Particle birefringence photon yield and particle beam attenuation coefficient derived from optical particle sensors deployed on GTC CTD casts on the U.S. GEOTRACES Pacific Meridional Transect (PMT) cruise (GP15) on R/V Roger Revelle from Sept-Nov 2018

Website: https://www.bco-dmo.org/dataset/941657
Data Type: Cruise Results
Version: 1
Version Date: 2024-10-30

Project
» US GEOTRACES Pacific Meridional Transect (GP15) (U.S. GEOTRACES PMT)
» Autonomous Ocean Carbon Observer Development and Calibration (OCO Development)

Program
» U.S. GEOTRACES (U.S. GEOTRACES)

Contributors	Affiliation	Role
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Abstract
This data set was derived from optical particle sensors deployed during casts of the GEOTRACES Trace Metal Carousel (GTC) as part of the GEOTRACES Pacific Meridional Transect (GP15 expedition). Data here are for the 0-500 meters (m) depth interval and include measures of particle birefringence photon yield (units of parts per million per meter) and particle beam attenuation coefficient (units of per meter). Data for the full depth of the water column are also included as a supplemental file, as are CTD data used in the profile data calculations.

Table of Contents

Coverage

Spatial Extent: **N**:56.05827 **E**:-151.99422 **S**:-19.99983767 **W**:-156.96217
Temporal Extent: 2018-09-24 - 2018-11-22

Methods & Sampling

The two particulate inorganic carbon (PIC) sensors (PIC010 and PIC011) used in this study have been extensively documented (Bishop et al. 2022). Briefly, the sensors are built on a digital WETLabs C-star 25-centimeter (cm) pathlength 6000-meter (m) rated transmissometer. A 660-nanometer (nm) laser replaced the transmissometer's LED light source. High crossing efficiency polarizers were externally mounted to both source and receiver windows; the source polarizer is aligned with the plane of polarization of the laser and the receiver polarizer is crossed to minimize transmission of the direct beam. As light from the primary beam encounters birefringent particles, its plane of polarization is rotated and the sensor receives a signal. Voltage signals recorded by a CTD arise from four sources: (a) dark current, (b) polarizer crossing blank, (c) stray light, and (d) birefringence (beta) (Equation 1):

$V_{beta} = V_{meas} - V_{dark} - Vc_{ross} - V_{stray}$ (1)

where V_{meas} is the raw signal from the CTD, V_{dark} is the reading with the beam blocked (0.007V), V_{cross} is the primary beam signal that is detected with no particles in the beam (~0.05V), and V_{stray} is light added to the beam by reflections. V_{stray} is assumed negligible as the primary beam is columnated and the detector receiver angle is small. In our data reduction scheme, we calculate instrument temperature, and rate of change of instrument temperature per minute. The full expression for calculation of birefringent photon yield is given by a reformulation of Equation 1:

$V_{beta\_corr = ((}V_{meas} - V_{dark} - V_{cross}\bullet Tr)/R - V_{drift} - V_{transient})/Tr^{0.5}$ (2).

V_{pradj} = press • $coefft_{press}$ (3). and $V_{beta\_corr\_final} = V_{beta\_corr} + V_{pradj}$ (4) and $Beta_{corr} = V_{beta\_corr\_final}$ • SF ppm m^{-1} (5).

Tr, is transmission measured by C-Star transmissometer (660 nm) over its 25 cm path length; As the crossing blank (V_{cross}) is a transmitted light signal, Tr compensates for attenuation of the crossing blank due to particles. The term, R, is the static thermal response correction calculated using instrument temperature (Bishop et al. 2022). The term V_{drift} is a small compensation for sensor drift during McLane pumping between the time of down and up casts (often <1 mV), $V_{transient}$ is derived from thermal cycling experiment data. The term, $Tr^{0.5}$, is from Guay and Bishop (2002) and compensates for attenuation of the birefringent photon signal resulting from scattering and absorption effects of other particles in the beam. Analog voltage data (0-5 V) from these sensors is converted to physical units of ppm m^{-1} (Equation 5) using scaling Factors (SF) of 448.4 ppm $V^{-1}m^{-1}$ and 644.7 ppm V^{-1} m^{-1} for PIC010 and PIC011, respectively (Bishop et al., 2022). The transmittance based corrections were no more than 20% of β_{corr} in surface waters and became negligible in waters below the euphotic zone.

