HPLC and fluorometric derived phytoplankton pigment concentrations from seawater collected on BATS Validation cruises from June 1996 to July 2024

Website: https://www.bco-dmo.org/dataset/926534
Data Type: Cruise Results
Version: 6
Version Date: 2025-01-15

Project
» Bermuda Atlantic Time-series Study (BATS)

Programs
» Ocean Carbon and Biogeochemistry (OCB)
» U.S. Joint Global Ocean Flux Study (U.S. JGOFS)
» Ocean Time-series Sites (Ocean Time-series)

Contributors	Affiliation	Role
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Abstract
Data presented here are discrete bottle HPLC derived phytoplankton pigments and fluorometric chlorophyll-a for BATS validation (BVAL) cruises from June 1996 (BVAL cruise #50016) through June/July 2024 (BVAL cruise #50061). Water samples are typically collected from 7-12 depths in the upper 250 meters of the water column, and then filtered under low vacuum through a 25mm GF/F filter. The filter is then flash frozen in liquid nitrogen and stored at -80 degrees C. Shoreside, analysis is performed on an HPLC using a method modified by Dr. R. Bidigare from the Wright et al. (1991) procedure. This method identifies the pigments chlorophyll-c3, chlorophyll-c2, peridinin, 19'-butanoyloxyfucoxanthin, fucoxanthin, 19'-hexanoyloxyfucoxanthin, prasinoxanthin, diadinoxanthin, alloxanthin, diatoxanthin, lutein, zeaxanthin, chlorophyll-b, chlorophyll-a, divinyl chlorophyllide-a, alpha and beta carotene. Additionally, chlorophyll-a and phaeopigments are analyzed using a fluorometric assay.

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Coverage

Location: Survey cruises in the Sargasso Sea with ranging from 19N-36N and 60W to 80W
Spatial Extent: **N**:39.453 **E**:-59.649 **S**:19.9663 **W**:-70.841
Temporal Extent: 1996-06-24 - 2024-07-09

Dataset Description

Following the first several years of the BATS project it was deemed necessary by the JGOFS steering committee and BATS PI's to conduct validation cruises in the vicinity of the nominal BATS site to better understand the mesoscale and larger scale variability of the region. In particular, a focus of the BVAL cruises was to assess the spatial scale representation of the BATS and Hydrostation ‘S’ programs. Initial focus of the BVAL cruises was to investigate mesoscale variability and meridional gradients of the local region. Later, cruises focused on specific mesoscale eddies (e.g., McGillicuddy et al., 1998; McGillicuddy et al., 1999) and effects of tropical cyclones through the local region. In the year 2000 it was deemed more important to document the larger scale changes in the North Atlantic Subtropical gyre so BVAL cruises established a transect line from ~ 35N to 19N (Bermuda to Puerto Rico) very similar to the WOCE A22 repeat hydrography line (Johnson et al., 2020). These annual Bermuda to Puerto Rico transects have been run since 2000 and target stations at every one degree of latitude and typically have been conducted in September/October of each year to capture maximal heat content in the upper ocean. However, since this timeframe coincides with high tropical cyclone activity the cruises were reluctantly (as of 2022) moved to begin in June/July of each year for safety and operational reasons. In the pentad prior to 2022 every BVAL cruise was significantly impacted by multiple tropical cyclones. Additionally, some BVAL cruises are transects from the US east coast to Bermuda and are opportunistic cruises leveraging times when the BIOS resident vessel (R/V Weatherbird II or R/V Atlantic Explorer) is in transit for other research cruises or ship yard visits. Parameters presented are the same as provided in the standard BATS datasets.

Methods & Sampling

Cruises
Data were collected on BATS validation (BVAL) cruise 50016 (June 1996) through BVAL cruise 50061 (June/July 2024). Please note that BVAL cruises 25, 43, and 54 were cancelled and hence no reporting.

Research was conducted on the R/V Weatherbird II through 2005 and thereafter on the R/V Atlantic Explorer. Numerous Chief Scientists: Rachel Dow, Anthony Michaels, Kjell Gundersen, Rodney Johnson, Paul Lethaby, Mike Lomas, Steven Bell, Gwyn Evans, Claire Medley and Dominic Smith.

