CTD-associated variables, bottle salinity measurements, oxygen titrations, nutrient analyses, biogeochemical/biological variables, and DIC chemistry variables from R/V Thomas G. Thompson cruise TN376 from January to March 2020

Website: https://www.bco-dmo.org/dataset/914901
Data Type: Cruise Results
Version: 1
Version Date: 2024-04-17

Project
» Collaborative Research: Biogeochemical and Physical Conditioning of Sub-Antarctic Mode Water in the Southern Ocean (Conditioning_SAMW)

Contributors	Affiliation	Role
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Abstract
These data are part of the NSF project "Collaborative Research: Biogeochemical and Physical Conditioning of Sub-Antarctic Mode Water in the Southern Ocean." Specifically, these are the discrete bottle data from cruise TN376 aboard R/V Thomas G. Thompson, which sailed from Cape Town, South Africa (22 January 2020) to the Southern Ocean and returned to Mauritius (3 March 2020). The purpose of the project was to define the processes that condition SubAntarctic Mode Water formed at the SubAntarctic Front in the Southern Ocean. The cruise track took us southeast from Cape Town for our first shakedown station at 38°35'S x 024°E, a station which was ultimately canceled due to heavy weather conditions. Two days out of Cape Town, the coupler between the ship's number three main engine and generator broke. This meant the ship only had one main engine, with an associated generator, plus two smaller engines/generators for all power needs. With the loss in redundancy, this meant we had to cut our cruise plans short, in order to stay within several hundred miles of Durban, SA, such that the ship could go in for repair once a replacement coupler could be found. This also meant we had to abandon the planned meridional transect that was to be done on this trip, since the travel to the shipyard, the repair, and return to the next station took over a week of sampling out of the cruise, and our proximity to Durban (and long distance from the Crozet Islands) meant we couldn't possibly accomplish the meridional transect and make it to Mauritius within the UNOLS ship schedule. We added the meridional transect to the second cruise of this project, RR2004. Bottle data were collected from CTD casts with tripped Niskin bottles on the CTD Rosette. Trace-metal-clean casts were performed using Niskin-X bottles suspended on Kevlar line and a trace-metal-clean block. The data reported herein fall into several categories: A) CTD-associated variables [temperature, salinity, density, dissolved oxygen and oxygen solubility, potential temperature, chlorophyll fluorescence, beam transmissivity, light], B) bottle salinity measurements using a salinometer, C) oxygen titrations and nutrient analyses performed aboard ship, biogeochemical/biological variables, and D) DIC chemistry variables. Regarding the specific data, we first report CTD variables (conductivity, salinity, temperature, potential temperature, density, dissolved oxygen, sound velocity, pressure, depth, conductivity, SeaBird-probe-derived oxygen concentrations, chlorophyll fluorescence, beam transmittance (660nm; %), backscattering, CTD PAR, and surface PAR reference). Next, results from bottle samples for salinity, lab oxygen titration, and nutrient concentrations (nitrate, phosphate, silicate, nitrite, and ammonium). The following biogeochemical and biological results are presented (analyzed post-cruise):

particulate organic carbon concentration (POC), particulate organic nitrogen (PON), particulate inorganic carbon (PIC), biogenic silicate (BSi), concentration of detached coccoliths (given as birefringent singlets, doublets, triplets or quadruplets, when viewed in a compound microscope with polarization optics), total coccolith concentration (the sum of singlets, doublets, triplets or quadruplets), concentration of birefringent plated coccolithophore cells, coccospheres or coccolith aggregates, planar area subtended by detached coccoliths or plated cells, concentration of extracted chlorophyll, phaeopigment and their sum (done aboard ship). There are a suite of variables from FlowCAM measurements (done aboard ship), mostly done on particles >5 micrometers (um) diameter: Particle size distribution function (PSDF) slope, standard error of that PSDF slope, Y-intercept of the PSDF, R^2 of the PDF slope, F statistic of PSDF slope, total cell concentration per mL, concentrations (in cells per mL) of small 0-4um diameter cells, 4-12um round cells, 4-12um diameter ovoid cells, dinoflagellates, ciliates, diatoms silicoflagellates, other unidentified cells, followed by percent of total cell concentrations, and carbon biomass (using equations of Menden Deuer and Lessard) for the same cell categories. Carbon fixation rates were performed aboard the ship and samples were analyzed aboard ship. The data are presented here for: ratio of calcification/photosynthesis, photosynthesis, calcification, standard deviation of photosynthesis and calcification measurements, chlorophyll concentration within incubation bottles, chlorophyll normalized photosynthesis and calcification. Corrected salinity (based on bottle salinity), corrected SeaBird oxygen values based on lab oxygen titrations, dissolved inorganic carbon (DIC) concentrations, and total alkalinity. Finally, photophysiological measurements were made aboard ship and the photophysiological coefficients are presented for (a) average bulk PAM (pulse amplitude modulation) fluorimetry results and (b) average PAM microscopy results made on individual coccolithophores, dinoflagellates, and diatoms.

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Coverage

Location: Southern Ocean, Indian Sector
Spatial Extent: **N**:-35.3848 **E**:37.6305 **S**:-41.5013 **W**:24.0011
Temporal Extent: 2020-01-27 - 2020-02-25

Methods & Sampling

R/V Thomas G. Thompson (cruise ID TN376) departed Cape Town, South Africa (SA) on 22 January 2020. The ship transited to the Southern Ocean and returned to Mauritius on 3 March 2020.

Due to the ship breakdown early into the cruise and the need to divert to Durban, SA, for engine repairs, we divided the cruise into five legs, as defined by our revised cruise plan, then pre- and post-diversion engine repairs in Durban, SA. A detailed summary of each of the legs and associated measurements can be found on the BCO-DMO cruise page for TN376: https://www.bco-dmo.org/deployment/904210. (For overall completeness of the sampling timeline, all science activities are included here (not necessarily just those for which this dataset encompasses). This dataset includes the CTD bottle data. Those activities not related to this dataset, but conducted on the cruise are: Video Plankton Recorder (VPR), carboy experiments, barite precipitation experiments, and real-time filter/freeze/transfer preparations for examination of phytoplankton during the cruise.)

Sampling methods:
At sea collections: Water samples were collected using CTD casts from 71 stations encompassing Agulhas,

Agulhas Retroflection, Southern Subtropical, and Subantarctic waters in the Indian Sector of the Southern Ocean.