$Beta_{corr}$ is converted to PIC (nM) using by multiplying by a scale factor (SF) of 15 (Bishop et al., 2022). In this paper we describe this quantity as "birefringence PIC" or "PIC_{β}". Pressure coefficients were derived using a best fit of PIC_{β} and McLane pump measured PIC in the mid water column (2000 m to 4000 m). These adjustments had minimal effect in the upper 500 m.

During GP15, Transmissometer CST1450 was the standard for beam attenuation coefficient (c_p) for the entire section as it was both stable and air calibrated prior to each deployment; the other transmissometers were adjusted to this standard.

Transmissometer beam attenuation coefficient calculation:

This method differs from standard procedure as it addresses temperature dependent hysteresis seen in transmissometer profiles.

cst1450_1=(cst1450-cst1450z)/cst1450r, where cst1450 = CTD measured voltage, cst1450z = the blocked beam voltage, and cst1450r is the temperature response function for the instrument

cst1450_2=cst1450_1-cum1450dr-cst1450t*0.3, where cum1450dr is voltage drift during cast, and cst1450t is a correction due to thermal hysteresis.>

tr=cst1450_2/CST1450_NetVref, Where CST1450_NetVref is Voltage the instrument reads in particle free water.

cp1450=-4*ln(tr), cp1450 is the beam attenuation coefficient calculated for this instrument.

the various quanities, CST1450_NetVref, cst1450z, cst1450r, cum1450dr, cst1450t are included in the data sets and defined in the parameter list

Data Processing Description

Optical data obtained during CTD deployments were despiked by computing the mean and standard deviation over 10-second intervals as described by Bishop et al. (2022). In discussions of transects of optically derived PIC and POC concentrations to 500m, we use the average of all profiles at each station. In a separate submission we use data from separate CTD casts.

BCO-DMO Processing Description

- Imported original file "GP15_GTC_CTD_0500m_ProfileData_cpadj.csv" into the BCO-DMO system.
- Calculated ISO date-time field (UTC) from the jdays column.
- Saved final file as "941657_v1_gp15_particle_birefringence_photon_yield_and_beam_attenuation_0-500m_gtc_ctd.csv".

[table of contents | back to top]

Related Publications

Bishop, J. K. B., Amaral, V. J., Lam, P. J., Wood, T. J., Lee, J.-M., Laubach, A., Barnard, A., Derr, A., & Orrico, C. (2022). Transmitted Cross-Polarized Light Detection of Particulate Inorganic Carbon Concentrations and Fluxes in the Ocean Water Column: Ships to ARGO Floats. Frontiers in Remote Sensing, 3. https://doi.org/10.3389/frsen.2022.837938
Results

Guay, C. K. H., & Bishop, J. K. B. (2002). A rapid birefringence method for measuring suspended CaCO3 concentrations in seawater. Deep Sea Research Part I: Oceanographic Research Papers, 49(1), 197–210. https://doi.org/10.1016/s0967-0637(01)00049-8
Methods

Li, Y., Bishop, J. K. B., Lam, P. J., & Ohnemus, D. (2024). Analysis of Satellite and in-situ Optical Proxies for PIC and POC during GEOTRACES GP15 and GP17-OCE Transects from the Subarctic North Pacific to the Southern Ocean. https://doi.org/10.22541/essoar.172988067.75831081/v1
Results

[table of contents | back to top]