Methods and Sampling

Phytoplankton use pigments to absorb energy from the sun to drive photosynthesis. Chlorophyll-a is used as the primary light harvesting molecule while other accessory pigments (chlorophyll-b, chlorophyll-c, and carotenoids) assist by expanding the light absorption capability of the organism, therefore increasing efficiency and adaptability (Bidigare et al., 2002).

Many individual algal pigments or combinations and ratios are taxon-specific. Therefore, pigment composition from seawater samples can be used to separate major algal groups and result in chemotaxonomic characterization. These analyses can be used to determine phytoplankton community structure and physiological state of the autotrophic assemblage (Wallerstein et al., 1999; Bidigare et al., 2002)

The methodology described here is based on the Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements (BATS, 1997), and describes the use of high performance liquid chromatography (HPLC) for the rapid separation of phytoplankton pigments with detection limits for chlorophylls and carotenoids on the order of one nanogram (Bidigare, 1991). This HPLC method was adopted as BATS protocol in July 1994 (BATS 70 cruise). This method uses less solvent and gives improved peak separation and better resolution at lower concentrations.

Field sampling
Discrete samples are collected monthly using Niskin bottles at the Bermuda Atlantic Time-series Study site from depths ranging from the surface to 250 meters. Expeditious sampling and contamination prevention protocols were used to obtain the best possible samples, since the physico-chemical and biological parameters of the

Niskin water become increasingly altered with time spent on deck, especially if in full sunlight. Sea water is filtered using glass fiber filters (GF/F) with standard pore size of 0.7 microns and the filtered samples then flash frozen and stored at -80ºC until analysis.

HPLC pigment measurements
Water samples were analyzed for the concentration of various phytoplankton pigments following the method of Wright et al. (1991) as modified by Dr. Robert Bidigare. Pigments present in a seawater sample can be separated by high-performance liquid chromatography (HPLC) based on differences in polarity. Pigment polarities determine how the pigments interact with the solid phase (column) and the mobile phase (solvent) within the HPLC. Pigments that are less polar will be more attracted to the non-polar stationary phase and take longer to pass through than more polar pigments, thus a temporal separation is achieved. The length of time it takes for the pigment to elute is known as the retention time. Under comparable conditions, pigment retention times are consistent and can therefore be used for identification when compared to a reference. The retention times are determined using a diode array detector (DAD), which detects absorption across a range of wavelengths in the UV-Vis portion of the spectrum. The separated pigments are transported by the flowing mobile phase to the detector, where the solution passes through a flow cell and is dispersed by a diffraction grating. Photodiode arrays detect the light intensity for each wavelength, which is converted to an electrical signal, resulting in a visible peak on a chromatogram. Concentration is proportional to the area of the peak, and can be calculated using calibration factors determined from known standards (aka response factor), in addition to other parameters such as volume of water sampled and dilution factors.

The HPLC currently in use is an Agilent 1100 series. The results from two different wavelengths are reported in this method, 436nm and 450nm. All pigments except divinyl chlorophyll-a produce a signal at 436nm. However, divinyl and monovinyl chl-a cannot be separated at 436nm due to a similar detector response, so 450nm is also used to try and separate mono and divnyl chl-a since divnyl absorbs at this wavelength and monovinyl does not.

Fluorometric measurements
In addition to the HPLC measurements, pigment samples from BATS are also analyzed using fluorometric techniques. Fluorescence is the physical property of compounds to absorb light energy and instantaneously re-emit light at a different wavelength to the absorbed light. Fluorescent compounds, such as chlorophyll-a, have characteristic absorption and emission wavelengths. In fluorometry, a sample is excited at the appropriate absorption wavelength and the intensity of the emitted light is measured using a photodiode detector to give a raw fluorescence recorded value that is proportional to concentration. When compared to reference standards, the raw fluorescence measurements are used to calculate the concentration of the fluorescent material in the sample.