Discrete samples were taken from 10L Niskin bottles for measurements of:

1. Chlorophyll - Water samples were filtered onto a 25-millimeter (mm) Millipore HA filter (mixed cellulose ester, 0.45-micrometer (µm) pore size). The filters were transferred to test tubes filled with chilled 90% acetone for extraction and vortexed until the filter dissolved. Tubes were stored in the dark in a freezer for 24 hours before analysis. Tubes were then re-vortexed and gently centrifuged (~1300 grams (g)) for 5 minutes before being decanted into a glass cuvette for the fluorometer. We used a Turner Designs 10AU to read Fb of the sample and then add 50 microliters (µl) of 10% HCL and read Fa. The fluorometer was calibrated pre-cruise with a pure chlorophyll extract (Turner Designs part# 10-850) to determine Tau τ=(Fb/Fa pure chl a) and chlorophyll a was then be calculated from: (Fb – Fa) * (τ/ τ-1) * (Vfiltered/Vextracted). Generally, all surface measurements were made in triplicate.

The fluorometers (Turner 10-AUs) were calibrated using the calibration method defined by Turner Designs using standards purchased from Turner Designs. Additionally, for long cruises such as this cruise, a calibration was performed on the ship. References: Trees, et al.

2. Particulate organic carbon (POC) plus particulate organic nitrogen (PON) - Water samples are filtered onto 25mm GF/F filters which have been pre-combusted (450°, 5 hours). Filters were rinsed with filtered seawater (FSW) and then stored in individual petri-plates and dried (60°) for storage. Prior to analysis, the plates were opened and placed overnight in a sealed container like a desiccator with saturated HCL fumes to remove any PIC. These samples were run by the Bigelow Laboratory Analytical Facility. The filters were packed into pre-combusted nickel sleeves and analyzed on a Perkin Elmer 2400 Series II CHNS/O for C, N, and H. The analyzer was calibrated using tin capsules as blanks and acetanilide to calibrate instrument response to carbon and nitrogen. NIST-certified check standards consisting of either low organic content soil or sediment are analyzed to determine accuracy of carbon detection. NIST-certified organic check standards such as corn flour or rice flour were analyzed to determine the accuracy of nitrogen detection. If values varied by more than 4% from stated values, instrument was examined, any problems were addressed and instrument was recalibrated and checked standards rerun until error was within acceptable limits. Duplicate samples were run during each sample run to ensure results were reproducible. If duplicates could not be run on actual samples, as in the case of filter samples, duplicate check standards were analyzed. Duplicate samples typically varied less than 2%. One instrument blank was analyzed for every 12 samples run. One acetanilide standard was analyzed for every 15 samples run. If blank or acetanilide values differed significantly from previous values, a new series of standards and blanks were analyzed to recalibrate the instrument. The actual minimum detection limit (3 times the standard error) determined from the standard error of the instrument blanks is 2 micrograms for carbon and 4 micrograms for nitrogen. References: JGOFS (1994).

3. PIC (Particulate Inorganic Carbon): - Water samples were filtered through a 25mm, 0.4 µm pore size polycarbonate filter. The dry filter was rinsed with potassium tetraborate (6.11 g/l $K_2B_4O_7 \cdot 4H_2O$) buffer while still in the filter tower to remove as much seawater salt and also to maintain a high pH (~8.1) during sample storage and to preserve the $CaCO_3$ on the filter. Filters were placed into trace metal clean polypropylene centrifuge tubes and dried at approximately 60°. For analysis, the filters were sent to (a) the Sawyer Environmental Chemistry Laboratory at the University of Maine or (b) the Department of Earth Sciences at Boston University. Filters were digested in a 5% nitric acid solution for 12 hours to dissolve all $CaCO_3$ and the solution was analyzed by ICP-AES (Inductively Couple Plasma - Atomic Emission Spectrometry) for Ca concentration. We ran filter and dissolution blanks as well as QC standards run with each batch of samples. We also used the concentration of dissolved Na in the digestate to correct for any Ca present in sea salts left on the filter. PIC concentrations were calculated using the volumes of water filtered and the volume of the digestions, and assuming all Particulate Inorganic Carbon was in the form of $CaCO_3$.

4. Biogenic Silicas - To determine reactive silicate, 200 milliliters (mL) of seawater sample is filtered onto a 25 mm, 0.4um pore size polycarbonate filter. Filters were folded and placed in a super clear polypropylene centrifuge tube and dried in a drying oven at 60°C for 24 hours then tightly capped and stored until analysis. On shore, 0.2N NaOH was added and the sample was placed in a 95°C water bath. The digestions were then cooled and neutralized with 1N HCl. After centrifuging, the supernatant was transferred to a new tube and diluted with MilliQ water. Molybdate reagent was added and then a reducing agent was added to reduce silicomolybdate to silicomolybdous acid. The transmission at 810 nanometers (nm) is read on a Hitachi U-3010 spectrophotometer (SN 0947-010). Reactive silicate is calculated using a silicate standard solution standard curve prepared at least every 5 days or whenever new reagents were prepared. Readings were corrected using a reagent blank run at the same time as the standard curve and three tube blanks interspersed in each batch. References: Brzezinski & Nelson (1989); JGOFS (1994); Strickland & Parsons (1977).

5. Dissolved Inorganic Carbon and Total Alkalinity Measurements - The analytical method followed standardized protocols (Bates et al., 1996; Bates et al., 2001; Dickson et al., 2007; Knap et al., 1993). Samples for DIC and TA were collected in 250ml borosilicate glass bottles according to standard JGOFS methods. Milli-Q cleaned bottles were rinsed out 3 times, bottom filled using silicone tubing, allowed to overflow at least 1X the bottle volume, ensuring no bubbles were in the sample and that it was sealed with a small headspace to allow for water expansion. Water samples were collected from all depths the CTD-rosette sampled on full casts and from eight depths on the 'trip-on-fly' casts. Two samples were collected from each Niskin bottle on the full casts. The first sample was poisoned with 100µl saturated mercuric chloride solution for analysis ashore. The second sample was not spiked and stored in the dark for no longer than 12 hours (to minimize any biological activity altering the sample) before being run aboard the ship, DIC first then TA. In addition to sampling from the rosette, samples were also collected and analyzed on board from the underway system. Both the underway and carboy samples were unpreserved, stored in the dark, and analyzed on board the ship. Samples were processed at sea using a highly precise (0.02%; 0.4 millimoles per kilogram (mmoles kg-1)) VINDTA system (Bates, 2007; Bates et al., 1996; Bates & Peters, 2007). TA was measured on the VINDTA 3S by titration with a strong acid (HCl). The titration curve shows 2 inflection points, characterizing the protonation of carbonate and bicarbonate respectively, where consumption of acid at the second point is equal to the titration alkalinity. DIC was measured on the AIRICA by the extraction of total dissolved inorganic carbon content from the sample by phosphoric acid addition. The liberated CO2 flowed with a N2 carrier gas into a Li-Cor non-dispersive IR gas analyzer where the CO2 levels were measured. For both instruments, within bottle replicates were run consecutively on start up to check the precision, continuing once the instrument precision was ±2µmol kg-1 or better. These were followed by a combination of Certified Reference Materials (CRMs) produced by the Marine Physical Laboratory at UCSD and low nutrient surface water from the Bermuda Atlantic Time Series (BATS) site, which were run every 20-24 samples on the VINDTA and every 6 samples on the AIRICA, to determine the accuracy and precision of the measurements and to correct for any discrepancies. The TA system CRM values did not vary more than 2mmol within each batch of HCl acid. The AIRICA was more susceptible to drift and was affected by the lab temperature which is why CRMs were run much more often on the AIRICA, the system did not drift much and the lab temperature did not vary markedly. Both of the DIC and TA methods had a precision and accuracy of ~1 mmol kg-1 (precision estimates were determined from between-bottle and within-bottle replicates, and accuracy assessed using CRMs). The values for DIC and TA were used to calculate other parameters of the carbonate system using the software CO2sys (Lewis and Wallace, 1998). The calculated parameters were: pH, fCO2, pCO2, [HCO3-], [CO3=], [CO2], alkalinity from borate; hydroxide ion; phosphate and silicate, Revelle Factor, plus the saturation states of calcite and aragonite.