Parameters

Parameter	Description	Units
station	station number	unitless
jdays	ordinal days in 2018	unitless
ISO_DateTime_UTC	Date and time (UTC) in ISO 8601 format	unitless
lat_avg	decimal latitute (north positive)	degrees
lon_avg	decimal longitude (east positive)	degrees
press	Pressure; Digiquartz [db]	decibars (db)
depth	Depth [salt water]	meters (m)
temp	CTD temperature. [ITS-90]	degrees Celsius
sal	Salinity	practical salinity units (PSU)
sigth	potential density anomaly	unitless
o2	Oxygen; SBE 43	micromoles per kilogram (umol/kg)

cp1035	Particle Beam Attenuation Coefficient [PPM m-1] from SENSOR CST1035 Filtered	parts per million per meter (ppm m-1)
cp1035_sd	Particle Beam Attenuation Coefficient Standard Deviation [PPM m-1] from SENSOR CST1035 Filtered	parts per million per meter (ppm m-1)
cp1035_n	Particle Beam Attenuation Coefficient number of Observations	unitless
pic010biref	Particle Birefringence Yield [PPM m-1] from SENSOR PIC010 Filtered	parts per million per meter (ppm m-1)
pic010biref_sd	Particle Birefringence Yield Standard Deviation [PPM m-1] from SENSOR PIC010 Filtered	parts per million per meter (ppm m-1)
pic010biref_n	Particle Birefringence Yield number of Observations	unitless
Fl	Fluorescence Chlorophyll Sepoint	milligrams per cubic meter (mg/m3)
Fl_sd	Fluorescence Chlorophyll Seapoint [mg/m3] standard deviation	milligrams per cubic meter (mg/m3)
Fl_n	Fluorescence Chlorophyll Sepoint number of observations	unitless
dindex	depth interval sequence	unitless
track_km	kilometers track distance from station 1	kilometers (km)

[table of contents | back to top]

Instruments

Dataset-specific Instrument Name	Sea Bird SBE19plus, S/N 5236
Generic Instrument Name	CTD Sea-Bird
Generic Instrument Description	Conductivity, Temperature, Depth (CTD) sensor package from SeaBird Electronics, no specific unit identified. This instrument designation is used when specific make and model are not known. See also other SeaBird instruments listed under CTD. More information from Sea-Bird Electronics.

Dataset-specific Instrument Name	PIC010 and PIC011
Generic Instrument Name	PIC Sensor
Generic Instrument Description	Description from Bishop et al. (2022) (doi: 10.3389/frsen.2022.837938) PIC Sensor Concept: The sensor concept has been described by Guay and Bishop (2002) (doi: 10.1016/s0967-0637(01)00049-8) and Bishop (2009) (doi: 10.5670/oceanog.2009.48). The first profiling sensor was a modified version of an analog WETLabs C-Star 25 cm pathlength transmissometer. A 660-nm laser replaced the LED source, and a cell with high crossing efficiency polarizers (630–700 nm, Polarcor, Corning) was inserted into the water path length of the instrument. At the source end, the polarizer is aligned with the plane of polarization of the laser; on the receiver end, the polarizer is crossed, thus minimizing the detection of the primary beam. The sensor thus detects the photon yield resulting from the interaction of polarized laser light with birefringent particles in the beam. The first full water column profiles of the first sensor (PIC001) took place in 2003 in the North Atlantic (Bishop, 2009). This sensor was stabilized in 2006 by replacing the cell with body-mounted polarizers. Over many iterations of the basic design and multiple sea trials, it was demonstrated in 2013 that multiple PIC sensors yielded identical results and exceeded the performance of PIC001.

[table of contents | back to top]

Deployments

RR1815

Website	https://www.bco-dmo.org/deployment/776917
Platform	R/V Roger Revelle
Report	https://datadocs.bco-dmo.org/docs/geotraces/GEOTRACES_PMT/casciotti/data_docs/GP15_Cruise_Report_with_ODF_Report.pdf
Start Date	2018-10-24
End Date	2018-11-24
Description	Additional cruise information is available from the Rolling Deck to Repository (R2R): https://www.rvdata.us/search/cruise/RR1815

RR1814

Website	https://www.bco-dmo.org/deployment/776913
Platform	R/V Roger Revelle
Report	https://datadocs.bco-dmo.org/docs/geotraces/GEOTRACES_PMT/casciotti/data_docs/GP15_Cruise_Report_with_ODF_Report.pdf
Start Date	2018-09-18
End Date	2018-10-21
Description	Additional cruise information is available from the Rolling Deck to Repository (R2R): https://www.rvdata.us/search/cruise/RR1814