Prior to January 2020, fluorometry was performed on the Turner 10-AU fluorometer, whereas samples are currently analyzed using the Trilogy Fluorometer at BIOS. Data from the fluorometer is compared to the chlorophyll-a data from the HPLC which allows an extra quality control method to ensure data from both methods are similar. This data is being released as part of the BATS dataset since fluorometry is often used instead of HPLC in the oceanographic community for chlorophyll analysis.

Additional information
Additional details on methods, standardization, and calibration can be found in the BATS methods document (Protocols for the Bermuda Atlantic Time-series Study Core Measurements).

Data Processing Description

BATS HPLC Data Processing

Once a sample has been analysed, the peaks in the resulting chromatogram are manually integrated, as the automatic integration processing in the software (Agilent OpenLab Chemstation Version 2) is not suitable for the high number of analytes.

The manual integration tool within the software is used to draw a line along the baseline from the start to the end of the peak, from which the area of the peak can be determined. The peaks are identified and labelled using the saved retention times from calibration with known standards.

The signal from the HPLC is proportional to the concentration of the pigment in the sample and is used to calculate the final concentration (C) in ng/L of pigment using the following equation:

$$C = (A * RF) / V_{inj} * DF * V_{ext} / V_f * 10^6$$

where,

$$DF = (V_{vial} + V_{ace} + V_{H20}) / V_{vial}$$

A = HPLC Peak Area
RF = HPLC Response factor (determined during calibration)
V_{inj} = Injection volume on HPLC (normally 200µl)
V_{ext} = Extraction volume of filter (normally 3.2ml)
V_f = volume of water filtered during sample collection (normally 4000ml)
V_{vial} = volume of sample decanted into HPLC vial (normally 1000µl)
V_{ace} = volume of acetone added to HPLC vial (usually zero)
V_{H20} = volume of water added to HPLC vial (usually 300µl)
10^6 = volume conversion factor

Notes:

- Extraction volume is 3.2ml due to the 3ml of acetone added and the 0.2ml of seawater retained on the filter

An in-house Matlab (Version 2015b) processing script is used to extract the data required for the concentration calculation from various sources, including sample ID files, HPLC chromatogram reports, and fluorescence results reports. It then calculates the concentration of each pigment for each sample in ng/L.

Finally, the reported data are converted to ng/kg simply by multiplying by 1000 and dividing by the density of the sample which is calculated using either the bottle salinity or CTD salinity at time of sample collection and an assumed laboratory temperature of 24°C.

BCO-DMO Processing Description

- imported "bval_pigments_v006.txt", and "bval_pigments_qcmask_v006.txt" into BCO-DMO system
- joined "bval_pigments_qcmask_v006.txt" and "bval_pigments_v006.txt" to add flag columns for the parameters
- converted longitude values to decimal degrees (degrees West are negative)
- converted date to ISO yyyy-mm-dd format
- combine date and time to create ISO UTC timestamp
- added Cruise_type, Cruise_num, Cast, Cast_type, and Bottle_number columns (extracted from ID column)
- added vessel names as defined in "bval_pigments_v006.txt"
- added cast types as defined in "bval_pigments_v006.txt"
- modified parameter names to conform with BCO-DMO naming conventions and to be more consistent with other BATS data submissions

Version Notes:
There is no version 5 of this dataset. See release notes to see changes from the last release.

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Data Files

File	
926534_v6_bats_bval_pigments.csv	(Comma Separated Values (.csv), 545.68 KB) MD5:f69b170e6929ebc7f2308ea8fcc05e41
Primary data file for dataset ID 926534, version 6	

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Supplemental Files

File
BVAL HPLC pigments data version v006 update file filename: bval_pigment_release_v006_update.txt (Plain Text, 437 bytes) MD5:4d671e68a4c57bdbab2a14fd8dea5553 ASCII file listing changes/ new data in current version (v006) from previous versions.