6. Nutrient analyses (phosphate, silicate, nitrate+nitrite, nitrite, and ammonia) - Analyses were performed at sea on a Seal Analytical continuous-flow AutoAnalyzer 3 (AA3). The methods used were described by Gordon et al [Gordon1992] Hager et al. [1972], and Atlas et al. [1971]. Details of modification of analytical methods used in this cruise are also compatible with the methods described in the nutrient section of the GO-SHIP repeat hydrography manual (Hydes et al., 2010).

7. Coccolithophore enumeration - Polarized microscopy was used to determine the concentration of coccolithophores and detached coccoliths in samples collected during cruise TN376. A volume of 200mL was filtered onto 0.4µm-pore size, 25mm diameter polycarbonate filter then processed according to Balch & Utgoff (2009).

8. Enumeration of major algal classes - A shipboard Yokogawa Fluid Imaging Technologies FlowCam imaging cytometer was used to enumerate the major microalgal classes and estimate the particle size distribution function. The instrument was keyed on particle backscattering and fluorescence properties. Samples were first filtered through 100um Nitex mesh to make sure the 100um diameter flow chamber did not clog. The instrument was run with a 10X objective in order to reliably count particles bigger than 4-5um diameter. Samples were processed according to Poulton and Martin (2010). Concentrations (per mL), percent contribution with respect to total particles, and biomass are presented. Carbon biomass was determined based on the method described by Menden-Deuer & Lessard (2000).

9. Primary Production and Calcification Carbon Fixation Rates - Samples were also taken for measuring photosynthesis and calcification rates from 21 morning, full-CTD stations over the course of the trip (here called Productivity Stations). For these measurements, Niskin bottles were tripped at specific light depths throughout the euphotic zone (0.56%, 3.86%, 7.10%, 23.4%, 42.2%, and 73.6%). During casts where there was sufficient light to measure PAR throughout the euphotic zone, these depths were calculated assuming a constant diffuse attenuation coefficient. For samples taken during the nighttime, estimation of those light depths was performed based on the assumption that the fluorescence maximum was located at the 1% light depth (Poulton et al., 2017). Water samples for incubation were transferred from Niskin bottles to incubation bottles, typically inside the ship's enclosed hanger, under subdued light conditions. Water samples were pre-

filtered through 120µm nitex mesh to remove large grazers. Incubations were performed in 70 mL polystyrene tissue culture bottles that were previously acid-cleaned, rinsed with ethanol, reverse-osmosis water, then rinsed 5x with each sea water sample prior to filling. Photosynthesis and calcification were measured using the microdiffusion technique (Paasche & Brubak, 1994) with modifications by Balch et al. (2000) (see also Fabry (2010)). 14C bicarbonate (~30 uCi) was added for each water sample. Incubations were performed in triplicate (with an additional 2% buffered formalin sample (final concentration) used as a killed control) in simulated in situ conditions on-deck, corrected for both light quantity (extinction using bags made of neutral-density shade cloth) and quality (spectral narrowing) using blue acetate bag inserts. Bottle transfers between the incubators and radioisotope van were always done in darkened bags to avoid light shock to the phytoplankton. Deck incubators consisted of blue plastic tubs open to sky light, chilled using surface seawater from the ship's flowing sea water system. Calibration of those light levels in the bag were previously made using a Biospherical OSR2100 scalar PAR sensor inserted into each bag relative to a scalar PAR sensor outside the bag. All filtrations were performed using 0.4 mm pore-size polycarbonate filters. Following sample filtration, polycarbonate filters were rinsed three times with filtered seawater, then carefully given a "rim rinse" to make sure that all 14C-HCO3 in interstitial seawater in the filters was rinsed out. Filters and sample "boats" were placed in scintillation vials with 7mL of Ecolume scintillation cocktail. Samples were counted using a high-sensitivity Beckman Tricarb liquid scintillation counter with channel windows set for 14C counting. Counts were performed for sufficient time to reach 1% precision or 25 minutes for samples with lower counts. Blank 14C counts were always run for scintillation cocktail as well as the phenethylamine CO2 absorbent. Standard equations were used for calculating primary production and calcification from the 14C counts with a 5% isotope discrimination factor assumed for the physiological fixation of 14C-HCO3 as opposed to 12C-HCO3. Specific intrinsic growth rates of organic matter were calculated by dividing daily photosynthetic carbon estimates by the concentration of POC. Carbon-specific intrinsic growth rates for PIC were calculated by dividing the calcification rate by the concentration of PIC.

10. Photophysiological variables - PAM fluorimetry is a widely used method for rapid assessment of the physiological state of the photosynthetic machinery in plants. The approach is based on measurement of chlorophyll fluorescence of photosystem II (PSII) as an indicator of the efficiency with which light absorbed by the photosynthetic machinery and converted into useful work in the form of electron transport in the chloroplast thylakoid membrane. The electron transport chains are ultimately responsible for providing the chemical energy for photosynthetic carbon fixation. Experimental measurements were made with a PAM fluorimeter (Water PAM, Walz, Germany) with 3 mL cuvette samples that were dark-adapted for >30 minutes prior to analysis. The following key photosynthetic parameters were calculated from values of Fo, Fm, F'm and F':

- Maximum photosynthetic efficiency/capacity of dark-adapted cells: Fv/Fm = (Fm-Fo)/Fm
- Effective photochemical quantum yield of PSII (photosynthetic efficiency in light conditions): Y(II) = (Fm'-F')/Fm'
- Electron transfer rate (ETR) at a given irradiance value = proportion of photons at a given light intensity that are converted into useful energy. ETR = Y(II) x PAR
- Non-photochemical quenching: NPQ = Fm/Fm'-1
> - Rapid light curves were also carried out to acquire ETR values at different irradiance values, providing information on initial slope (alpha), ETRmax at saturating irradiance and photoinhibition.

