Primary production determinations at the Bermuda Atlantic Time-series Study site (BATS) from 1988-2022

Website: https://www.bco-dmo.org/dataset/893182
Data Type: Cruise Results
Version: 1
Version Date: 2023-04-18

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 are primary production estimates at the Bermuda Atlantic Time-series Study (BATS) site in the Sargasso Sea from December 1988 (BATS Cruise 3) through December 2022 (BATS cruise 399). The rate of carbon fixation by autotrophs in seawater was determined by tracing the uptake of radioactive 14C from the inorganic form to the particulate organic form. Incubations were performed in situ at depths ranging from the surface to 140 meters from dusk to dawn. Seawater samples were collected prior to sunrise, separated into three light bottles and one dark bottle, and a radioactive 14C tracer added. The bottles were then deployed on an incubation array at their collection depths, and allowed to drift on the array for the full light day. Samples were recovered after sunset and filtered for subsequent analysis on a liquid scintillation counter.

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Coverage

Spatial Extent: **N**:32.108 **E**:-64.012 **S**:30.729 **W**:-65.168
Temporal Extent: 1988-12-18 - 2022-12-16

Methods & Sampling

Primary production is measured *in situ* as part of the monthly Bermuda Atlantic Time Series (BATS) cruises.

Scope and field of application
Primary production is a fundamental ecological variable for understanding the flow of energy into an ecosystem as it supports the availability of organic material as building blocks for higher trophic levels. This method uses a radiocarbon ^{14}C spike and liquid scintillation counter (LSC) techniques to quantify the rate of primary production. This procedure describes the method for the determination of primary production in seawater, expressed as milligrams of carbon per cubic meter per day (mg C m^{-3} day^{-1}) . This method is suitable for the assay of all levels of primary production found in the ocean.

Primary production is defined as the rate of uptake of inorganic carbon (DIC) into particulate organic carbon (POC),

$$\text{C uptake} = \frac{DIC_n * POC^{14}C * 1.05}{DIC^{14}C}, \text{ where}$$

C uptake = rate of carbon fixation (mg Carbon m^{-3} day^{-1})
DIC_n = naturally occurring dissolved inorganic carbon
$POC^{14}C$ = ^{14}C spiked particulate organic carbon
$DIC^{14}C$ = ^{14}C spiked dissolved inorganic carbon
1.05 = metabolic discrimination factor due to biological isotopic fractionation (preferable uptake of lighter isotopes)

Principle of analysis
The rate of carbon fixation by autotrophs in seawater is measured by tracing the uptake of radioactive ^{14}C from the inorganic form to the particulate organic form. Radiocarbon is added at an assumed ratio to the total inorganic carbon content of the seawater sample. The uptake of radiocarbon by the particulate phytoplankton is converted to total carbon uptake by the application of this radiocarbon: total carbon ratio. Inorganic carbon is not measured because samples are acidified before analysis. The seawater is collected using the CTD at discrete depths every 20 meters from the surface to 140 meters. The radioactive ^{14}C spike is added and samples are incubated in situ at their respective depths using a free-floating array. The array is deployed prior to first light and recovered after sunset to capture the dawn to dusk light cycle.

A liquid scintillation counter (LSC) is used to calculate the level of radioactivity in the sample and therefore the amount of ^{14}C particulate organic carbon. The LSC measures the conversion of radioactive decay events into photons of light, which are detected by photomultiplier tubes and converted into electrical pulses. In order to aid the detection of radioactivity, a liquid scintillation cocktail is added (Ultima gold for this method). The cocktail contains both solvent and scintillator molecules. The radioactive decay from the ^{14}C excites the solvent molecule, and the energy is transferred to the scintillator which re-emits the energy in the form of light. Often more than one type of scintillator is present in the cocktail to allow for the emission of light at a suitable wavelength to be detected by the photomultiplier tubes. The resulting electrical signal that is generated is recorded as counts per minute (CPM).

Field sampling
Samples for primary production are collected two hours before dawn (pre-dawn production cast) and no other samples are taken during this cast. Nitrile gloves are used during the handling of samples. The polycarbonate incubation bottles are filled directly from the Niskins under low light conditions. Each bottle is rinsed 3 times before filling. Five bottles are filled for each sample depth. 250 µl of the ^{14}C working solution is added to each of the five bottles in the shared use radioisotope lab container. Low light levels are maintained by using red lights in the lab. One of the five bottles is wrapped in electrical tape; this bottle is then wrapped in aluminium foil to ensure it is kept in dark conditions. One of the five productivity bottles is used as the time-zero (T-0) sample. The spike is added, the sample is then thoroughly shaken before 50 ml is filtered. A 250 µl aliquot -- to be used for counting total added ^{14}C activity -- is removed from each of the T-0 bottles and is placed in a 20 ml glass scintillation vial containing 250 µl ethanolamine.

