# Seawater biogeochemistry inshore and offshore the Bermuda coral reef from the Bermuda coral reef platform and adjacent Sargasso Sea extending to Bermuda Atlantic Time Series-station from 2014-2018

**Website**: https://www.bco-dmo.org/dataset/785658
**Data Type**: Cruise Results
**Version**: 0
**Version Date**: 2020-01-03

**Project**
» Collaborative Research Ocean Acidification: Establishing the links between offshore biogeochemistry, coral reef metabolism and acidification (BEACON II)

| Contributors | Affiliation | Role |
|---|---|---|
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| Andersson, Andreas | University of California-San Diego (UCSD-SIO) | Co-Principal Investigator |
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**Abstract**
From 2014 to 2018, surface seawater samples from the Bermuda coral reef platform were collected every month at 0.5–1-m depth using a 5-L Niskin bottle. Samples were also collected along a transect between Bermuda and BATS in conjunction with BATS cruises. All parameters were collected following BATS methodology (Knap et al., 1996).

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## Coverage

**Spatial Extent**: **N**:32.975 **E**:-63.971 **S**:31.579 **W**:-64.843
**Temporal Extent**: 2014-08-13 - 2018-07-21

## Dataset Description

From 2014 to 2018, surface seawater samples from the Bermuda coral reef platform were collected every month at 0.5–1-m depth using a 5-L Niskin bottle. Samples were also collected along a transect between Bermuda and BATS in conjunction with BATS cruises. All parameters were collected following BATS methodology (Knap et al., 1996).

### Methods & Sampling

Samples for dissolved oxygen were collected in 140 ml Pyrex iodine flasks, stored in a dark location and the necks of the flasks were sealed with seawater. Samples were analyzed after 6-8 hours, based on the Strickland and Parsons (1968) modification of the Winkler (1888) method. Analysis was performed on an automated

titration system using an UV light endpoint detection system as designed by the late Robert Williams of SIO. Prior to running the samples, a series of standards (6-8) and blanks (3-4) were run for determination of the thiosulphate normality value. Precision was typically <0.5 µmol kg-1.

TA and DIC samples were collected according to standard protocols (Dickson et al., 2007) using 250-mL Kimax brand glass sample bottles. Samples were immediately poisoned with 100 µL saturated solution of HgCl2. DIC was analyzed coulometrically using a UIC CM5011 CO2 coulometer combined with a VINDTA3C (Marianda Inc) or SOMMA system, alternatively based on infrared absorption using an AIRICA (Marianda, Inc) and a Li-Cor 7000 as the detector. TA was analyzed based on potentiometric acid titrations (~0.1 N HCl) using a VINDTA3S (Marianda Inc). Performance and precision of the instruments were regularly verified using certified reference material (CRM) prepared by A. Dickson at Scripps Institution of Oceanography (SIO). The accuracy and precision of replicate CRMs on any given day of analyses were typically in the range of ±2–4 µmol kg−1 for both TA and DIC.

Samples for nitrate+nitrite, nitrite, phosphate, silicic acid and ammonia were filtered through 0.8 µm Nuclepore filters then frozen (-20°C) in HDPE bottles until analysis. Samples were analyzed on a four channel SEAL AutoAnalyzer III using modified methods from Knap et al. (1996). Analytical precision for triplicate nutrient measurements was approximately 0.03-0.05 µmoles kg-1. Certified standards from Ocean Scientific International were analyzed on a regular interval to maintain data quality.

Particulate Organic Carbon and Nitrogen (POC/PON) samples (2L) were filtered onto pre-combusted (450ºC, 5 hours) Whatman GF/F glass fiber filters (nominal pore size 0.7µm), and stored at -20°C. Dried acidified samples were be combusted at 980 ºC on an Exeter Analytical Elemental Analyzer as described in Knap et al. (1996). Field blanks and acetanilide standards were run with each batch of samples.