11. PAM microscopy - Analysis of single-cell chlorophyll fluorescence was applied using similar PAM protocols to the above PAM fluorimeter measurements. The PAM microscope (PSI, Cz) allows images of Fo, Fm, F'm and F' by using LED arrays to provide measuring pulses, saturating pulses, and actinic light. Under rough weather conditions, it was only possible to obtain Fv/Fm values due to focus drift associated with vertical movements of the ship. The microscope allowed the acquisition of bright field and polarized light images to identify individual phytoplankton cells and calcifying coccolithophores. Cells were allowed to settle in darkness for >1 hour before gentle transfer to the microscope imaging chamber, which comprised a glass-bottomed dish and X20 or X40 Zeiss water immersion objectives. The dish was mounted on a temperature-controlled perfusion cell, which allowed cells to be maintained at the precise collection temperature. All manipulations were carried out in darkness. Bright field images were obtained using far red light, which does not activate the PSII reaction centers.

Data Processing Description

PAM fluorometry data were processed with with Walz (Germany) WinControl-3 software. (https://www.walz.com/products/chl_p700/water-pam/downloads.html). Imaging PAM data were processed with Photon Systems Instruments Fluorcam 7 software (https://psi.cz/imaging-sensors/fluorescence-imaging/).

BCO-DMO Processing Description

- Imported original file "TN376 MergedMasterBottleFile_06072022_CTD_DatawBalchBatesBrownleeFinal for BCO-DMO V4 corrected.xlsx" into the BCO-DMO system.
- Flagged "-999" as a missing data value (missing data are empty/blank in the final CSV file).
- Re-named fields to comply with BCO-DMO naming conventions.
- Changed the year from 2021 to 2020 for Station 51.
- Converted the date/time field to ISO 8601 format.
- Saved the final file as "914901_v1_tn376_bottle_data.csv".

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Data Files

File	
914901_v1_tn376_bottle_data.csv	(Comma Separated Values (.csv), 945.47 KB) MD5:59eac5065883bdea6b88d821ade936bc
Primary data file for dataset ID 914901, version 1	

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Related Publications

Balch, W. M., Bowler, B. C., Drapeau, D. T., Lubelczyk, L. C., Lyczkowski, E., Mitchell, C., & Wyeth, A. (2019). Coccolithophore distributions of the North and South Atlantic Ocean. Deep Sea Research Part I: Oceanographic Research Papers, 151, 103066. https://doi.org/10.1016/j.dsr.2019.06.012
Methods

Balch, W. M., Drapeau, D. T., & Fritz, J. J. (2000). Monsoonal forcing of calcification in the Arabian Sea. Deep Sea Research Part II: Topical Studies in Oceanography, 47(7–8), 1301–1337. https://doi.org/10.1016/s0967-0645(99)00145-9
Methods

Balch, W. M., Drapeau, D. T., Bowler, B. C., Booth, E. S., Windecker, L. A., & Ashe, A. (2007). Space-time variability of carbon standing stocks and fixation rates in the Gulf of Maine, along the GNATS transect between Portland, ME, USA, and Yarmouth, Nova Scotia, Canada. Journal of Plankton Research, 30(2), 119–139. doi:10.1093/plankt/fbm097
Methods

Balch, W., & Utgoff, P. (2009). Potential Interactions Among Ocean Acidification, Coccolithophores, and the Optical Properties of Seawater. Oceanography, 22(4), 146–159. https://doi.org/10.5670/oceanog.2009.104
Methods

Bates, N. R. (2007). Interannual variability of the oceanic CO2sink in the subtropical gyre of the North Atlantic Ocean over the last 2 decades. Journal of Geophysical Research, 112(C9). https://doi.org/10.1029/2006jc003759
Methods

Bates, N. R., & Peters, A. J. (2007). The contribution of atmospheric acid deposition to ocean acidification in the subtropical North Atlantic Ocean. Marine Chemistry, 107(4), 547–558. https://doi.org/10.1016/j.marchem.2007.08.002
Methods

Bates, N. R., Michaels, A. F., & Knap, A. H. (1996). Seasonal and interannual variability of oceanic carbon dioxide species at the U.S. JGOFS Bermuda Atlantic Time-series Study (BATS) site. Deep Sea Research Part II: Topical Studies in Oceanography, 43(2-3), 347–383. doi:10.1016/0967-0645(95)00093-3
Methods

Bates, N. R., Samuels, L., & Merlivat, L. (2001). Biogeochemical and physical factors influencing seawater ƒCO2 and air-sea CO2 exchange on the Bermuda coral reef. Limnology and Oceanography, 46(4), 833–846. Portico.

https://doi.org/10.4319/lo.2001.46.4.0833
Methods

Brzezinski, M. A., & Nelson, D. M. (1989). Seasonal changes in the silicon cycle within a Gulf Stream warm-core ring. Deep Sea Research Part A. Oceanographic Research Papers, 36(7), 1009–1030. doi:10.1016/0198-0149(89)90075-7
Methods

Fabry, V. J., & Balch, W. M. (2010), Direct measurements of calcification rates in planktonic organisms, in Guide to Best Practices in Ocean Acidification Research and Data Reporting, edited by U. Riebeseil, V. J. Fabry, L. Hansson & J.-P. Gattuso, pp. 185-196, European Project on Ocean Acidification (EPOCA), Bremerhaven, Germany.
Methods

Goldstein, J. I., Newbury, D. E., Michael, J. R., Ritchie, N. W. M., Scott, J. H. J., & Joy, D. C. (2018). Scanning Electron Microscopy and X-Ray Microanalysis. Springer Science + Business Media, LLC, New York. (Third edition) https://doi.org/10.1007/978-1-4939-6676-9
Methods

JGOFS (1996). Protocols for the Joint Global Ocean Flux Study (JGOFS) core measurements. In: Knap, A. (Ed.), Report no. 19 of the Joint Global Ocean Flux Study. Scientific committee on oceanic research, international council of scientific unions. Intergovernmental Oceanographic Commission, Bergen, Norway, p. 170.
Methods

Knap, A., Michaels, R., Dow, R., Johnson, K., Gundersen, J., Sorensen, A., ... & Waterhouse, T. (1993). Bermuda Atlantic time-series study methods manual (Version 3). Bermuda Biological Station for Research, US JGOFS. https://www.researchgate.net/publication/245583966_Bermuda_Atlantic_Time-series_Study_Methods_Manual_Version_3
Methods

Menden-Deuer, S., & Lessard, E. J. (2000). Carbon to volume relationships for dinoflagellates, diatoms, and other protist plankton. Limnology and Oceanography, 45(3), 569–579. doi:10.4319/lo.2000.45.3.0569
Methods

Paasche, E., & Brubak, S. (1994). Enhanced calcification in the coccolithophorid Emiliania huxleyi (Haptophyceae) under phosphorus limitation. Phycologia, 33(5), 324–330. https://doi.org/10.2216/i0031-8884-33-5-324.1
Methods