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Related Publications

BATS (2023). Protocols for the Bermuda Atlantic Time-series Study Core Measurements. Bermuda Institute of Ocean Sciences, 142 pp.
Methods

Bermuda Atlantic Time-series Study Methods (online at https://bats.bios.edu/about/cruise-information/)
Methods

Bidigare, R. R., Van Heukelem, L., & Trees, C. C. (2002). HPLC phytoplankton pigments: sampling, laboratory methods, and quality assurance procedures. Ocean optics protocols for satellite ocean color sensor validation, revision, 3(2), 258-268.
Methods

Bidigare, R. R., Van Heukelem, L., & Trees, C. C. (2005). Analysis of Algal Pigments by High-Performance Liquid Chromatography. Algal Culturing Techniques, 327–345. https://doi.org/10.1016/b978-012088426-1/50021-4 https://doi.org/10.1016/B978-012088426-1/50021-4
Methods

Bidigare, R.R., 1991. Analysis of algal chlorophylls and carotenoids. In: D.C. Hurd and D.W. Spencer (Editors), Marine Particles: Analysis and Characterization. Am. Geophys. Union, Washington, DC, pp. 119-123.
Methods

Grasshoff, K., Kremling, K., & Ehrhardt, M. (Eds.). (1999). Methods of Seawater Analysis. doi:10.1002/9783527613984
Methods

Holm-Hansen, O., Lorenzen, C. J., Holmes, R. W., & Strickland, J. D. H. (1965). Fluorometric Determination of Chlorophyll. ICES Journal of Marine Science, 30(1), 3–15. doi:10.1093/icesjms/30.1.3
Methods

Intergovernmental Oceanographic Commission (1994) Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements. Paris, France, UNESCO-IOC, 170pp. (Intergovernmental Oceanographic Commission Manuals and Guides: 29), (JGOFS Report; 19). DOI: https://doi.org/10.25607/OBP-1409
Methods

Johnson, R.J., Bates, N.R., Lomas, M.W., Stevens, S., Lethaby, P., Anderson, A., Pacheco, F., and Knap, A.H. (2020, February 16-21) Meridional heat and salinity budgets of the Sargasso Sea inferred from two decades of ocean time-series and transect observations. [Poster session]. Ocean Sciences Meeting, San Diego, USA. https://agu.confex.com/agu/osm20/meetingapp.cgi/Paper/656848
Related Research

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

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. http://eprints.soton.ac.uk/id/eprint/361194
Methods

McGillicuddy, D. J., Johnson, R., Siegel, D. A., Michaels, A. F., Bates, N. R., & Knap, A. H. (1999). Mesoscale variations of biogeochemical properties in the Sargasso Sea. Journal of Geophysical Research: Oceans, 104(C6), 13381–13394. Portico. https://doi.org/10.1029/1999jc900021 https://doi.org/https://doi.org/10.1029/1999JC900021
Results

McGillicuddy, D. J., Robinson, A. R., Siegel, D. A., Jannasch, H. W., Johnson, R., Dickey, T. D., McNeil, J., Michaels, A. F., & Knap, A. H. (1998). Influence of mesoscale eddies on new production in the Sargasso Sea. Nature, 394(6690), 263–266. https://doi.org/10.1038/28367
Results

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

Wallerstein, P., & Liebezeit, G. (n.d.). Determination of photosynthetic pigments. Methods of Seawater Analysis, 557–566. https://doi.org/10.1002/9783527613984.ch27
Methods

Wright, S., Jeffrey, S., Mantoura, R., Llewellyn, C., Bjornland, T., Repeta, D., & Welschmeyer, N. (1991). Improved HPLC method for the analysis of chlorophylls and carotenoids from marine phytoplankton. Marine Ecology Progress Series, 77, 183–196. https://doi.org/10.3354/meps077183
Methods

Yentsch, C. S., & Menzel, D. W. (1963). A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. Deep Sea Research and Oceanographic Abstracts, 10(3), 221–231. doi:10.1016/0011-7471(63)90358-9
Methods

