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: 2
Version Date: 2025-03-26

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). There are several related data files provided. Data files are provided containing the average of all optical data profiles at each station for 0-500 meters (m) depth as well as for the full depth of the water column (6000 meters). CTD data used in the profile data calculations are also provided.

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Coverage

Spatial Extent: **N**:56.0583 **E**:-151.9954667 **S**:-19.9999 **W**:-156.9622
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).

$V_{pradj} = press \bullet coefft_{press}$ (3). and $V_{beta\_corr\_final} = V_{beta\_corr} + V_{pradj}$ (4) and $Beta_{corr} = V_{beta\_corr\_final} \bullet SF$ 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_{drift} was not applied to PIC010 data as the GTC CTD cast duration was short. $V_{transient}$ 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

Version history:
Version 1 date: 2025-02-04
- original set of files was published by BCO-DMO

Version 2 date: 2025-03-26
- files were renamed and re-organized to align with presentation of similar GP17-OCE datasets. Contents of the data files have not changed.

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Supplemental Files

File	
01_GP15_GTC_CTD_Cast_MetaData_Parameters.csv	(Comma Separated Values (.csv), 2.16 KB) MD5:376b7e90d8399bd794e0d8f59b5fb64f
Metadata file for dataset ID 941657, version 2. This file includes descriptions of the parameters (columns) in the file "02_GP15_GTC_CTD_Cast_MetaData_Values.csv", which contains cast data from the GTC CTD.	
02_GP15_GTC_CTD_Cast_MetaData_Values.csv	(Comma Separated Values (.csv), 15.31 KB) MD5:5fa69a74e7f3cff36c39437e9dbe62d4
Data file for dataset ID 941657, version 2. This file contains the GTC CTD Cast Meta Data Values used in profile data calculations as well as data on mixed layer depths, etc.	
03_GP15_GTC_CTD_Average_MetaData_20241112.csv	(Comma Separated Values (.csv), 1.96 KB) MD5:68ccbb11b92c65fcf5ab327ceae9f550
Metadata file for dataset ID 941657, version 2. This file contains the parameter (column) definitions for profile data averaged over all casts at each station, contained in files named 04_GP15_GTC_CTD_Profile_Average_0500m_data_20241112_submit.csv and 05_GP15_GTC_CTD_Profile_Average_6000m_data_20241112_submit.csv.	
04_GP15_GTC_CTD_Profile_Average_0500m_data_20241112_submit.csv	(Comma Separated Values (.csv), 896.30 KB) MD5:d0035a737ef8842d5f900842336c60b5
Data file for dataset ID 941657, version 2. This file contains data from the GTC CTD on Particle Birefringence Yield, Particle Beam Attenuation Coefficient from sensors PIC010 and CST1035 collected during GEOTRACES GP15. Ancillary data include standard CTD parameters, Temperature, Salinity, Oxygen, and Fluorescence. Data are restricted 0-500 m.	
05_GP15_GTC_CTD_Profile_Average_6000m_data_20241112_submit.csv	(Comma Separated Values (.csv), 3.19 MB) MD5:040e1a8d499c7fde51990e3fac29a8a0
Data file for dataset ID 941657, version 2. This file contains data from the GTC CTD on Particle Birefringence Yield and Particle Beam Attenuation Coefficient from sensors PIC010 and CST1035 collected during GEOTRACES GP15 for the full depth of the water column. Ancillary data include standard CTD parameters, Temperature, Salinity, Oxygen, and Fluorescence.	
06_GP15_GTC_CTD_ByCast_MetaData_20241112.csv	(Comma Separated Values (.csv), 2.45 KB) MD5:837f3dd3ac7ed03380ce98655db43aac
Metadata file for dataset ID 941657, version 2. Contains parameter (column) definitions for the profile data averaged over all casts at each station contained in files: 07_GP15_GTC_CTD_Profile_ByCast_0500m_data_20241112_submit.csv and 08_GP15_GTC_CTD_Profile_ByCast_6000m_data_20241112_submit.csv.	
07_GP15_GTC_CTD_Profile_ByCast_0500m_data_20241112_submit.csv	(Comma Separated Values (.csv), 3.00 MB) MD5:027e5363dea8c86a809acd91f1464a06
Data file for dataset ID 941657, version 2. This file contains the GP15 GTC CTD optics data (0-500 m) separated by cast and cast direction in this data version.	
08_GP15_GTC_CTD_Profile_ByCast_6000m_data_20241112_submit.csv	(Comma Separated Values (.csv), 13.37 MB) MD5:4c2d8189cecc5f5ea84827d13b83638f
Data file for dataset ID 941657, version 2. GP15 GTC CTD optics data (full water column) separated by cast and cast direction in this data version.	
09_GP15_GTC_CTD__cpbad_20241112.csv	(Comma Separated Values (.csv), 777 bytes) MD5:f2bcb325d3f3a1663243cb1a982d9bc5
Supplemental file for dataset ID 941657, version 2. Lists specific beam attenuation coefficient data replaced by -9999's in cast data. These data were excluded from "ByCast" and "Average" profile results based on raw data showing obvious fouling of the sensor.	
10_GP15_GTC_CTD_PICbad_20241112.csv	(Comma Separated Values (.csv), 3.00 KB) MD5:7b88b79a6b16e69d0f1adfd281630bbb
Supplemental file for dataset ID 941657, version 2. Lists specific pic sensor data replaced by -9999's in cast data. These data were excluded from "ByCast" and "Average" profile results based on raw data showing obvious fouling of the sensor.	

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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. (2025). 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/v2
Results

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Parameters

Parameters for this dataset have not yet been identified

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Instruments

Dataset-specific Instrument Name	Sea Bird SBE19plus, S/N 5236
Generic Instrument Name	CTD Sea-Bird
Generic Instrument Description	A Conductivity, Temperature, Depth (CTD) sensor package from SeaBird Electronics. This instrument designation is used when specific make and model are not known or when a more specific term is not available in the BCO-DMO vocabulary. Refer to the dataset-specific metadata for more information about the specific CTD used. More information from: http://www.seabird.com/

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.

Dataset-specific Instrument Name	SeaBird (formerly WETLabs) Transmissometer 1035
Generic Instrument Name	WET Labs {Sea-Bird WETLabs} C-Star transmissometer
Dataset-specific Description	The transmissometer used was a SeaBird transmissometer operating at 650 nM. They used to be made by WETLabs Inc., Philomath, OR. The complete ID is CST1035DR (meaning it was 6000 m rated and operating at a red wavelength of 650 nm). See: https://www.seabird.com/c-star-transmissometer/product?id=60762467717
Generic Instrument Description	The C-Star transmissometer has a novel monolithic housing with a highly intgrated opto-electronic design to provide a low cost, compact solution for underwater measurements of beam transmittance. The C-Star is capable of free space measurements or flow-through sampling when used with a pump and optical flow tubes. The sensor can be used in profiling, moored, or underway applications. Available with a 6000 m depth rating. More information on Sea-Bird website: https://www.seabird.com/c-star-transmissometer/product?id=60762467717

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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

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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.

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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.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1657781
NSF Division of Ocean Sciences (NSF OCE)	OCE-2023315
NSF Division of Ocean Sciences (NSF OCE)	OCE-1736601
NSF Division of Ocean Sciences (NSF OCE)	OCE-2123942

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