Phytoplankton pigment samples (4L) were filtered onto 25mm Whatman GF/F glass fiber filters, frozen in liquid nitrogen, and analyzed by both standard fluorometric and high performance liquid chromatography (HPLC) techniques. Samples were analyzed using the method of Bidigare et al. (2005) on an Agilent 1100 series HPLC. Samples were calculated based upon instrument response and retention times that were standardized annually with pigment standards obtained from Danish Hydraulic Institute.

Samples for bacterial abundance were collected in 50ml Falcon tubes then preserved with 0.2µm filtered formalin and stored at -80 °C. Direct counts of DAPI (4,6-Diaminino-2-phenylidole) stained cells were conducted using an epifluorscence microscope to determine abundance (Knap et al., 1996).

Salinity samples were collected in 250 ml borosilicate glass bottles (Ocean Scientific, UK) and analyzed using a Guildline Autosal 8400B. The salinometer were calibrated with standard seawater provided by Ocean Scientific, UK. Salinity was calculated based on the mean sample conductivity ratio from two separate measurements averaged over 5 seconds and computed according to the 1978 definition of Practical salinity (UNESCO, 1978). The precision of replicate samples was typically less than 0.001 psu.

Dissolved calcium samples were analyzed using a titration system developed by J. Ballard and Dr. T. Martz at SIO. Samples were collected in 100 ml plastic bottles. The dissolved calcium concentration was determined by EGTA titration with Zn-zincon as an indirect photometric indicator (Anfält and Granéli, 1976) using a custom photometric cell with a white LED, 620 nm filter, and photodiode. The voltage of the cell was monitored with Labview software and a 24-bit analog to digital converter (NI-9219). In the first step, 1 M borate buffer was added to 25 g of sample and diluted 10 fold. Zincon indicator (0.1%, 1ml) and equimolar Zn-EGTA (0.01 M, 2.5ml) were then added prior to an EGTA (0.02 M) gravimetric addition (~11 g) and software controlled volumetric additions (~0.1 ml). Accuracy and precision of IAPSO standard seawater was in the range of 2-5 mol kg-1.

**Data Processing Description**

BCO-DMO Processing Notes:
- added conventional header with dataset name, PI name, version date
- modified parameter names to conform with BCO-DMO naming conventions
- prepended hhmm_in field with zeros when number of digits was less than 4.
- combined YYYYMMDD_in and hhmm_in fields to generate ISO_DateTime_UTC field.
- split Sample_id field to generate cruise_type, cruise_no, cast_no, and niskin_no fields.

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## Related Publications


Anfält, T., & Granéli, A. (1976). Successive high-precision determination of calcium and magnesium in sea water with a new probe photometer. Analytica Chimica Acta, 86, 13–19. doi:10.1016/s0003-2670(01)83012-9 https://doi.org/10.1016/S0003-2670(01)83012-9
*Methods*

Bidigare R. R., L. Van Heukelem, C. C. Trees, Analysis of algal pigments by high performance liquid chromatography, in Algal Culturing Techniques (R. A. Andersen, ed.), Academic Press, New York, 327-345 (2005).
*Methods*

Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. Guide to best practices for ocean CO2 measurements. PICES Special Publication 3, 191 pp. ISBN: 1-897176-07-4. URL: https://www.nodc.noaa.gov/ocads/oceans/Handbook_2007.html https://hdl.handle.net/11329/249
*Methods*

Knap, A.H., Michaels, A.F., Steinberg, D.K., Bahr, F., Bates, N.R., Bell, S., Countway, P., Close, A.R., Doyle, A.P., Dow, R.L., Howse, F.A., Gundersen, K., Johnson, R.J., Kelly, R., Little, R., Orcutt, K., Parsons, R., Rathburn, C., Sanderson, M. and Stone, S. (1997) BATS Methods Manual, Version 4 Woods Hole, MA, US. U.S. JGOFS Planning Office 136pp. *Chapter 16. Determination of Dissolved Organic Carbon by a High Temperature Combustion/Direct Injection Technique.* Updated by R.Parsons 4/1997, pp. 99-109. https://eprints.soton.ac.uk/361194/#chapter16
*Methods*

Strickland, J. D. H. and Parsons, T. R. (1972). A Practical Hand Book of Seawater Analysis. Fisheries Research Board of Canada Bulletin 157, 2nd Edition, 310 p.
*Methods*