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Parameters

Parameter	Description	Units
ID	Sample identification; a unique number which identifies cruise, cast, and bottle number	unitless
ISO_DateTime_UTC	Collection time in UTC format	unitless
Vessel	Name of vessel used for cruise	unitless
Latitude	Latitude of sample collection	decimal degrees
Longitude	Longitude of sample collection (West is negative)	decimal degrees
Cruise_type	Cruise type (BATS Validation)	unitless
Cruise_num	BATS Validation Cruise number	unitless
Cast	Cast Number (1-80 = CTD, 81-99 = Hydrocast)	unitless

Cast_type	Cast type (CTD or Hydrocast)	unitless
Bottle_number	Niskin bottle number	unitless
QF_Niskin_GoFlo	Niskin/GoFlo quality flag (-3 = suspect, 1=unverified, 2= verified/acceptable)	uniteless
Depth	Collection depth	meters (m)
QF_depth	Quality control flag for depth; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p1	pigment 1 = Chlorophyll c3	nanograms per kilogram (ng/kg)
QF_p1	Quality control flag for p1; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p2	pigment 2 = Chlorophyllide_a	nanograms per kilogram (ng/kg)
QF_p2	Quality control flag for p2; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p3	pigment 3 = Chlorophyll c1 + c2	nanograms per kilogram (ng/kg)
QF_p3	Quality control flag for p3; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p4	pigment 4 = Peridinin	nanograms per kilogram (ng/kg)
QF_p4	Quality control flag for p4; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p5	pigment 5 = 19-prime-Butanoyloxyfucoxanthin	nanograms per kilogram (ng/kg)
QF_p5	Quality control flag for p5; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless

p6	pigment 6 = Fucoxanthin	nanograms per kilogram (ng/kg)
QF_p6	Quality control flag for p6; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p7	pigment 7 = 19-prime-Hexanoyloxyfucoxanthin	nanograms per kilogram (ng/kg)
QF_p7	Quality control flag for p7; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p8	pigment 8 = Prasinoxanthin	nanograms per kilogram (ng/kg)
QF_p8	Quality control flag for p8; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p9	pigment 9 = Diadinoxanthin	nanograms per kilogram (ng/kg)
QF_p9	Quality control flag for p9; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p10	pigment 10 = Alloxanthin	nanograms per kilogram (ng/kg)
QF_p10	Quality control flag for p10; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p11	pigment 11 = Diatoxanthin	nanograms per kilogram (ng/kg)
QF_p11	Quality control flag for p11; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p12	pigment 12 = Zeaxanthin + Lutein	nanograms per kilogram (ng/kg)
QF_p12	Quality control flag for p12; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless

p13	pigment 13 = Chlorophyll b	nanograms per kilogram (ng/kg)
QF_p13	Quality control flag for p13; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p14	pigment 14 = Chlorophyll a	nanograms per kilogram (ng/kg)
QF_p14	Quality control flag for p14; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p15	pigment 15 = a + b Carotene	nanograms per kilogram (ng/kg)
QF_p15	Quality control flag for p15; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p16_Chl	pigment 16 = fluorometric Chlorophyll a	micrograms per kilogram (ug/kg)
QF_p16_Chl	Quality control flag for p16; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p17_Phae	pigment 17 = fluorometric Phaeopigments	micrograms per kilogram (ug/kg)
QF_p17_Phae	Quality control flag for p17; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p18	pigment 18 = Lutein	nanograms per kilogram (ng/kg)
QF_p18	Quality control flag for p18; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p19	pigment 19 = Zeaxanthin	nanograms per kilogram (ng/kg)
QF_p19	Quality control flag for p19; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p20	pigment 20 = alpha-Carotene	nanograms per kilogram (ng/kg)

QF_p20	Quality control flag for p20; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
p21	pigment 21 = beta-Carotene	nanograms per kilogram (ng/kg)
QF_p21	Quality control flag for p21; Parameter quality flags defined as 1= unverified, 2= verified acceptable, 3= questionable, 4= bad, 9= no data	unitless
yyyymmdd	Year Month Day of collection	unitless
decy	Decimal year	unitless
time	Time of collection	unitless

