gaps. *International Innovation* (North America, June 2013), 12-14.
- *Eos* meeting report Improving Intercomparability of Marine Biogeochemical Time Series, full workshop report to be released soon
- Peer-reviewed literature:
  - Hauri, C. et al. (2013). Spatiotemporal variability and long-term trends of ocean acidification in the California Current System. *Biogeosciences*, 10: 193-216. [oi:10.5194/bg-10-193-2013].
  - Khatiwala, S. et al. (2013). Global ocean storage of anthropogenic carbon. *Biogeosciences*, 10: 2169-2191. [doi:10.5194/bg-10-2169-2013].
  - Le Quéré, C. et al. (2013). The global carbon budget 1959–2011. *Earth System Science Data*, 5: 165-185. [doi:10.5194/essd-5-165-2013].
  - Moore, C. M. et al. (2013). Processes and patterns of oceanic nutrient limitation. *Nature Geosciences*, 1-10. [doi:10.1038/ngeo1765].
  - Wang, Z. A. et al. (2013). The marine inorganic carbon system along the Gulf of Mexico and Atlantic coasts of the United States: Insights from a transregional coastal carbon study. *Limnology and Oceanography*, 58: 325-342. [10.4319/lo.2013.58.1.0325].

OCB Co-Sponsorships & Travel Support

- » International Ocean Colour Science Meeting (May 6-8, 2013, Darmstadt, Germany)
- » 45th International Liege Colloquium on Ocean Dynamics (May 13-17, 2013, Liege, Belgium)
- » Summer Satellite Remote Sensing Training Course* (May 31-Jun 14, 2013, Ithaca, NY)
- » 9th International Carbon Dioxide Conference (ICDC9) (Beijing, China)
- » Ocean Optics Summer Class: Calibration and validation of ocean color remote sensing* (July 7-August 2, 2013, Walpole, ME)
- » Researcher Colloquium *Key Uncertainties in the Global Carbon-Cycle: Perspectives across terrestrial and ocean ecosystems*

*In an effort to promote training in remote sensing techniques, OCB is providing tuition and housing support for eight students to participate in the Summer Satellite Remote Sensing Training Course (May 31-Jun 14, 2013, Ithaca, NY). OCB will also provide travel support for 13 students to attend the Ocean Optics Summer Class: Calibration and validation of ocean color remote sensing (July 7-August 2, 2013, Walpole, ME).

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

Community Resources

Data and Research

- » PACIFICA Database NDP-092
- » Takahashi, T., S.C. Sutherland, and A. Kozyr. 2013. Global Ocean Surface Water Partial Pressure of CO_2 Database: Measurements Performed During 1957–2012 (Version 2012). ORNL/CDIAC-160, NDP-088(V2012). Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee, doi: 10.3334/CDIAC/OTG.NDP088(V2012).
- » The global carbon budget: 1959-2011 (LeQuéré et al., 2013)
- » Release of Version 2 of the Surface Ocean CO_2 Atlas (SOCAT) at 9th International Carbon Dioxide Conference (ICDC9) (Beijing, China, June 4, 12:15-13:30, more information)
- » International intercalibration exercise for dissolved total methylated mercury (dMeHg) and dissolved total mercury (dHg) in seawater – for more information
- » The VENTUS Project is compiling information on all of the world's power plants (location, emission, generation, fuel, etc.)
- » ESA Climate Change Initiative producing initial data sets, including ocean color, sea surface temperature, aerosol, cloud, greenhouse gases, ozone, ice sheets, sea ice, and sea level

Reading

- » NRC Ocean Studies Board seeking nominations for committee members to conduct new study *A Decadal Survey of Ocean Sciences: Guidance for NSF on National Ocean Research Priorities* (**deadline to submit nominations: June 17**)
- » *Eos* meeting report Improving Intercomparability of Marine Biogeochemical Time Series
- » U.S. Global Change Research Program releases 2013 Our Changing Planet
- » Smith et al. (2013) COMPASS: Navigating the Rules of Scientific Engagement. PLoS Biol 11(4): e1001552. doi:10.1371/journal.pbio.1001552
- » Subcommittee on Ocean Science and Technology releases *Science for an Ocean Nation: Update of the Ocean Research Priorities Plan*
- » White House releases National Ocean Policy Implementation Plan
- » National Academies Report *A National Strategy for Advancing Climate Modeling (2012)*

Partner Program Updates

IMBER

» IMBER Open Science Conference (June 23-27, 2014, Bergen, Norway)

SOLAS

» 2013 SOLAS Summer School (August 23-September 2, 2013 in Xiamen, China)

» *Evolving research directions in Surface Ocean-Lower Atmosphere (SOLAS) Science* (Law et al., 2013, *Envir. Chem.*)

U.S. CLIVAR

» *U.S. AMOC/UK RAPID International Science Meeting AMOC variability: Dynamics and impacts* (July 16-19, 2013, Baltimore, MD)

» Researcher workshop *Key uncertainties in the global carbon cycle: Perspectives across terrestrial and ocean ecosystems* (curricular component of NCAR ASP Student Colloquium *Carbon-climate connections in the Earth System*) (August 6-10, 2013, Boulder, CO)

