Determination of carbon, nitrogen, and phosphorus content in sinking particles at the Bermuda Atlantic Time-series Study (BATS) site from December 1988 to December 2024 using a Particle Interceptor Trap System (PITS)

Website: https://www.bco-dmo.org/dataset/894099
Data Type: Cruise Results
Version: 6
Version Date: 2025-06-24

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)

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Abstract
Data presented here contain elemental sinking fluxes of carbon, nitrogen, and phosphorus (C, N, P) from the Bermuda Atlantic Time-series Study site from December 1988 (BATS Cruise 3) through December 2024 (BATS cruise 422). The BATS program uses a method developed by Knauer et al. (1979) which was used extensively in the VERTEX program. In summary, to trap oceanic sediment flux, BATS uses a floating array comprised of polycarbonate tubes (7 cm diameter by 53 cm height) containing a buffered brine solution, with polycarbonate filters at the bottom to collect flux. Four tubes are deployed at each depth (150, 200, and 300 meters) and three additional tubes for blank counts are prepared but not deployed. The floating sediment trap array with collection tubes is deployed during monthly BATS cruises for a target time of 72 hours, but deployment time is subject to change depending on weather and/or emergency conditions. After recovery, the filters are examined under a microscope to remove swimming zooplankton caught on the traps to prevent skewed end results. Three samples from each depth are acidified to remove inorganic carbon before measuring organic carbon and nitrogen using a CE440 Elemental Analyzer, while the remaining non-acidified sample is used for total carbon estimates. Additional tubes are also prepared and deployed (three per depth) for phosphorus samples that are analyzed at Bigelow Laboratory of Ocean Sciences using a separate analytical procedure supervised by Dr. Michael Lomas.

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Coverage

Location: Bermuda Atlantic TimeSeries Study (BATS) station in the Sargasso Sea
Spatial Extent: **N**:32 **E**:-63 **S**:30 **W**:-66
Temporal Extent: 1988-12-16 - 2024-12-13

Dataset Description

Sinking particle data were collected from BATS cruises #3 (December 1988) through BATS cruise #422 (December 2024). Nominal deployment location at BATS site (31°40' N, 64°10' W).

Research was conducted on many research vessels including:

- R/V Weatherbird I (cruises 1,2,8,9,10,11,12 and 13)
- R/V Cape Henlopen (cruises 3,4,5,6 and 7)
- R/V Cape Hatteras (cruises 33,52,52a,53,53a,54,54a,55,55a and 56,195,196,196a 208,208a,209)
- R/V Weatherbird II (all other cruises through 207)
- R/V Oceanus (cruise 242)
- R/V Endeavor (cruise 331, 422)
- R/V Atlantic Explorer (cruises 210 through 241, and 243 onwards except those mentioned above)

Numerous chief scientists: Tony Knap, Rachel Dow, Anthony Michaels, Kjell Gundersen, Rodney Johnson, Ann Close, Deborah Steinberg, Paul Lethaby, Julian Mitchell, Vivienne Lochhead, Debra Lomas, Steven Bell, Jonathan Whitefield, Gwyn Evans, James Sadler, Samuel Monk, Samuel Stevens, Afonso Goncalves, Matt Enright, Fernando Pacheco, Zac Anderson, Claire Medley, and Dominic Smith.

Please see the Supplemental Files section for a listing of the cruises and associated measurements specific to this version of the BATS particle flux data (bats_flux_release_v006_updates.txt)

Methods & Sampling

Background
Particulate Organic Matter (POM) in the ocean consists of a variety of material such as live organisms, zooplankton carcasses, organic debris, zooplankton fecal pellets, transparent exopolymer particles, and minerals of both biogenic and terrestrial origin. The adhesive, coagulative nature of these particles leads to the formation of aggregates that become dense enough to sink towards the sea floor (McDonnell et al., 2011). It is well understood that the flux of marine particulate matter is a key process that links the surface with the deep ocean, and is a controlling factor in the distribution of many elements that form the building blocks of marine biota (Buesseler et al., 2007). These sinking particles are closely linked to the biological carbon pump (Ducklow et al., 2001), represent a key component in the ocean food web and can also act as a sink for inorganic minerals and pollutants that are scavenged by the sinking particles.