Winkler, L. W. (1888). Die Bestimmung des im Wasser gelösten Sauerstoffes. Berichte Der Deutschen Chemischen Gesellschaft, 21(2), 2843–2854. doi:10.1002/cber.188802102122
*Methods*


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## Parameters

| Parameter | Description | Units |
|---|---|---|
| depth | water depth | meters (m) |
| pressure | CTD pressure | bar |
| temperature | water temperature | degrees Celsius |
| oxygen | dissolved oxygen | micromole per kilogram (micromol kg-1) |
| CO2 | dissolved inorganic carbon | micromole per kilogram (micromol kg-1) |
| alkalinity | total alkalinity | micromole per kilogram (micromol kg-1) |

| | | |
|---|---|---|
| Nitrate_nitrite | dissolved nitrate+nitrite (LOD=0.03) reported as zero if < LOD | micromole per kilogram (micromol kg-1) |
| nitrite | dissolved nitrite (LOD=0.01) reported as zero if < LOD | micromole per kilogram (micromol kg-1) |
| phosphate | dissolved phosphate (LOD=0.02) reported as zero if < LOD+B48 | micromole per kilogram (micromol kg-1) |
| sillicate | dissolved silicate | micromole per kilogram (micromol kg-1) |
| TOC | total organic carbon | micromole per kilogram (micromol kg-1) |
| TON | total organic nitrogen | micromole per kilogram (micromol kg-1) |
| POC | particulate organic carbon | microgram per kilogram (micro g kg-1) |
| PON | particulate organic nitrogen | microgram per kilogram (micro g kg-1) |
| bacteria | total bacterial cells | cells x10^8 per kilogram (cellsX10^8 kg-1) |
| pig1 | HPLC- chlorophyll C3 | nanograms per kilogram (ng kg-1) |
| pig2 | HPLC- chlidea | nanograms per kilogram (ng kg-1) |

| | | |
|---|---|---|
| pig3 | HPLC- chlorophyll c1+c2 | nanograms per kilogram (ng kg-1) |
| pig4 | HPLC- peridinon | nanograms per kilogram (ng kg-1) |
| pig5 | HPLC- 19 butanoyloxyfucoxanthin | nanograms per kilogram (ng kg-1) |
| pig6 | HPLC- fucoxanthin | nanograms per kilogram (ng kg-1) |
| pig7 | HPLC- 19 hexanoyloxyfucoxanthin | nanograms per kilogram (ng kg-1) |
| pig8 | HPLC- prasinoxanthin | nanograms per kilogram (ng kg-1) |
| pig9 | HPLC- diadinoxanthin | nanograms per kilogram (ng kg-1) |
| pig10 | HPLC- alloxanthin | nanograms per kilogram (ng kg-1) |
| pig11 | HPLC- diatoxanthin | nanograms per kilogram (ng kg-1) |
| pig12 | HPLC- zeaxanthin+lutein | nanograms per kilogram (ng kg-1) |
| pig13 | HPLC- chlorophyll b | nanograms per kilogram (ng kg-1) |
| pig14 | HPLC- chlorophyll a | nanograms per kilogram (ng kg-1) |
| pig15 | HPLC- a+b carotene | nanograms per kilogram (ng kg-1) |