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Instruments

Dataset-specific Instrument Name	Seabird CTD 9/11+
Generic Instrument Name	CTD Sea-Bird SBE 911plus
Generic Instrument Description	The Sea-Bird SBE 911 plus is a type of CTD instrument package for continuous measurement of conductivity, temperature and pressure. The SBE 911 plus includes the SBE 9plus Underwater Unit and the SBE 11plus Deck Unit (for real-time readout using conductive wire) for deployment from a vessel. The combination of the SBE 9 plus and SBE 11 plus is called a SBE 911 plus. The SBE 9 plus uses Sea-Bird's standard modular temperature and conductivity sensors (SBE 3 plus and SBE 4). The SBE 9 plus CTD can be configured with up to eight 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	Agilent1100 series HPLC
Generic Instrument Name	High-Performance Liquid Chromatograph
Dataset-specific Description	The HPLC currently in use is an Agilent 1100 series.
Generic Instrument Description	A High-performance liquid chromatograph (HPLC) is a type of liquid chromatography used to separate compounds that are dissolved in solution. HPLC instruments consist of a reservoir of the mobile phase, a pump, an injector, a separation column, and a detector. Compounds are separated by high pressure pumping of the sample mixture onto a column packed with microspheres coated with the stationary phase. The different components in the mixture pass through the column at different rates due to differences in their partitioning behavior between the mobile liquid phase and the stationary phase.

Dataset-specific Instrument Name	Niskin bottle
Generic Instrument Name	Niskin bottle
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	Turner 10-AU fluorometer
Generic Instrument Name	Turner Designs Fluorometer 10-AU
Generic Instrument Description	The Turner Designs 10-AU Field Fluorometer is used to measure Chlorophyll fluorescence. The 10AU Fluorometer can be set up for continuous-flow monitoring or discrete sample analyses. A variety of compounds can be measured using application-specific optical filters available from the manufacturer (read more from Turner Designs, turnerdesigns.com, Sunnyvale, CA, USA).

Dataset-specific Instrument Name	Turner Trilogy fluorometer
Generic Instrument Name	Turner Designs Trilogy fluorometer
Generic Instrument Description	The Trilogy Laboratory Fluorometer is a compact laboratory instrument for making fluorescence, absorbance, and turbidity measurements using the appropriate snap-in application module. Fluorescence modules are available for discrete sample measurements of various fluorescent materials including chlorophyll (in vivo and extracted), rhodamine, fluorescein, cyanobacteria pigments, ammonium, CDOM, optical brighteners, and other fluorescent compounds.

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Deployments

BVAL_cruises

Website	https://www.bco-dmo.org/deployment/944358
Platform	Multiple Vessels
Start Date	1991-04-29
Description	Following the first several years of the BATS project it was deemed necessary by the JGOFS steering committee and BATS PIs to conduct validation cruises in the vicinity of the nominal BATS site to better understand the mesoscale and larger scale variability of the region. Initial focus of the BVAL cruises was to investigate mesoscale variability and meridional gradients of the local region. Later, cruises focused on specific mesoscale eddies and effects of tropical cyclones through the local region. In the year 2000 it was deemed more important to document the larger scale changes in the North Atlantic Subtropical gyre so BVAL cruises established a transect line from ~ 35N to 19N (Bermuda to Puerto Rico) very similar to the WOCE A22 repeat hydrography line. These annual Bermuda-to-Puerto Rico transects have been run since 2000 and target stations at every one degree of latitude and typically have been conducted in September/October of each year to capture maximal heat content in the upper ocean. However, since this timeframe coincides with high tropical cyclone activity the cruises were reluctantly (as of 2022) moved to begin in June/July of each year for safety and operational reasons. In the pentad prior to 2022 every BVAL cruise was significantly impacted by multiple tropical cyclones.

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Project Information

Bermuda Atlantic Time-series Study (BATS)

Website: http://bats.bios.edu

Coverage: Northwest Sargasso Sea at 31 deg 40' N, 64 deg 10' W

A full description of the BATS research program (including links to the processed BATS data) is available from the BATS Web site (see above for Project URL/ Project Website links). Any data contributed from selected ancillary projects are listed (linked) in the 'Datasets Collection' section below.