[table of contents | back to top]

Project Information

US GEOTRACES Pacific Meridional Transect (GP15) (U.S. GEOTRACES PMT)

Website: http://www.geotraces.org/

Coverage: Pacific Meridional Transect along 152W (GP15)

A 60-day research cruise took place in 2018 along a transect form Alaska to Tahiti at 152° W. A description of the project titled "*Collaborative Research: Management and implementation of the US GEOTRACES Pacific Meridional Transect*", funded by NSF, is below. Further project information is available on the [US GEOTRACES website]() and on the [cruise blog](). A detailed [cruise report is also available]() as a PDF.

Description from NSF award abstract:
GEOTRACES is a global effort in the field of Chemical Oceanography in which the United States plays a major role. The goal of the GEOTRACES program is to understand the distributions of many elements and their isotopes in the ocean. Until quite recently, these elements could not be measured at a global scale. Understanding the distributions of these elements and isotopes will increase the understanding of processes that shape their distributions and also the processes that depend on these elements. For example, many "trace elements" (elements that are present in very low amounts) are also important for life, and their presence or absence can play a vital role in the population of marine ecosystems. This project will launch the next major U.S. GEOTRACES expedition in the Pacific Ocean between Alaska and Tahiti. The award made here would support all of the major infrastructure for this expedition, including the research vessel, the sampling equipment, and some of the core oceanographic measurements. This project will also support the personnel needed to lead the expedition and collect the samples.

This project would support the essential sampling operations and infrastructure for the U.S. GEOTRACES Pacific Meridional Transect along 152° W to support a large variety of individual science projects on trace element and isotope (TEI) biogeochemistry that will follow. Thus, the major objectives of this management proposal are: (1) plan and coordinate a 60 day research cruise in 2018; (2) obtain representative samples for a wide variety of TEIs using a conventional CTD/rosette, GEOTRACES Trace Element Sampling Systems, and in situ pumps; (3) acquire conventional CTD hydrographic data along with discrete samples for salinity, dissolved oxygen, algal pigments, and dissolved nutrients at micro- and nanomolar levels; (4) ensure that proper QA/QC protocols are followed and reported, as well as fulfilling all GEOTRACES intercalibration protocols; (5) prepare and deliver all hydrographic data to the GEOTRACES Data Assembly Centre (via the US BCO-DMO data center); and (6) coordinate all cruise communications between investigators, including preparation of a hydrographic report/publication. This project would also provide baseline measurements of TEIs in the Clarion-Clipperton fracture zone (~7.5°N-17°N, ~155°W-115°W) where large-scale deep sea mining is planned. Environmental impact assessments are underway in partnership with the mining industry, but the effect of mining activities on TEIs in the water column is one that could be uniquely assessed by the GEOTRACES community. In support of efforts to communicate the science to a wide audience the investigators will recruit an early career freelance science journalist with interests in marine science and oceanography to participate on the cruise and do public outreach, photography and/or videography, and social media from the ship, as well as to submit articles about the research to national media. The project would also support several graduate students.

Autonomous Ocean Carbon Observer Development and Calibration (OCO Development)

Coverage: Pacific Ocean

NSF Award Abstract
The very fast and dynamic ocean biological carbon pump (OBCP) plays a fundamental role in the global carbon cycle and in setting concentrations of atmospheric carbon dioxide. Photosynthetic organisms that that fuel the OCBP live and die on a week to week basis, and the resulting sinking (or export) of organic and inorganic carbon particles from the surface layer and consumption losses of these particles in deeper waters are similarly variable. Simply stated, the OCBP is poorly understood due to dependence on short- term, and seasonally and spatially limited ship observations; thus model estimates of its strength and future trajectory are highly uncertain. To address this gap, the investigators will engineer and sea-test two robotic Lagrangian Ocean Carbon Observer (OCO) floats capable of 8 month to multi-year missions, yet able to resolve flux processes on hourly to daily time scales and relay data in real time via satellite telemetry while operating anywhere in the ocean. The development of the OCO enables the identification of specific pathways and controls on the vertical transfer of particulate organic and inorganic carbon (POC and PIC) from the surface ocean to subsurface waters. The project logically follows on from the investigator’s development and successful deployment of robotic Lagrangian Carbon Explorer (CE) and Carbon Flux Explorer (CFE) floats, which measure optically POC and PIC concentration and flux variability to depths of 1000 m. A unique capability of the CFE is that it is able to measure the sinking flux of carbon carried by different sizes and classes of particles. The project will merge CFE and CE capabilities to create the OCO. The team will contribute to the development of a STEM workforce by engaging UC Berkeley undergraduates and one graduate student in all phases (development, laboratory, seagoing, and interpretive) of the project and in the class room.