Poulton, A. J., Holligan, P. M., Charalampopoulou, A., & Adey, T. R. (2017). Coccolithophore ecology in the tropical and subtropical Atlantic Ocean: New perspectives from the Atlantic meridional transect (AMT) programme. Progress in Oceanography, 158, 150–170. https://doi.org/10.1016/j.pocean.2017.01.003
Methods

Poulton, N. J. and Martin, J.L. (2010). Imaging flow cytometry for quantitative phytoplankton analysis — FlowCAM. In: Intergovernmental Oceanographic Commission of ©UNESCO. Karlson, B., Cusack, C. and Bresnan, E. (editors). Microscopic and molecular methods for quantitative phytoplankton analysis. Paris, UNESCO. (IOC Manuals and Guides, no. 55.) (IOC/2010/MG/55), 110 pages. Available from: https://unesdoc.unesco.org/ark:/48223/pf0000187824
Methods

Sturm, D., Langer, G., & Wheeler, G. (2022). Novel combination coccospheres from Helicosphaera spp indicate complex relationships between species. Journal of Plankton Research, 44(6), 838–838. https://doi.org/10.1093/plankt/fbac044
Results

Sturm, D., de Vries, J., Balch, W. M., Wheeler, G., & Brownlee, C. (2023). Mesoscale oceanographic meanders influence protist community function and structure in the southern Indian Ocean. Environmental Microbiology. Portico. https://doi.org/10.1111/1462-2920.16500
Results

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Parameters

Parameter	Description	Units

Station	station number (between 1 and 103)	unitless
Bottle	number of the Niskin bottle tripped on CTD cast	unitless
Cruise	cruise ID number (TN376)	unitless
Type	All "B" (bottle) (added to make data set Ocean Data View-compatible)	unitless
Longitude	longitude of sample location; negative values = West	decimal degrees
Latitude	latitude of sample location; negative values = South	decimal degrees
Depth	water depth	meters (m)
ISO_DateTime_UTC	Date and time (UTC) in ISO 8601 format	unitless
Event	unique event number for start time of each event given as year (4 digits), month (2 digits), day (2 digits), and then a period followed by GMT time (4 digits)	unitless
Month	month of year	unitless
Day	day of month	unitless
Year	year	unitless
Sigma_E900	density anomaly of seawater calculated from salinity derived from conductivity probe 0	kilograms per cubic meter (kg m-3)
Sigma_E911	density anomaly of seawater calculated from salinity derived from conductivity probe 1	kilograms per cubic meter (kg m-3)
Sbeox0	Oxygen concentration derived from primary Sea Bird oxygen probe #0 on CTD	milliliters per liter (mL L-1)
Sbeox1	Oxygen concentration derived from secondary Sea Bird oxygen probe #1 on CTD	milliliters per liter (mL L-1)
Oxsol	Estimated 100%-saturated concentration of oxygen based on primary temperature and primary salinity probes	milliliters per liter (mL L-1)
Oxsol2	Estimated 100%-saturated concentration of oxygen based on secondary temperature and secondary salinity probes	milliliters per liter (mL L-1)
Sbox0	primary oxygen probe	micromoles per kilogram (umol kg-1)
Sbox1	secondary oxygen probe	micromoles per kilogram (umol kg-1)
Potemp090C	Potential temperature (primary temperature probe)	degrees Celsius (ITS-90)

Potemp190C	Potential temperature (secondary temperature probe)	degrees Celsius (ITS-90)
Salinity1_PSU	salinity of water sample as estimated by primary conductivity probe	PSU
Salinity2_PSU	salinity of water sample as estimated by secondary conductivity probe	PSU
Density00	density of seawater calculated from salinity derived from primary conductivity probe and primary thermo probe	kilograms per cubic meter (kg m-3)
Density11	density anomaly of seawater calculated from salinity derived from secondary conductivity probe 1 and secondary thermo probe 1	kilograms per cubic meter (kg m-3)
SvCM	Sound Velocity [Chen-Millero 1977] based on temperature & salinity primary probes	meters per second (m/s)
SvCM1	Sound Velocity [Chen-Millero 1977] based on temperature & salinity secondary probes	meters per second (m/s)
Depth_m	depth of water sample	meters (m)
Temperature	CTD temperature (ITS-90) primary probe	degrees Celsius
Temperature_2	CTD temperature (ITS-90) secondary probe	degrees Celsius
C0	Conductivity based on primary conductivity probe	Siemens per meter (S/m)
C1	Conductivity based on secondary conductivity probe	Siemens per meter (S/m)
Sbeox0V	SeaBird oxygen probe 0	Volts
Sbeox1V	SeaBird oxygen probe 1	Volts
Fluorescence	Chlorophyll Fluorescence, WET Labs ECO-AFL/FL sensor 0	Volts DC
CStarTr0	Beam transmission WetLabs Cstar	percent (%)
AltM	Altitude of CTD from sea floor	meters (m)
PAR	Photosynthetically Available Radiation measured at depth	microEinsteins per square centimeter per second (uE/(cm^2 sec))
V4	Voltage of fluorescence sensor	Volts
Scan	number of the CTD scan in which measurements were made	unitless
POC_ug_per_L	concentration of particulate organic carbon	micrograms per liter (ug/L)
PON_ug_per_L	concentration of particulate organic nitrogen	micrograms per liter (ug/L)

POC_umol_per_L	concentration of particulate organic carbon	micromoles per liter (umol/L)
PON_umol_per_L	concentration of particulate organic nitrogen	micromoles per liter (umol/L)
PIC_umol_per_L	concentration of particulate inorganic carbon	micromoles per liter (umol/L)
PIC_ug_per_L	concentration of particulate inorganic carbon	micrograms per liter (ug/L)
PIC_mol_per_cubic_m	concentration of particulate inorganic carbon	moles per cubic meter (mol/m^3)
Single_Lith_count_per_mL	concentration of birefringent particles-singlets	number per milliliter (mL)
Double_Lith_count_per_mL	concentration of birefringent particles-doublets	number per milliliter (mL)
Triple_Lith_count_per_mL	concentration of birefringent particles-triplets	number per milliliter (mL)
Quadruple_Lith_count_per_mL	concentration of birefringent particles-quadruplets	number per milliliter (mL)
Tot_Lith_count_per_mL	concentration of birefringent particles-all	number per milliliter (mL)
Cell_Agg_count_per_mL	concentration of birefringent plated cells, coccospheres and aggregates	number per milliliter (mL)
Lith_Area_square_um_per_mL	total area subtended by by detached coccoliths	square micrometers per milliliter (um^2 per mL)
Cell_Agg_Area_square_um_per_mL	total area subtended by by plated coccolithophores, coccospheres and aggregates	square micrometers per milliliter (um^2 per mL)
BSi_umol_per_L	concentration of biogenic silica	micromoles per liter (umol/L)
Avg_Corr_Chl_a_ug_per_L	concentration of chlorophyll a	micrograms per liter (ug/L)
Avg_Corr_Phaeo_ug_per_L	concentration of phaeopigments	micrograms per liter (ug/L)
Avg_Corr_Chl_a_Phaeo_ug_per_L	concentration of chlorophyll a plus phaeopigments	micrograms per liter (ug/L)