Collaborative Research: The Bermuda Atlantic Time-series Study: Sustained Biogeochemical, Ecosystem and Ocean Change Observations and Linkages in the North Atlantic (Years 36-40) ***Awards OCE*-2241455*, OCE*-2241456 *and OCE*-2241457*)***
NSF award abstract

Long-term observations of ocean physics, biology, and chemistry across decades provide a powerful lens for understanding the response of the oceans to environmental change. This award will continue the Bermuda Atlantic Time-series Study (BATS) research program, which began in 1988, for another five years. Observations at the BATS site provide crucial information for understanding the ocean?s role in the global climate system and the response of the ocean carbon system and marine ecosystems to climate perturbations. The research goals of the BATS program continue to be to improve our understanding of the time-varying components of the ocean carbon cycle and related elements of interest (such as nitrogen, phosphorus, and silica) and to identify the physical, chemical, and ecosystem properties responsible for this variability. The BATS program has substantial broader impacts, contributing to the field of ocean sciences by providing high-quality ocean observations and a framework in which other researchers can conceive and test hypotheses. In addition, the recent acquisition of the Bermuda Institute of Ocean Sciences by the Global Futures Laboratory of Arizona State University provides new avenues for educational opportunities and

innovation.

In the subtropical gyre of the North Atlantic Ocean, warming, salinification, deoxygenation, ocean ecosystem changes, and acidification have accelerated their rate of change. Fundamental questions and challenges remain about understanding present and future ocean function, prediction, and modelling. An overarching question for the BATS program is: Will ocean biogeochemistry and ecosystem functioning continue to change in response to the acceleration of ocean warming, salinification, stratification, deoxygenation and acidification? With this question in mind, the sustained goals for the BATS program are: 1. Quantify the role of ocean-atmosphere coupling and climate variability on air-sea exchange of carbon dioxide (CO2) and carbon export to the ocean interior; 2. Document trends and controls of the following: (a) the interannual to decadal scale variability in carbon and nutrient cycles and their coupling in the surface and deep ocean via the Redfield Ratio paradigm; and, (b) biological community structure in the oligotrophic North Atlantic Ocean in response to low-frequency climate variability; 3. Quantify the response of planktonic and microbial community structure and function and impact on biogeochemical cycles (including new and export productivity) to variability in surface fluxes (e.g., heat, freshwater and momentum) and physical processes (e.g., mesoscale eddies, Rossby Waves, internal waves); 4. Facilitate development, calibration and validation of next-generation oceanographic sensors, tools and technologies; 5. Generate datasets that can be used by empiricists and modelers to test new hypotheses about North Atlantic Ocean biogeochemistry and ecosystem functioning; 6. Use BATS cruise, infrastructure, laboratory and analytical expertise, and data to improve education and training programs for BATS staff, STEM-literate students, and future oceanographers.

This award reflects NSF's statutory mission and has been deemed worthy of support through evaluation using the Foundation's intellectual merit and broader impacts review criteria.

Please see the BATS Web site (http://bats.bios.edu) for additional information.

List of References (PDF)

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Program Information

Ocean Carbon and Biogeochemistry (OCB)

Website: http://us-ocb.org/

Coverage: Global

The Ocean Carbon and Biogeochemistry (OCB) program focuses on the ocean's role as a component of the global Earth system, bringing together research in geochemistry, ocean physics, and ecology that inform on and advance our understanding of ocean biogeochemistry. The overall program goals are to promote, plan, and coordinate collaborative, multidisciplinary research opportunities within the U.S. research community and with international partners. Important OCB-related activities currently include: the Ocean Carbon and Climate Change (OCCC) and the North American Carbon Program (NACP); U.S. contributions to IMBER, SOLAS, CARBOOCEAN; and numerous U.S. single-investigator and medium-size research projects funded by U.S. federal agencies including NASA, NOAA, and NSF.

The scientific mission of OCB is to study the evolving role of the ocean in the global carbon cycle, in the face of environmental variability and change through studies of marine biogeochemical cycles and associated ecosystems.