» U.S. CLIVAR High Latitude Surface Flux Working Group Article in BAMS: *High-Latitude Ocean and Sea Ice Surface Fluxes: Challenges for Climate Research*

IOCCP

» New IOCCP website

» Surface Ocean CO_2 Atlas (SOCAT) Version 2 to be released during the 9th International Carbon Dioxide Conference (ICDC9)

OCB Calendar

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

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

2013	
May 28-June 29, 2013	C-MORE 2013 Summer Course on Microbial Oceanography (Honolulu, HI)
May 31-June 14**	Summer Satellite Remote Sensing Training Course (Ithaca, NY)
June 3-7***	9th International Carbon Dioxide Conference (ICDC9) (Beijing, China)
June 16-July 6	BIOS Summer Course - Microbial Oceanography: The Biogeochemistry, Ecology and Genomics of Oceanic Microbial Ecosystems (BIOS, Bermuda)
June 17-21	Croucher summer course Climate Change and Marine Ecosystems (Hong Kong)
July 7-August 2***	Ocean Optics Summer Class: Calibration and validation of ocean color remote sensing (Darling Marine Center, Walpole, ME)
July 9-11	U.S. CLIVAR Summit (Annapolis, MD, invitation only)
July 16-19	U.S. AMOC/UK RAPID International Science Meeting AMOC variability: Dynamics and impacts (Baltimore, MD)
July 22-24	3rd Annual Science Meeting of the UK Ocean Acidification Research Programme (UKOA ASM) (St. Andrews, Scotland)
July 24-26	2nd International Workshop of the Global Ocean Acidification Observing Network (GOA-ON) (St. Andrews, Scotland)
July 22-25*	Ocean Carbon & Biogeochemistry (OCB) Summer Workshop (Woods Hole, MA)
July 22-26	Symposium on Climate Change and Molluscan Ecophysiology (Azores)
July 22-August 23	Summer Course on Ocean Acidification Methodologies (Friday Harbor Laboratories, WA)
July 29-August 16	NCAR Advanced Studies Program (ASP) Student Colloquium Carbon-climate connections in the Earth System) (Boulder, CO)
August 4-9	2013 Gordon Research Conference on Chemical Oceanography (Biddeford, ME)
August 5-9	Summer school on Solar Radiation Management (SRM) (Cambridge, MA)
August 6-10**	Researcher workshop Key Uncertainties in the Global Carbon-Cycle: Perspectives across terrestrial and ocean ecosystems (curricular component of NCAR Advanced Studies Program (ASP) Student Colloquium Carbon-climate connections in the Earth System) (Boulder, CO)
August 12-16	2013 Community Earth System Modeling Tutorial (Boulder, CO)
August 19-23	PICES Summer School Ocean observing systems and ecosystem monitoring (Newport, OR)
August 19-23	AIMEN thematic school on marine environment modeling (Brest, France)
August 23-September 2	2013 SOLAS Summer School (Xiamen, China)
August 25-30	Goldschmidt 2013 (Florence, Italy)

OCB Calendar (cont.)

August 26-28	Open Science Conference on Isotopes of Carbon, Water, and Geotracers in Paleoclimate Research (Bern, Switzerland)
September 18-20*	U.S. Ocean Acidification PI Meeting (Washington, DC)
September 23-25	International Conference on Marine Data and Information Systems (IMDIS2013) (Lucca, Italy)
September 24-27	ESA-EGU international workshop: Air-sea Gas Flux Climatology; Progress and Future Prospects (Brest, France)
October 12-19	DISCCRS VIII Interdisciplinary Climate Change Research Symposium (La Foret Conference and Retreat Center, CO)
October 13-17	ECSA 53: Estuaries and coastal areas in times of intense change (Shanghai, China)
November 3-7	22nd Biennal Conference of the Coastal and Estuarine Research Federation CERF 2013 (San Diego, CA)
December 9-13	Fall American Geophysical Union (AGU) Meeting (San Francisco, CA)
2014	
February 23-28, 2014	2014 Ocean Sciences Meeting (Honolulu, HI)
April 15-18	North pacific Marine Science Organization (PICES) Open Science Meeting Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems (FUTURE) (Kohala coast, Big Island, HI)
June 23-27	Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) Open Science Conference: Future Oceans – Research for marine sustainability: multiple stressors, drivers, challenges and solutions (Bergen, Norway)
July 6-11	Gordon Research Conference Ocean Global Change Biology (Waterville Valley, NH)
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	
May 30	NASA Ocean Biology & Biogeochemistry full proposal deadline
June 28	NASA ROSES New (Early Career) Investigator Program in Earth Science NOIs due
July 15	North Pacific Research Board (NPRB) Long-term monitoring program pre-proposal deadline
July 31	NASA Carbon Cycle Science Step 2 proposal deadline (ROSES '13)
July 31	Paul G. Allen Ocean Challenge: Mitigating acidification impacts concept submission deadline
August 15	NSF Chemical and Biological Oceanography proposal deadlines
August 30	NASA ROSES New (Early Career) Investigator Program in Earth Science proposal deadline
October 1	Sensors and Sensing Systems proposal deadline

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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