Specifically, CFEs and two new Ocean Carbon Observers (OCOs) that simultaneously measure both particle flux and concentration profiles will be constructed and test-deployed at sea in January 2023. During the times that these autonomous instruments drift at target depths within the upper kilometer (interrupted by transit to the surface for location and real time bidirectional telemetry), they will autonomously quantify the inherent optical properties and size distributions of sinking material captured. Bishop et al. (2016; Biogeosciences 13, 3019-3129, doi:10.5194/bg-13-3109) describe CFE capabilities and methodology for rendering raw OSR imagery to rigorously defined inherent optical measures of particle loading -- attenuance and cross-polarized photon yield. Bourne et al. (2019; Biogeosciences, 16, 1249-1264; doi:10.5194/bg-16-1249-2019) show that attenuance is strongly correlated ($r^2 > 0.86$) with POC and PN sampled at 150 m by sampler-equipped CFEs "(CFE-Cal floats)" over a broad range of particle flux and particle size distributions. Planned further deployment of the CFE-Cal floats to sample sinking material to depths of at least 500 m will enable validation of our calibration of the attenuance proxy and to enable a first calibration of the PIC optical flux proxy. Bourne et al. (2021; Biogeosciences, 18, 3053–3086, doi:10.5194/bg-18-3053-2021) demonstrate the unique capability of CFEs to resolve and quantify the vertical flux carried by different particle size classes in the mesopelagic; furthermore, they describe prototype algorithms that will lead to flux size-distribution analysis in real time on the CFEs. The project will enable fully autonomous long-term deployments of CFE and OCO systems in the global ocean. The involvement a commercial float vendor (MRV Systems) and sensor manufacturer (Seabird Scientific) may lead to a commercialization pathway for the OCO.

[table of contents | back to top]

Program Information

U.S. GEOTRACES (U.S. GEOTRACES)

Website: http://www.geotraces.org/

Coverage: Global

GEOTRACES is a SCOR sponsored program; and funding for program infrastructure development is provided by the U.S. National Science Foundation.

GEOTRACES gained momentum following a special symposium, S02: Biogeochemical cycling of trace elements and isotopes in the ocean and applications to constrain contemporary marine processes (GEOSECS II), at a 2003 Goldschmidt meeting convened in Japan. The GEOSECS II acronym referred to the Geochemical Ocean Section Studies To determine full water column distributions of selected trace elements and isotopes, including their concentration, chemical speciation, and physical form, along a sufficient number of sections in each ocean basin to establish the principal relationships between these distributions and with more traditional hydrographic parameters;

> * To evaluate the sources, sinks, and internal cycling of these species and thereby characterize more completely the physical, chemical and biological processes regulating their distributions, and the sensitivity of these processes to global change; and
>
> * To understand the processes that control the concentrations of geochemical species used for proxies of the past environment, both in the water column and in the substrates that reflect the water column.

GEOTRACES will be global in scope, consisting of ocean sections complemented by regional process studies. Sections and process studies will combine fieldwork, laboratory experiments and modelling. Beyond realizing the scientific objectives identified above, a natural outcome of this work will be to build a community of marine scientists who understand the processes regulating trace element cycles sufficiently well to exploit this knowledge reliably in future interdisciplinary studies.

Expand "Projects" below for information about and data resulting from individual US GEOTRACES research projects.

[table of contents | back to top]

Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1736601
NSF Division of Ocean Sciences (NSF OCE)	OCE-2123942