Approximately one hour before sunrise the productivity array is deployed. The incubation occurs throughout the day and the array is recovered approximately half an hour after sunset. Upon recovery and under low light conditions, a 50 ml aliquot is withdrawn from each productivity bottle and filtered onto a 25 mm Whatman® Glass Fibre Filter, maintaining vacuum levels of 70 mm Hg or less. Neither the filter nor the syringe is rinsed. The filter is placed into a 20 ml glass scintillation vial. Under a fume hood, excess radioactive carbon is driven off by adding 250 µl 0.5 N hydrochloric acid. A 250 µl aliquot for counting total added ^{14}C activity (Time End

Specific Activity) is removed from one of the light productivity bottles. This is placed in a 20 ml glass scintillation vial containing 250 µl ethanolamine (Sigma), similar to the T-0 described in Time Zero Specific Activity Sample. The samples are then stored at room temperature until analysis.

For additional details, please see Protocols for the Bermuda Atlantic Time-series Study Core Measurements.

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
- converted latitude and longitude to decimal degrees
- added columns for Cruise_type, Cruise_num, Cast_type, Cast, and Bottle_number based on the ID column info
- added column for ISO date
- missing data identifier of -999 maintained as per PI request

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Data Files

File
bats_primary_production.csv (Comma Separated Values (.csv), 590.90 KB) MD5:c0279727bc94f8539fe5c0390605d0b2 BATS primary production

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Related Publications

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

Fitzwater, S. E., Knauer, G. A., & Martin, J. H. (1982). Metal contamination and its effect on primary production measurements1. Limnology and Oceanography, 27(3), 544–551. doi:10.4319/lo.1982.27.3.0544
Methods

Joint, I., Pomroy, A., Savidge, G., & Boyd, P. (1993). Size-fractionated primary productivity in the northeast Atlantic in May–July 1989. Deep Sea Research Part II: Topical Studies in Oceanography, 40(1–2), 423–440. https://doi.org/10.1016/0967-0645(93)90025-i
Methods

Laws, E. A., DiTullio, G. R., Betzer, P. R., Karl, D. M., & Carder, K. L. (1989). Autotrophic production and elemental fluxes at 26°N, 155°W in the North Pacific subtropical gyre. Deep Sea Research Part A. Oceanographic Research Papers, 36(1), 103–120. https://doi.org/10.1016/0198-0149(89)90021-6
Methods

Lohrenz, S. E., Wiesenburg, D. A., Rein, C. R., Arnone, R. A., Taylor, C. D., Knauer, G. A., & Knap, A. H. (1992). A comparison of in situ and simulated in situ methods for estimating oceanic primary production. Journal of Plankton Research, 14(2), 201–221. https://doi.org/10.1093/plankt/14.2.201
Methods

Richardson, K. (1991). Comparison of 14C primary production determinations made by different laboratories. Marine Ecology Progress Series, 72, 189–201. https://doi.org/10.3354/meps072189
Methods

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Parameters

Parameter	Description	Units
Cruise_type	Cruise type (BATS Core, Bloom A, or Bloom B)	unitless
Cruise_num	Cruise number	unitless
Cast_type	Cast type (CTD or Hydrocast)	unitless
Cast	Cast Number (1-80 = CTD, 81-99 = Hydrocast)	unitless
Bottle_number	Niskin bottle number	unitless
Date	Date of collection	unitless
ID	Sample identification; a unique number which identifies cruise, cast, and bottle number	unitless
decy_in	Deployment date in decimal year	decimal year
decy_out	Recovery date in decimal year	decimal year
Latitude_in	Latitude of deployment (and initial pre-dawn water collection)	decimal degrees
Latitude_out	Latitude of recovery	decimal degrees
Longitude_In	Longitude of deployment (and initial pre-dawn water collection)	decimal degrees
Longitude_Out	Longitude of recovery	decimal degrees
QF	Niskin bottle Quality Flag (-2 = misfire, 0= no data, 1 = unverified, 2= verified acceptable, 5= no CTD data)	unitless
dep1	Collection depth in meters	meters (m)
pres	Pressure as measured by CTD	decibars (dbar)
temp	CTD temperature	degrees Celsius
salt	Salinity from GoFlo bottle or CTD	unitless
lt1	14C Primary Production light bottle #1	milligrams C per cubic meter per day (mgC/m^3/day)
lt2	14C Primary Production light bottle #2	milligrams C per cubic meter per day (mgC/m^3/day)
lt3	14C Primary Production light bottle #3	milligrams C per cubic meter per day (mgC/m^3/day)
dark	14C Primary Production dark bottle	milligrams C per cubic meter per day (mgC/m^3/day)
t0	14C Primary Production Time zero	milligrams C per cubic meter per day (mgC/m^3/day)
pp	Primary production mean of light values minus dark value	milligrams C per cubic meter per day (mgC/m^3/day)
yymmdd_in	Year Month Day of deployment	unitless
yymmdd_out	Year Month Day of recovery	unitless
hhmm_in	Time of deployment	unitless
hhmm_out	Time of recovery	unitless