PSD_Slope_logABD_grthan_point_75	PDF Slope logABD>0.75 (only particles >5um); Particle size Distribution Function slope of the plot of log cell abundance (particles per mL) versus Area Based Diameter (micrometers) calculated for particles of >5 micrometers diameter using a Yokogowa FlowCAM. Area Based Diameter (ABD) is defined as the diameter measured by the number of grey scale pixels of the binary image converted to a circle with the same number of pixels	unitless
Std_Err_of_PSD_Slope_logABD_grthan_point_75	Std Err of PDF Slope logABD>0.75 (for particles >5um); Standard error of the above particle size distribution slope for only particles of 5 micrometers diameter or larger using a Yokogowa FlowCAM	unitless
Y_int_of_PSD_Slope_logABD_grthan_point_75	Y-int of PDF Slope logABD>0.75 (only particles >5um); the Y intercept of above PDF for only particles of ~5um diameter or larger using a Yokogowa FlowCAM	unitless
R2of_PSD_Slope_logABD_grthan_point_75	R-squared value of PDF Slope logABD>0.75(only particles >5um); squared correlation coefficient of above PDF for only particles of >5um diameter or larger using a Yokogowa FlowCAM	unitless
F_statistic_of_PSD_Slope_logABD_grthan_point_75	F-statistic of PDF Slope logABD>0.75 (only particles >5um); the F statistic of of above PDF for only particles of >5um diameter or larger using a Yokogowa FlowCAM	unitless
Total_cells_per_mL	Concentration of total particles measured by Yokogowa measured by Yokogowa FlowCAM imaging cytometer	cells per milliliter (cells/mL)
Small_0_4um_cells_per_mL	Concentration of small particles with diameters of 0 to 4 micrometers measured by Yokogowa FlowCAM imaging cytometer	cells per milliliter (cells/mL)
Round_4_12um_cells_per_mL	Concentration of round particles with diameters of 4 to 12 micrometers measured by Yokogowa FlowCAM imaging cytometer	cells per milliliter (cells/mL)
Ovoid_4_12um_cells_per_mL	Concentration of ovoid particles with diameters of 4 to 12 micrometers measured by Yokogowa FlowCAM imaging cytometer	cells per milliliter (cells/mL)
Dinoflagellates_cells_per_mL	Concentration of dinoflagellates measured by Yokogowa FlowCAM imaging cytometer	cells per milliliter (cells/mL)
Ciliates_cells_per_mL	Concentration of ciliates measured by Yokogowa FlowCAM imaging cytometer	cells per milliliter (cells/mL)

Diatoms_cells_per_mL	Concentration of diatoms measured by Yokogowa FlowCAM imaging cytometer	cells per milliliter (cells/mL)
Silicoflagellates_cells_per_mL	Concentration of silicoflagellates measured by Yokogowa FlowCAM imaging cytometer	cells per milliliter (cells/mL)
Other_Cells_cells_per_mL	Concentration of other unidentified cells as measured by Yokogowa FlowCAM imaging cytometer	cells per milliliter (cells/mL)
Small_0_4um_pcnt	Percent of total particles contributed by small (0-4 um) particles as measured by Yokogowa FlowCAM imaging cytometer	unitless
Round_4_12um_pcnt	Percent of total particles contributed by round (4-12 um) particles as measured by Yokogowa FlowCAM imaging cytometer	unitless
Ovoid_4_12um_pcnt	Percent of total particles contributed by ovoid (4-12 um) particles as measured by Yokogowa FlowCAM imaging cytometer	unitless
Dinoflagellates_pcnt	Percent of total particles contributed by dinoflagellates as measured by Yokogowa FlowCAM imaging cytometer	unitless
Ciliates_pcnt	Percent of total particles contributed by ciliates as measured by Yokogowa FlowCAM imaging cytometer	unitless
Diatoms_pcnt	Percent of total particles contributed by diatoms as measured by Yokogowa FlowCAM imaging cytometer	unitless
Silicoflagellates_pcnt	Percent of total particles contributed by silicoflagellates as measured by Yokogowa FlowCAM imaging cytometer	unitless
Other_Cells_pcnt	Percent of total particles contributed by unidentified other cells as measured by Yokogowa FlowCAM imaging cytometer	unitless
Total_C_Biomass_Menden_Deuer_ug_per_L	Total carbon biomass (based on Menden-Deuer and Lessard 2000) for total particles measured by Yokogowa FlowCAM imaging cytometer	micrograms per liter (ug/L)
Small_0_4um_C_Biomass_Menden_Deuer_ug_per_L	Carbon biomass of small 0-4um cells (based on Menden-Deuer and Lessard 2000) for total particles measured by Yokogowa FlowCAM imaging cytometer	micrograms per liter (ug/L)
Round_4_12um_C_Biomass_Menden_Deuer_ug_per_L	Carbon biomass of round 4-12um cells (based on Menden-Deuer and Lessard 2000) for total particles measured by Yokogowa FlowCAM imaging cytometer	micrograms per liter (ug/L)

Ovoid_4_12um_C_Biomass_Menden_Deuer_ug_per_L	Carbon biomass of ovoid 4-12um cells (based on Menden-Deuer and Lessard 2000) for total particles measured by Yokogowa FlowCAM imaging cytometer	micrograms per liter (ug/L)
Dinoflagellates_C_Biomass_Menden_Deuer_ug_per_L	Carbon biomass of dinoflagellates (based on Menden-Deuer and Lessard 2000) for total particles measured by Yokogowa FlowCAM imaging cytometer	micrograms per liter (ug/L)
Ciliates_C_Biomass_Menden_Deuer_ug_per_L	Carbon biomass of ciliates (based on Menden-Deuer and Lessard 2000) for total particles measured by Yokogowa FlowCAM imaging cytometer	micrograms per liter (ug/L)
Diatoms_C_Biomass_Menden_Deuer_ug_per_L	Carbon biomass of diatoms (based on Menden-Deuer and Lessard 2000) for total particles measured by Yokogowa FlowCAM imaging cytometer	micrograms per liter (ug/L)
Silicoflagellates_C_Biomass_Menden_Deuer_ug_per_L	Carbon biomass of silicoflagellates (based on Menden-Deuer and Lessard 2000) for total particles measured by Yokogowa FlowCAM imaging cytometer	micrograms per liter (ug/L)
Other_Cells_C_Biomass_Menden_Deuer_ug_per_L	Carbon biomass of unidentified other cells (based on Menden-Deuer and Lessard 2000) for total particles measured by Yokogowa FlowCAM imaging cytometer	micrograms per liter (ug/L)
Psy_Avg_C_to_P	Ratio of calcification to photosynthesis	unitless
Psy_Avg_P	Average photosynthesis rate	micromoles C per liter per day (umol C/L/d)
Psy_Avg_C	Average calcification rate	micromoles C per liter per day (umol C/L/d)
Psy_P_SD	standard deviation of photosynthesis rate	micromoles C per liter per day (umol C/L/d)
Psy_C_SD	standard deviation of calcification rate	micromoles C per liter per day (umol C/L/d)
Psy_Avg_Pmb_ug_C_per_ug_chl_d	chlorophyll-normalized primary production rate	micrograms C per microgram chlorophyll per day (ugC/ugchl/d)