| | | |
|---|---|---|
| pig16 | Turner chlorophyll a | nanograms per kilogram (ng kg-1) |
| pig17 | Turner phaeopigments | nanograms per kilogram (ng kg-1) |
| pig18 | HPLC- lutein | nanograms per kilogram (ng kg-1) |
| pig19 | HPLC- zeaxanthin | nanograms per kilogram (ng kg-1) |
| pig20 | HPLC- a-carotene | nanograms per kilogram (ng kg-1) |
| pig21 | HPLC- b-carotene | nanograms per kilogram (ng kg-1) |
| Prochlorococcus | Flow cytometer total counts of Prochlorococcus | cells per mililiter (cells ml-1) |
| Synechococcus | Flow cytometer total counts of Synechococcus | cells per mililiter (cells ml-1) |
| Picoeukaryotes | Flow cytometer total counts of Picoeukaryotes | cells per mililiter (cells ml-1) |
| Nanoeukaryotes | Flow cytometer total counts of Nanoeukaryotes | cells per mililiter (cells ml-1) |
| Calcium | dissolved calcium | micromole per kilogram (micromol kg-1) |
| CTD_salinity | CTD salinity | psu |
| salinity | bottle salinity | psu |
| Sample_id | refers to a unique 8 digit Nisken ID following the format: !###$$$@@ where; !=Cruise type; ### = Cruise number; $$$ = Cast number; @@ = Niskin number | unitless |
| Station_number | Station_number refers to nominal inshore and offshore station.Total of 7 offshore stations which are: 1= Sea Buoy (0 km offshore); 2= 5km offshore; 3= 10km offshore; 4= 15km offshore; 5= Hydrostation 'S' (~20km offshore); 6= BATS Spatial Station #2 ( ~ 50km offshore); 7= BATS (~ 80km offshore); Total of 11 inshore stations which are: 1= Crescent Reef. 2= Dockyard 3= Hog Breaker; 4= Mid-Platform; 5= North Channel; 6= Tynes Bay; 7= TT2; 8= TT4; 9= TT6; 10= TT7; 11= TT8 | unitless |
| YYYYMMDD_in | date in GMT following YYYYMMDD format | unitless |

| | | |
|---|---|---|
| dec_year_in | decimal year in GMT | unitless |
| dec_day_in | decimal day in GMT | unitless |
| Lat_in | latitude with positive values indicating North | decimal degrees |
| Long_in | longitude with negative values indicating West | decimal degrees |
| quality_flag | quality flags following the WOCE convention | unitless |
| hhmm_in | time in four digit hhmm format | unitless |
| ISO_DateTime_UTC | Date and time following ISO8601 conventions | unitless |
| cruise_type | type of cruise; 7= Offshore cruise R/V Atlantic Explorer; 8= Inshore small boat survey. | unitless |
| cruise_no | cruise number | unitless |
| cast_no | cast number | unitless |
| niskin_no | niskin number | unitless |

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## Instruments

| | |
|---|---|
| **Dataset-specific Instrument Name** | Automated Winkler titration system |
| **Generic Instrument Name** | Automatic titrator |
| **Dataset-specific Description** | Automated Winkler titration system using an UV light endpoint detection system as designed by the late Robert Williams of SIO. Precision was typically |
| **Generic Instrument Description** | Instruments that incrementally add quantified aliquots of a reagent to a sample until the end-point of a chemical reaction is reached. |

| | |
|---|---|
| **Dataset-specific Instrument Name** | Guildline Autosal 8400B |
| **Generic Instrument Name** | Autosal salinometer |
| **Dataset-specific Description** | Guildline Autosal 8400B for salinity. The precision of replicate samples was typically less than 0.001 psu. |
| **Generic Instrument Description** | The salinometer is an instrument for measuring the salinity of a water sample. |

| | |
|---|---|
| **Dataset-specific Instrument Name** | SeaBird 9/11 CTD |
| **Generic Instrument Name** | CTD Sea-Bird 911 |
| **Dataset-specific Description** | SeaBird 9/11 CTD equipped with dual SBE-03 temperature sensors, SBE-04 conductivity sensors, and SBE45 dissolved oxygen sensors. Auxiliary sensors include Chelsea flurometer, Wetlabs fluorometer, Wetlabs, transmissometer, Biospherical PAR sensor. Discrete samples collected din 12l Ocean Test Equipment bottles. |
| **Generic Instrument Description** | The Sea-Bird SBE 911 is a type of CTD instrument package. The SBE 911 includes the SBE 9 Underwater Unit and the SBE 11 Deck Unit (for real-time readout using conductive wire) for deployment from a vessel. The combination of the SBE 9 and SBE 11 is called a SBE 911. The SBE 9 uses Sea-Bird's standard modular temperature and conductivity sensors (SBE 3 and SBE 4). The SBE 9 CTD can be configured with auxiliary sensors to measure other parameters including dissolved oxygen, pH, turbidity, fluorescence, light (PAR), light transmission, etc.). More information from Sea-Bird Electronics. |