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Instruments

Dataset-specific Instrument Name	light and dark incubation bottles
Generic Instrument Name	Light-Dark Bottle
Dataset-specific Description	Seawater samples were collected prior to sunrise, separated into three light bottles and one dark bottle, and a radioactive 14C tracer added. The bottles were then deployed on an incubation array at their collection depths, and allowed to drift on the array for the full light day.
Generic Instrument Description	The light/dark bottle is a way of measuring primary production by comparing before and after concentrations of dissolved oxygen. Bottles containing seawater samples with phytoplankton are incubated for a predetermined period of time under light and dark conditions. Incubation is preferably carried out in situ, at the depth from which the samples were collected. Alternatively, the light and dark bottles are incubated in a water trough on deck, and neutral density filters are used to approximate the light conditions at the collection depth.Rates of net and gross photosynthesis and respiration can be determined from measurements of dissolved oxygen concentration in the sample bottles.

Dataset-specific Instrument Name	Liquid Scintillation Counter
Generic Instrument Name	Liquid Scintillation Counter
Dataset-specific Description	A Liquid Scintillation Counter is used to calculate the level of radioactivity in the sample and therefore the amount of 14C particulate organic carbon
Generic Instrument Description	Liquid scintillation counting is an analytical technique which is defined by the incorporation of the radiolabeled analyte into uniform distribution with a liquid chemical medium capable of converting the kinetic energy of nuclear emissions into light energy. Although the liquid scintillation counter is a sophisticated laboratory counting system used the quantify the activity of particulate emitting (ß and a) radioactive samples, it can also detect the auger electrons emitted from 51Cr and 125I samples.

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.

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Deployments

BATS_cruises

Website	https://www.bco-dmo.org/deployment/58883
Platform	Unknown Platform
Report	http://bats.bios.edu/bats-data/
Start Date	1988-10-20
Description	Bermuda Institute of Ocean Science established the Bermuda Atlantic Time-series Study with the objective of acquiring diverse and detailed time-series data. BATS makes monthly measurements of important hydrographic, biological and chemical parameters throughout the water column at the BATS Study Site, located at 31 40N, 64 10W.

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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 31-35) ***Awards OCE-1756105, OCE-1756054, and OCE-1756312)***
NSF award abstract
Long-term observations over several decades are a powerful tool for investigating ocean physics, biology, and chemistry, and the response of the oceans to environmental change. The Bermuda Atlantic Time-Series Study, known as BATS, has been running continuously since 1988. The research goals of the BATS program are: (1) to improve our understanding of the time-varying components of the ocean carbon cycle and the cycles of related nutrient elements such as nitrogen, phosphorus, and silicon; and, (2) to identify the relevant physical, chemical and ecosystem properties responsible for this variability. In addition, the BATS program has strong and diverse broader impacts, contributing to the field of ocean sciences by providing high quality ocean observations and data for seagoing scientists and modelers, and a framework through which researchers can conceive and test hypotheses. This award will support the operations of the BATS program for five more years.

The primary BATS research themes are as follows: (1) Quantify the role of ocean-atmosphere coupling and climate variability on air-sea exchange of CO2, and carbon export to the ocean interior; (2) Document trends and the controls on the interannual to decadal scale variability in carbon and nutrient cycles to their coupling in the surface and deep ocean via the Redfield Ratio paradigm; (3) Quantify the response of planktonic community structure and function, and impact on biogeochemical cycles to variability in surface fluxes and dynamical processes; (4) Facilitate development, calibration and validation of next generation oceanographic sensors, tools and technologies; and, (5) Generate a dataset that can be utilized by empiricists, modelers and students. This research integrates ocean physics, chemistry and biology into a framework for understanding oceanic processes and ocean change in the North Atlantic subtropical gyre. The existing 29 years of BATS data provide robust constraints on seasonal and interannual variability, the response of the Sargasso Sea ecosystem to natural climate variability, and signal detection of potential ocean changes. This project would extend the BATS program through years 31-35 to address a series of ten interlinked questions through integrated research approaches and a multitude of collaborative efforts. In addition to the themes above, and embedded into the ten questions and approaches, the BATS team will focus on, for example, coupling of particle production and biogeochemistry; revisiting the complexities of the biological carbon pump; oxygen decline; and changes in the hydrography, physics, ocean carbon cycle and biogeochemistry of the Sargasso Sea. The highest quality data observation and collection will be maintained and used to address these questions. Importantly, a wide range of collaborations at the BATS site, spanning the physical and

biogeochemical disciplines, will aid these broad goals. Strong links to community stakeholders, and close collaboration (including methods intercomparisons and personnel exchanges) with the Hawaii Ocean Time-series are proposed. This work will extend the research findings of the project into educational and training opportunities within and beyond the oceanographic community, including training and mentorship of both undergraduate and graduate students.

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-0752366
NSF Division of Ocean Sciences (NSF OCE)	OCE-1756105

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