Sample collection

The BATS program uses a method developed by Knauer et al. (1979), which was used extensively at the VERTEX time-series site in the northeast Pacific, and is suitable for the assay of all levels of sinking flux found in the ocean. Particle flux is collected within a floating array of polycarbonate tubes (7 cm diameter by 53 cm height) containing a buffered brine solution with polycarbonate filters at the bottom. During monthly cruises to the BATS site, tubes are deployed at three depths (150, 200, and 300 meters) for a target time of 72 hours, depending on weather and conditions. The array is tracked using Argos, Iridium, RDF, and AIS localization units.

Before the array is deployed, tubes are arranged in deployment racks for the different depths and filled with a heavy brine (~85 ppt) and 2% formalin solution. Equipment used and the specific arrangement of the array is represented in Figure 1 (See Supplemental Files section). Four tubes are deployed for carbon and nitrogen determinations, three tubes are deployed for phosphorus counts, and three tubes are prepared (but not deployed) for blank counts.

Upon recovery, the ambient seawater above the interface (at approximately half height of the tubes) is siphoned off and the brine in the lower half of the tube is drained through the filter by means of opening a valve. Tubes are disassembled inside a fume hood and the pre-weighed polycarbonate filters containing the flux sample are transferred to clean petri dishes. Samples are misted with pH buffer solution once in the petri dish to keep them moist. Misting is done during transfer of samples as well as during the time they remain stored at 4ºC until analysis. Care is taken to store samples no longer than 3 to 6 months to prevent any biological processes that could modify organic carbon contents.

Sample analysis

After recovery, filters are examined under a microscope at 12x and 25x magnification to remove swimming zooplankton and other organisms which are not considered sediment flux. Manual removal is needed to prevent overestimation of sinking material that could skew the end results. The remaining flux on each filter is scraped into a bolus, dried and then placed into a silver capsule. For each depth, three samples are acidified to remove inorganic carbon prior to measurement of organic carbon and nitrogen. The non-acidified sample (fourth bolus) is measured for total carbon. Samples are analyzed with a CE440 Elemental Analyzer (Exeter Analytical), which combusts and reduces the sample, converting all C and N present into CO_2 and N_2. These gas concentrations are measured by thermal conductivity detectors and converted to electrical millivolt signals. Calibration coefficients are then used to convert millivolt outputs to carbon and nitrogen concentrations in micrograms. Acetanilide conditioners and machine blanks are also run to standardize the instrument and monitor performance and accuracy during a run. (See Data Processing Section below for additional information).

The PITS samples that are collected for determination of total particulate phosphorus (PPhos) are analyzed at Bigelow Laboratory of Ocean Sciences following the methods described in Lomas et al. (2010). The PPhos samples have swimmers removed (as detailed above) and are then analyzed using the ash-hydrolysis method of Solarzano and Sharp (1980). This procedure does not separate inorganic from organic phosphorus so these results should be considered as total particulate phosphorus.

Considerations, concerns, and challenges

Sediment traps are the only tools for directly collecting sinking particles in the ocean. They are largely un-calibrated in the field and there are significant unresolved questions on their accuracy and precision. It is assumed that the collection of particles is linearly related to the aperture area of the sediment trap and that this collection is an accurate estimate of the mass of sinking particles at that depth and the particle sinking speeds. But hydrodynamics and other factors influence the collection of material by sediment traps so the interpretation of trap data should be approached with caution (Antia, 2005; Butman et al., 1986; Gardner et al., 1980; Kahler and Bauerfeind, 2001; Lee et al., 1988). The U.S. JGOFS Planning Report #10 provides an overview of these issues (U.S. JGOFS Planning Office, 1989) and there have been significant published papers on trap accuracy since that report.

- Any investigator using sediment traps should become aware of the facts and challenges in order to make informed decisions about appropriate methods for their investigation.
- Any scientist looking to use sediment trap data should be familiar with the factors affecting flux estimates, the methods used for the study, and the assumptions made for the flux calculations

Data Processing Description

The CE440 elemental analyzer calculates the amount in micrograms (ug) of C and N present in a sample. However, results are reported in milligrams carbon per square meter per day (C mg/m2day). The raw data downloaded from the instrument provides K values, blank values, R and Z values (in milliVolts), and calculated C and N values (ug).