Psy_Avg_Cmb_ug_C_per_ug_chl_d	chlorophyll-normalized calcification rate	micrograms C per microgram chlorophyll per day (ugC/ugchl/d)
NO3_umol_per_L	concentration of nitrate	micromoles per liter (umoles/L)
PO4_umol_per_L	concentration of phosphate	micromoles per liter (umoles/L)
SIL_umol_per_L	concentration of silicate	micromoles per liter (umoles/L)
NO2_umol_per_L	concentration of nitrite	micromoles per liter (umoles/L)
NH4_umol_per_L	concentration of ammonium	micromoles per liter (umoles/L)
Bottle_O2_mL_per_L	Oxygen concentration from shipboard titration	millilieters per liter (mL/L)
Bottle_Salts	salinometer-derived salinity	PSU (Practical Salinity Units)
DIC_umol_per_kg	dissolved inorganic carbon concentration	micromoles per kilogram (umol kg-1)
TA_umol_per_kg	Total akalinity	micromoles per kilogram (umol kg-1)
Avg_F	Average Fluorescence	Arbitrary fluorescence units
Avg_Fm_Light	Maximum Fluorescence, Fm', measured in the light	Arbitrary fluorescence units
Avg_Y_II	Effective photochemical quantum yield of PSII (photosynthetic efficiency in light conditions = proportion of photons at a given light intensity that are converted into useful energy)	unitless
Avg_ETR	Electron transfer rate (ETR) at a given irradiance	micromoles electrons per square meter per second (umol electrons m-2 s-1) (Y-II x PAR(umol photos m-2s-1) x 0.42)
Avg_qP	Average photochemical quenching	arbitrary units
Avg_qN	average qN	arbitrary units

Avg_qL	Average qL	arbitrary units
Avg_NPQ	Non-photochemical quenching	unitless
Avg_Y_NO	Average Y_NO	unitless
Avg_Y_NPQ	Average Y_NPQ	unitless
Avg_Fo	average dark fluorescence of all cells	Arbitrary fluorescence units
Avg_Fm_Dark	Maximum Fluorescence, Fm, immediately after dark adaptation (i.e. at the beginning of the measurements).	Arbitrary fluorescence units
Avg_Fv_Fm	average Fv/Fm	unitless
Coccolithophore_single_cell_Avg_Fv_Fm	Coccolithophore single cell Avg Fv_Fm	unitless
Dinoflagellate_single_cell_Avg_Fv_Fm	Dinoflagellate single cell Avg Fv_Fm	unitless
Diatom_single_cell_Avg_Fv_Fm	Diatom single cell Avg Fv_Fm	unitless

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Instruments

Dataset-specific Instrument Name	FluorCam Imaging Pulse Amplitude Modulation system
Generic Instrument Name	Fluorometer
Dataset-specific Description	The FluorCam Imaging Pulse Amplitude Modulation system (Photon Systems Instruments Cz) is a Fluorescence Kinetic Microscope (FKM) that extends the complete capacity of kinetic chlorophyll or multicolor fluorescence imaging to the realm of individual cells and subcellular structures.
Generic Instrument Description	A fluorometer or fluorimeter is a device used to measure parameters of fluorescence: its intensity and wavelength distribution of emission spectrum after excitation by a certain spectrum of light. The instrument is designed to measure the amount of stimulated electromagnetic radiation produced by pulses of electromagnetic radiation emitted into a water sample or in situ.

Dataset-specific Instrument Name	Water PAM
Generic Instrument Name	Fluorometer
Dataset-specific Description	The Water PAM (Walz, Germany) is a portable cuvette system for analyzing the photosynthetic activity of a wide variety of phytoplankton samples.
Generic Instrument Description	A fluorometer or fluorimeter is a device used to measure parameters of fluorescence: its intensity and wavelength distribution of emission spectrum after excitation by a certain spectrum of light. The instrument is designed to measure the amount of stimulated electromagnetic radiation produced by pulses of electromagnetic radiation emitted into a water sample or in situ.

Dataset-specific Instrument Name	A3 microscope (Zeiss UK)
Generic Instrument Name	Microscope - Optical
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	TC-344C Dual channel temperature controller
Generic Instrument Name	thermostat
Dataset-specific Description	The TC-324C and TC-344C temperature controllers (Warner Instruments, USA) provide power to a variety of heating devices including Warner heated platforms such as the microscope stage used here. Each channel supplies up to 22 watts into a load of 10 ohms. Heat setpoint was controlled automatically in Auto mode via thermistor feedback. A loop-speed selector provided three feedback speeds to optimize the thermal stability of the device being heated. Heat setpoint also could be manually controlled in Manual mode.
Generic Instrument Description	A device designed to regulate temperature by controlling the starting and stopping of a heating/cooling system.

Dataset-specific Instrument Name	Yokogowa FlowCAM imaging cytometer
Generic Instrument Name	Yokogawa Fluid Imaging Technologies FlowCam VS particle imaging system
Generic Instrument Description	Imaging cytometers are automated instruments that quantify properties of single cells, one cell at a time. They combine some aspects of flow cytometry with particle imaging capabilities in an automated device to classify small particles, including phytoplankton and protozoa. They can measure a variety of properties: cell size, cell granularity, cell aspect ratio, equivalent spherical diameter (ESD) and area-based diameter (ABD) [to estimate bio-volume, which is used to estimate cell carbon biomass]. Particle images are digitally recorded and sorted into different classes according to training libraries using a support vector machine (supervised learning methods). The instruments particle-size is calibrated using different sizes of latex beads. The FlowCam VS series are automated imaging-in-flow instruments that generate high-resolution digital images for measuring size and shape of microscopic particles. The sample introduced in the system is attracted by a peristaltic or a syringe pump into a flow cell (or flow chamber) with known dimensions, located in front of a microscope objective which is connected to a camera video. The benchtop model is ideally suited to a typical laboratory environment with applications in oceanographic research, municipal water, biopharmaceutical formulations, chemicals, oil and gas, biofuels, and many other markets. FlowCam VS is available in four models, from the imaging-only VS-I (i.e. without excitation wavelength or fluorescence emission wavelengths) to the top-of-the-line VS-IV with two channels of fluorescence measurement and scatter triggering capabilities. The instrument can measure particles between 2µm and 2mm; can analyse in vivo or fixed samples; has a flow rate between 0.005 ml/minute and 250 ml/minute (dependant upon magnification, flow cell depth, camera frame rate, efficiency desired, etc.). It can produce either 8-bit Grayscale (Monochrome Camera) or 24-bit Colour (Colour Camera) images, depending on the model.