| | |
|---|---|
| **Dataset-specific Instrument Name** | Exeter Analytical Elemental Analyzer |
| **Generic Instrument Name** | Elemental Analyzer |
| **Dataset-specific Description** | Exeter Analytical Elemental Analyzer for POC and PON. |
| **Generic Instrument Description** | Instruments that quantify carbon, nitrogen and sometimes other elements by combusting the sample at very high temperature and assaying the resulting gaseous oxides. Usually used for samples including organic material. |

| | |
|---|---|
| **Dataset-specific Instrument Name** | Li-Cor 7000 |
| **Generic Instrument Name** | LI-COR LI-7000 Gas Analyzer |
| **Dataset-specific Description** | AIRICA (Marianda, Inc) and a Li-Cor 7000 as the detector for DIC analyses. Accuracy and precision was typically |
| **Generic Instrument Description** | The LI-7000 CO2/H2O Gas Analyzer is a high performance, dual cell, differential gas analyzer. It was designed to expand on the capabilities of the LI-6262 CO2/ H2O Gas Analyzer. A dichroic beam splitter at the end of the optical path provides radiation to two separate detectors, one filtered to detect radiation absorption of CO2 and the other to detect absorption by H2O. The two separate detectors measure infrared absorption by CO2 and H2O in the same gas stream. The LI-7000 CO2/ H2O Gas Analyzer is a differential analyzer, in which a known concentration (which can be zero) gas is put in the reference cell, and an unknown gas is put in the sample cell. |

| | |
|---|---|
| **Dataset-specific Instrument Name** | VINDTA3C (Marianda Inc) |
| **Generic Instrument Name** | MARIANDA VINDTA 3C total inorganic carbon and titration alkalinity analyser |
| **Dataset-specific Description** | VINDTA3C (Marianda Inc) combined with a UIC CM5011 CO2 coulometer or SOMMA system for DIC analyses. Accuracy and precision was typically |
| **Generic Instrument Description** | The Versatile INstrument for the Determination of Total inorganic carbon and titration Alkalinity (VINDTA) 3C is a laboratory alkalinity titration system combined with an extraction unit for coulometric titration, which simultaneously determines the alkalinity and dissolved inorganic carbon content of a sample. The sample transport is performed with peristaltic pumps and acid is added to the sample using a membrane pump. No pressurizing system is required and only one gas supply (nitrogen or dry and CO2-free air) is necessary. The system uses a Metrohm Titrino 719S, an ORION-Ross pH electrode and a Metrohm reference electrode. The burette, the pipette and the analysis cell have a water jacket around them. Precision is typically +/- 1 umol/kg for TA and/or DIC in open ocean water. |

| | |
|---|---|
| **Dataset-specific Instrument Name** | Niskin bottle |
| **Generic Instrument Name** | Niskin bottle |
| **Dataset-specific Description** | General oceanic Niskin bottle 5L |
| **Generic Instrument Description** | A Niskin bottle (a next generation water sampler based on the Nansen bottle) is a cylindrical, non-metallic water collection device with stoppers at both ends. The bottles can be attached individually on a hydrowire or deployed in 12, 24, or 36 bottle Rosette systems mounted on a frame and combined with a CTD. Niskin bottles are used to collect discrete water samples for a range of measurements including pigments, nutrients, plankton, etc. |

| | |
|---|---|
| **Dataset-specific Instrument Name** | SEAL AutoAnalyzer III |
| **Generic Instrument Name** | Seal Analytical AutoAnalyser 3HR |
| **Dataset-specific Description** | SEAL AutoAnalyzer III for inorganic nutrients. |
| **Generic Instrument Description** | A fully automated Segmented Flow Analysis (SFA) system, ideal for water and seawater analysis. It comprises a modular system which integrates an autosampler, peristaltic pump, chemistry manifold and detector. The sample and reagents are pumped continuously through the chemistry manifold, and air bubbles are introduced at regular intervals forming reaction segments which are mixed using glass coils. The AA3 uses segmented flow analysis principles to reduce inter-sample dispersion, and can analyse up to 100 samples per hour using stable LED light sources. |