For BATS processing, the mean of all the calculated K values is used for C and N estimations, and therefore a slightly different K is used than that of the CE440 software. The calculations for the K value for BATS are as follows:

$$K = \frac{R - Z - B}{C \ (or \ N)}$$

where:
    B (mV) = Blank capsule reading in millivolts (i.e the first run with ID 'blank')
    R (mV) = Sample reading in mV from standards (Std1's)
    Z (mV) = Instrument baseline, without capsule
    C (ug) = mass of carbon. Acetanilide (ug) x 0.7109 from Std1's
    N (ug) = mass of nitrogen. Acetanilide (ug) x 0.1036 from Std1's

Then, to calculate the Carbon or Nitrogen content in the sample, we use an average of the field blanks (FB) rather than the instrument blank measured using the following equation:

$$Carbon \ content \ (ug) = \frac{R - Z - FB}{K}$$

where FB = Average_R(mV) minus Average_Z(mV)

Since the elemental content measured is a part of the total sample captured (assuming some sample was lost in the scraping and bolus loading process), we adjust the carbon or nitrogen content to represent the entire filter sample:

$$C\_adjusted = \frac{C\_CE440}{M\_bolus} * (M\_sample*1000)$$

where:
C_adjusted (ug) = Carbon content adjusted to represent the entire filter sample
C_CE440 (ug) = Carbon in subsample calculated by CE440 mV data in MATLAB program.
M_bolus (ug) = subsample weight taken from microbalance when putting bolus in silver capsule
M_sample(ug) = average sample and filter weight minus average filter weight

Finally, the flux is calculated over the trap area, and number of deployment days, in milligrams (mg):

$$C\_flux = \frac{C\_adjusted}{(0.0039m^2 * T)} *1000$$

where:
C_flux = mg/m2/day
0.0039m^2 = is the cross-section area of the trap with a 7cm diameter
T = number of days
*1000 = converts the ug to mg

BCO-DMO Processing Description

- Imported data from source file "bats_flux_v006.txt" into the BCO-DMO data system. Data file imported using missing data identifiers "NA" and -999.
- combined yyyymmdd and time columns for both deployment and recovery
- converted datetimes to ISO Date format of yyyy-mm-dd hh:mm

- converted latitude and longitude to decimal degrees
- added columns for Cruise_type and Cruise_num
- added column for Vessel
- modified parameter names to conform with BCO-DMO naming conventions
- adjusted column order to match other time series datasets

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Data Files

File
894099_v6_bats_particle_flux.csv (Comma Separated Values (.csv), 255.81 KB) MD5:425d17c636ac0106a36640c505b5cc97 Primary data file for dataset ID 894099, version 6

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Supplemental Files

File	
bats_flux_release_v006_updates.txt	(Plain Text, 440 bytes) MD5:6693728b42e585e77d345068cb225ee7
ASCII file listing changes/updates in current version (v006) of BATS sediment trap flux data from previous versions.	
Figure1_PITS_Array_Diagram.pdf	(Portable Document Format (.pdf), 61.10 KB) MD5:549064e841cb44d2d896b855c4e76553
Figure 1: Particle Interceptor Trap System Array Diagram	

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Related Publications

Antia, A. N. (2005). Particle-associated dissolved elemental fluxes: revising the stoichiometry of mixed layer export. https://doi.org/10.5194/bgd-2-275-2005
Related Research

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

Buesseler, K. O., Antia, A. N., Chen, M., Fowler, S. W., Gardner, W. D., Gustafsson, O., Harada, K., Michaels, A. F., Rutgers van der Loeff, M., Sarin, M., Steinberg, D. K., & Trull, T. (2007). An assessment of the use of sediment traps for estimating upper ocean particle fluxes. Journal of Marine Research, 65(3), 345–416. https://doi.org/10.1357/002224007781567621
Related Research

Butman, C. A., W. D. Grant, and Stolzenbach K. D. (1986). Predictions of sediment trap biases in turbulent flows: a theoretical analysis based on observations from the literature. J. Mar. Res 44: l-644
Related Research

Ducklow, H., Steinberg, D., & Buesseler, K. (2001). Upper Ocean Carbon Export and the Biological Pump. Oceanography, 14(4), 50–58. https://doi.org/10.5670/oceanog.2001.06
Related Research

Gardner, Wilford. (1980). Sediment trap dynamics and calibration: a laboratory evaluation.. Journal of Marine Research. 38. 17-39.