The overarching OCB science themes include improved understanding and prediction of: 1) oceanic uptake and release of atmospheric CO2 and other greenhouse gases and 2) environmental sensitivities of biogeochemical cycles, marine ecosystems, and interactions between the two.

The OCB Research Priorities (updated January 2012) include: ocean acidification; terrestrial/coastal carbon fluxes and exchanges; climate sensitivities of and change in ecosystem structure and associated impacts on biogeochemical cycles; mesopelagic ecological and biogeochemical interactions; benthic-pelagic feedbacks on biogeochemical cycles; ocean carbon uptake and storage; and expanding low-oxygen conditions in the coastal

and open oceans.

U.S. Joint Global Ocean Flux Study (U.S. JGOFS)

Website: http://usjgofs.whoi.edu/

Coverage: Global

The United States Joint Global Ocean Flux Study was a national component of international JGOFS and an integral part of global climate change research.

The U.S. launched the Joint Global Ocean Flux Study (JGOFS) in the late 1980s to study the ocean carbon cycle. An ambitious goal was set to understand the controls on the concentrations and fluxes of carbon and associated nutrients in the ocean. A new field of ocean biogeochemistry emerged with an emphasis on quality measurements of carbon system parameters and interdisciplinary field studies of the biological, chemical and physical process which control the ocean carbon cycle. As we studied ocean biogeochemistry, we learned that our simple views of carbon uptake and transport were severely limited, and a new "wave" of ocean science was born. U.S. JGOFS has been supported primarily by the U.S. National Science Foundation in collaboration with the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the Department of Energy and the Office of Naval Research. U.S. JGOFS, ended in 2005 with the conclusion of the Synthesis and Modeling Project (SMP).

Ocean Time-series Sites (Ocean Time-series)

Coverage: Bermuda, Cariaco Basin, Hawaii

Program description text taken from Chapter 1: Introduction from the **Global Intercomparability in a Changing Ocean: An International Time-Series Methods Workshop** report published following the workshop held November 28-30, 2012 at the Bermuda Institute of Ocean Sciences. The full report is available from the workshop Web site hosted by US OCB: http://www.whoi.edu/website/TS-workshop/home

Decades of research have demonstrated that the ocean varies across a range of time 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 represent one of the most valuable tools scientists have to characterize and quantify ocean carbon fluxes and biogeochemical processes and their links to changing climate (Karl, 2010; Chavez et al., 2011; Church et al., 2013). They provide the oceanographic community with the long, temporally resolved datasets needed to characterize ocean climate, biogeochemistry, and ecosystem change.

The temporal scale of shifts in marine ecosystem variations in response to climate change are on the order of several decades. The long-term, consistent and comprehensive monitoring programs conducted by time-series sites are essential to understand large-scale atmosphere-ocean interactions that occur on interannual to decadal time scales. Ocean time-series represent one of the most valuable tools scientists have to characterize and quantify ocean carbon fluxes and biogeochemical processes and their links to changing climate.

Launched in the late 1980s, the US JGOFS (Joint Global Ocean Flux Study; http://usjgofs.whoi.edu) research program initiated two time-series measurement programs at Hawaii and Bermuda (HOT and BATS, respectively) to measure key oceanographic measurements in oligotrophic waters. Begun in 1995 as part of the US JGOFS Synthesis and Modeling Project, the CARIACO Ocean Time-Series (formerly known as the CArbon Retention In A Colored Ocean) Program has studied the relationship between surface primary production, physical forcing variables like the wind, and the settling flux of particulate carbon in the Cariaco Basin.

The objective of these time-series effort is to provide well-sampled seasonal resolution of biogeochemical variability at a limited number of ocean observatories, provide support and background measurements for

process-oriented research, as well as test and validate observations for biogeochemical models. Since their creation, the BATS, CARIACO and HOT time-series site data have been available for use by a large community of researchers.

Data from those three US funded, ship-based, time-series sites can be accessed at each site directly or by selecting the site name from the Projects section below.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1756105
NSF Division of Ocean Sciences (NSF OCE)	OCE-2241455

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