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## Project Information

**Collaborative Research Ocean Acidification: Establishing the links between offshore biogeochemistry, coral reef metabolism and acidification (BEACON II)**

**Coverage**: Bermuda

NSF abstract:

Time-series observations from the Atlantic and Pacific Oceans have revealed indisputable evidence of long-term acidification of open-ocean surface seawater due to uptake of anthropogenic carbon dioxide from the atmosphere. Concurrent evidence of negative effects of acidification on the production and preservation of calcium carbonate have fueled concern about the potential consequences to coral reefs. Although long-term acidification in coral reef environments in general has not been observed, seawater acidification rates on the Bermuda coral reef platform between 2007-2012 have been found to be three times faster than the long-term (1983-2012) acidification rate observed at a nearby offshore open-ocean time-series station. The investigators on this project believe that they now understand how this happens and have designed a study to confirm or refute their ideas. Specifically they believe that the observed changes in 2007-2012 are attributable to a recent shift in reef metabolic processes associated with an increase in net reef calcification and heterotrophy. The evidence they have in-hand suggests that these changes have been fueled by an increase in food supply to the reef as a result of increased offshore primary production seemingly linked to the state of the North Atlantic Oscillation (NAO), a periodic back-and-forth shifting of atmospheric pressure differences between the subpolar and the subtropical North Atlantic. In this project, by collecting an extensive set of physical, chemical, and biological data extending from the reef platform at Bermuda to the offshore open-water time-series station, they will explore this idea.

The primary scientific and societal broader impacts of this project will be its relevance to advancing current understanding of the effects of ocean acidification on coral reefs. Robust prediction of future effects on this ecosystem requires knowledge of the main drivers of reef biogeochemical processes and of local seawater acidification. Secondly, the project will support the education and research activities of both graduate and undergraduate students working as members of the research team, and foster community educational outreach through the Ocean Discovery Institute in San Diego and the Ocean Academy in Bermuda to engage students from underrepresented minorities.

The central hypothesis of this research is that during years of negative winter NAO, intensified mixing and increased nutrient supply enhance offshore production leading to coral reef calcification and reef heterotrophy, thus intensifying the local seawater acidification on the reef. To address this hypothesis, the team will measure and characterize inshore seawater biogeochemical properties (temperature, salinity, dissolved inorganic carbon, total alkalinity, calcium, partial pressure of carbon dioxide, inorganic nutrients, particulate organic carbon and nitrogen, total organic carbon and nitrogen, phytoplankton pigments, and bacterial abundance) on a monthly interval across the Bermuda coral reef. These data will be evaluated in concert with data collected as part of the Bermuda-Atlantic Time-Series and Hydrostation S programs and along inshore-offshore transects. It is expected that this approach will further the understanding of how seawater biogeochemical properties, including seawater carbonate chemistry, vary over time and space on the Bermuda coral reef, and identify the main drivers of these variations. It will specifically address the coupling between offshore and inshore biogeochemical processes and how they are linked to larger-scale oceanographic and climatic forcings, such as the NAO. It also addresses how reef biogeochemical processes may alleviate or exacerbate ocean acidification, and whether these changes are important to reef metabolism in the context of other forcings such as light, nutrients, and food availability.

Based on the findings of the BEACON project, and especially the results published in Andersson et al. (Nature Climate Change, 4, 56-61, 2014) and Yeakel et al. (PNAS, 112, 14512-14517, 2015), BEACON II (https://www.bco-dmo.org/project/737955) aims to assess the links between offshore and reef biogeochemistry by continuing and expanding on the physical and chemical measurements on the Bermuda coral reef and in the surrounding Sargasso Sea.

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## Funding

| Funding Source | Award |
| --- | --- |
| NSF Division of Ocean Sciences (NSF OCE) | OCE-1416670 |
| NSF Division of Ocean Sciences (NSF OCE) | OCE-1416518 |


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