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

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Related Research

Knauer, G. A., Martin, J. H., & Bruland, K. W. (1979). Fluxes of particulate carbon, nitrogen, and phosphorus in the upper water column of the northeast Pacific. Deep Sea Research Part A. Oceanographic Research Papers, 26(1), 97–108. doi:10.1016/0198-0149(79)90089-x https://doi.org/10.1016/0198-0149(79)90089-X
Methods

Kähler, P., & Bauerfeind, E. (2001). Organic particles in a shallow sediment trap: Substantial loss to the dissolved phase. Limnology and Oceanography, 46(3), 719–723. Portico. https://doi.org/10.4319/lo.2001.46.3.0719
Related Research

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

Lee, C., Wakeham, S., & Hedges, J. (1988). The Measurement of Oceanic Particle Flux—Are "Swimmers" a Problem? Oceanography, 1(2), 34–36. https://doi.org/10.5670/oceanog.1988.06
Methods

Lomas, M. W., Burke, A. L., Lomas, D. A., Bell, D. W., Shen, C., Dyhrman, S. T., & Ammerman, J. W. (2010). Sargasso Sea phosphorus biogeochemistry: an important role for dissolved organic phosphorus (DOP). Biogeosciences, 7(2), 695–710. doi:10.5194/bg-7-695-2010
Methods

Lorrain, A., Savoye, N., Chauvaud, L., Paulet, Y.-M., & Naulet, N. (2003). Decarbonation and preservation method for the analysis of organic C and N contents and stable isotope ratios of low-carbonated suspended particulate material. Analytica Chimica Acta, 491(2), 125–133. https://doi.org/10.1016/s0003-2670(03)00815-8 https://doi.org/10.1016/S0003-2670(03)00815-8
Related Research

McDonnell, A. M. (2011). Marine particle dynamics: sinking velocities, size distributions, fluxes, and microbial degradation rates (Doctoral dissertation, Massachusetts Institute of Technology). http://hdl.handle.net/1721.1/65326
Related Research

Solórzano, L., & Sharp, J. H. (1980). Determination of total dissolved phosphorus and particulate phosphorus in natural waters1. Limnology and Oceanography, 25(4), 754–758. doi:10.4319/lo.1980.25.4.0754
Methods

U.S. GOFS Report No. 10. (1989). Sediment Trap Technology and Sampling. Available from U.S. JGOFS Planning Office, Woods Hole Oceanographic Institution, Woods Hole, MA, 94 pp.
Related Research

Related Datasets

IsRelatedTo

Brenner, A., Maas, A., Blanco-Bercial, L., Noyes, K., Neuer, S. (2025) **Measurements of sinking particle types from deployed Particle Interceptor Trap System (PITS) at the Bermuda Atlantic Time-series Study (BATS) site from Jul 2021 to Mar 2023.** Biological and Chemical Oceanography Data Management Office (BCO-DMO). (Version 1) Version Date 2025-10-08 doi:10.26008/1912/bco-dmo.982170.1 [view at BCO-DMO]
Relationship Description: Data were derived from the the same sampling events.

Parameters

Parameter	Description	Units
BATS_Cruise_ID	BATS cruise ID	unitless
Vessel	Name of vessel used for the cruise	unitless
Date_deployed	Date of PITS array deployment (yyyy-mm-dd)	unitless
Latitude_deployed	Latitude of PITS array deployment	decimal degrees
Longitude_deployed	Longitude of PITS array deployment	decimal degrees
Date_recovered	Date of PITS array recovery (yyyy-mm-dd)	unitless
Latitude_recovered	Latitude of PITS array recovery	decimal degrees
Longitude_recovered	Longitude of PITS array recovery	decimal degrees
Cruise_type	Cruise type (BATS Core, Bloom A, or Bloom B)	unitless
Cruise_num	Cruise number	unitless
Depth	Collection depth	meters (m)
M1	Mass flux #1	milligrams material per square meter per day (mg/m^2/day)
M2	Mass flux #2	milligrams material per square meter per day (mg/m^2/day)
M3	Mass flux #3	milligrams material per square meter per day (mg/m^2/day)
M_avg	Average mass flux	milligrams material per square meter per day (mg/m^2/day)
C1	Organic Carbon flux #1	milligrams carbon per square meter per day (mgC/m^2/day)

C2	Organic Carbon flux #2	milligrams carbon per square meter per day (mgC/m^2/day)
C3	Organic Carbon flux #3	milligrams carbon per square meter per day (mgC/m^2/day)
C_avg	Average organic carbon flux	milligrams carbon per square meter per day (mgC/m^2/day)
N1	Nitrogen flux #1	milligrams nitrogen per square meter per day (mgN/m^2/day)
N2	Nitrogen flux #2	milligrams nitrogen per square meter per day (mgN/m^2/day)
N3	Nitrogen flux #3	milligrams nitrogen per square meter per day (mgN/m^2/day)
N_avg	Average nitrogen flux	milligrams nitrogen per square meter per day (mgN/m^2/day)
P1	Phosphorus flux #1	millimoles phosphorus per square meter per day (mmolP/m^2/day)
P2	Phosphorus flux #2	millimoles phosphorus per square meter per day (mmolP/m^2/day)
P3	Phosphorus flux #3	millimoles phosphorus per square meter per day (mmolP/m^2/day)
P_avg	Average phosphorus flux	millimoles phosphorus per square meter per day (mmolP/m^2/day)
FBC1	Field-blank-corrected Organic carbon flux #1	milligrams carbon per square meter per day (mgC/m^2/day)
FBC2	Field-blank-corrected Organic carbon flux #2	milligrams carbon per square meter per day (mgC/m^2/day)
FBC3	Field-blank-corrected Organic carbon flux #3	milligrams carbon per square meter per day (mgC/m^2/day)
FBC_avg	Field-blank-corrected average Organic carbon flux	milligrams carbon per square meter per day (mgC/m^2/day)
FBN1	Field-blank-corrected Nitrogen flux #1	milligrams nitrogen per square meter per day (mgN/m^2/day)
FBN2	Field-blank-corrected Nitrogen flux #2	milligrams nitrogen per square meter per day (mgN/m^2/day)

FBN3	Field-blank-corrected Nitrogen flux #3	milligrams nitrogen per square meter per day (mgN/m^2/day)
FBN_avg	Field-blank-corrected average Nitrogen flux	milligrams nitrogen per square meter per day (mgN/m^2/day)

Instruments

Dataset-specific Instrument Name	Exeter Analytical CE440 Elemental Analyzer
Generic Instrument Name	Elemental Analyzer
Dataset-specific Description	An Exeter Analytical CE440 Elemental Analyzer was use to measured the carbon and nitrogen present in the sediment trap flux samples. For information on operation of this instrument, refer to: http://www.exeteranalytical.co.uk/theory-of-operation/
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	microscope
Generic Instrument Name	Microscope - Optical
Dataset-specific Description	BATS particle flux filter samples are examined under a microscope to remove swimming zooplankton that were caught in the traps.
Generic Instrument Description	Instruments that generate enlarged images of samples using the phenomena of reflection and absorption of visible light. Includes conventional and inverted instruments. Also called a "light microscope".

Dataset-specific Instrument Name	Particle Interceptor Trap System (PITS)
Generic Instrument Name	Sediment Trap - Floating
Dataset-specific Description	To sample oceanic sediment flux, the Bermuda Atlantic Time-series Study (BATS) uses a Particle Interceptor Trap System (PITS), which consists of a floating array holding polycarbonate tubes with a filter at the bottom
Generic Instrument Description	Floating sediment traps are specially designed sampling devices deployed to float in the water column (as opposed to being secured to a mooring at a fixed depth) for periods of time to collect particles from the water column that are falling toward the sea floor. In general a sediment trap has a container at the bottom to collect the sample and a broad funnel-shaped opening at the top with baffles to keep out very large objects and help prevent the funnel from clogging. The 'Sediment Trap -Floating' designation is used for a floating type of sediment trap about which no other design details are known.

Dataset-specific Instrument Name	Particle Interceptor Trap System (PITS)
Generic Instrument Name	Sediment Trap - Particle Interceptor
Dataset-specific Description	To sample oceanic sediment flux, the Bermuda Atlantic Time-series Study (BATS) uses a Particle Interceptor Trap System (PITS), which consists of a floating array holding polycarbonate tubes with a filter at the bottom
Generic Instrument Description	A Particle Interceptor Trap is a prototype sediment trap designed in the mid 1990s to segregate 'swimmers' from sinking particulate material sampled from the water column. The prototype trap used 'segregation plates' to deflect and segregate 'swimmers' while a series of funnels collected sinking particles in a chamber (see Dennis A. Hansell and Jan A. Newton. September 1994. Design and Evaluation of a "Swimmer"-Segregating Particle Interceptor Trap, Limnology and Oceanography, Vol. 39, No. 6, pp. 1487-1495).

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Deployments

BATS_cruises

Website	https://www.bco-dmo.org/deployment/58883
Platform	Multiple Vessels
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 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 (CO_2) 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)

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 CO_2 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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