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Deployments

TN376

Website	https://www.bco-dmo.org/deployment/904210
Platform	R/V Thomas G. Thompson
Start Date	2020-01-25
End Date	2020-03-03
Description	See more information at R2R: https://www.rvdata.us/search/cruise/TN376 Description of Cruise (provided by Chief Scientist Barney Balch): Due to the ship breakdown early into the cruise and the need to divert to Durban, SA, for engine repairs, we divided the cruise into five legs, as defined by our revised cruise plan, then pre- and post-diversion engine repairs in Durban, SA. We present a summary below of each of the legs and associated measurements. Leg 1: Transit from Cape Town, South Africa (S.A.), zonal transect through Agulhas meander system, and sampling of a coccolith-rich filament; CTD stations 1-17, VPR tows 1-7; trace metal casts 1, 3, 5, 6, 7, 8, 12 and 17; 0800h, 25 January to 0222h, 4 February, 2020. For this leg, we transited across the Agulhas Meander system, beginning with a station in the Agulhas Retroflection eddy (station 2), criss-crossing the Agulhas, Southern Subtropical Fronts with Video Plankton Recorder (VPR) and underway bio-optical systems running, and performed full CTD water casts (stations 2-4). This line of stations crossed into the end of our filament of interest, which showed (with the Acoustic Doppler Current Profiler (ADCP), cyclonic circulation around a zero-velocity core of this frontally-embedded eddy. Station 35 was situated in the western interior side of this eddy. This was where we collected water for our first carboy experiment and also performed a trace metal cast consisting of nine Niskin X samplers deployed on a Kevlar line. After collecting seawater for the carboy experiment, the VPR was deployed and towed for the entire west-to-east section, then north-to-south section through the center of the eddy. The same sections were then visited (in reverse) for CTD casts. Daily productivity casts to measure photosynthesis and calcification, plus trace metal casts were run at stations 1, 3, 4, 5, 6, 7, 8, 12, and 17. The carboy experiment for this feature was run from surface water taken at station five. Measurements of photosynthetic photophysiological variables were made underway and at stations 1-17. These included photosynthetic efficiency and rapid light curve data. An imaging PAM system (PSI, Cz) was also used to obtain cell type-specific photosynthetic efficiency data. Filter/freeze/transfer (FFT) preparations were made for qualitative viewing of surface and fluorescence maxima phytoplankton assemblages (400x magnification bright-field, polarized microscopy, and epi-fluorescence using 480nm and 530nm excitation) viewing at stations 5,6,7,8, 12, and 17. Barite precipitation measurements were performed at station 5 in this feature. Leg 2: Transit to eddy feature and its survey; CTD stations 18-25; VPR tows 8-9; trace metal casts 18, 20, and 23; 0222h, 4 Feb. to 1400h, 8 Feb., 2020. This leg of the cruise involved sampling a cyclonic eddy roughly centered at 35° 53'S and 37° 38'E. We first did a full 195-kilometer east-to-west VPR survey, and towed it from the east end of the eddy to the northern end of the eddy followed by a complete VPR section (163 kilometers) from north to south. The area of this PIC-enhanced, elliptical eddy was about 25,000 km². Productivity and trace metal casts were performed at stations 18, 20, and 23 and the water for a second carboy experiment was collected from station 18 (eddy interior). Measurements of photosynthetic variables were made underway and at stations 18-25. FTF preparations were made for semi-quantitative viewing of surface and fluorescence maxima phytoplankton assemblages (400x magnification bright-field, polarized microscopy, and epi-fluorescence microscopy using 480nm and 530nm excitation wavelengths) viewing at stations 18, 20, and 23. Barite precipitation measurements were performed at station 18 in this feature. A 10m-sock drogue equipped with a satellite Argos transmitter was deployed in the eddy center prior to our departure for Durban as a means to track the feature in our absence. Leg 3: science stopped and ship diverted for engine repair; 1400h, Feb. 8, with science sampling resumed at 1726h, 16 February. All overboard sampling at Leg 2 stopped on 8 February for the steam back to the port of Durban for engine repairs. Only the carboy experiments were sampled during the two-day transit to the port but given that we had a temperature-controlled seawater incubator, the carboy experiments could be maintained at

	their in situ temperatures for the duration of the multi-day experiment. The engine repair work in Durban was completed by the evening of 13 February, after which the ship sailed for station 26 to resample the first filament that we had sampled in Leg 1. Leg 4: Re-sampling the meander filament and transit to first deep CTD; CTD Stations 26-53; VPR tows 10-12; trace metal casts 28 and 39; 0347h,16 Feb. to 0418h, Feb. 20, 2020. The ship proceeded to re-sample the meander filament by performing three east-to-west, VPR sections across the feature, followed by three CTD sections made immediately afterward across the same lines, from west-to-east. Those sections were made zonally at 41°30', 40°30'S and 39°30'S and had lengths of 222km, 222km, and 167km, respectively, such that they adequately sampled the cross-section of the feature. Beginning with station 27, we alternated each CTD full-water cast with a "trip on the fly" water cast. These later casts were used only to sample DIC and nutrients and served to provide greater resolution sections across the features. This pattern of CTD sampling was continued for the remaining feature surveys. Following the completion of each VPR and CTD zonal leg, the VPR was towed to the next zonal leg. Productivity/TM casts were made at stations 28, 39, and 50, near the mid-points of the filament. The carboy experiment in this feature was run using water from station 28. Measurements of photosynthetic variables were made underway and at stations 26, 28, 30, 32, 34, 35, 37, 39, 41, 43, 44, 46, 48, 50, and 52. Filter-Transfer-Freeze (FTF) preparations were made for semi-quantitative microscopy viewing at stations 28, 29, 30, 39, 42, and 50. Barite precipitation measurements were performed at station 28 in this feature. Leg 5: Re-sampling Eddy 3, Deepwater casts, transit to Mauritius; CTD Stations 54-73; VPR tows 13-14; trace metal casts 50, 56, and 70; 0418h, Feb. 20 to 0800h, March 3, 2020. From leg 4, we proceeded to re-sample the cyclonic eddy, originally sampled in leg 2. On the way, we made the first deep CTD cast to sample for nutrients, oxygen, and carbonate chemistry down to the sea floor (4500m). The eddy re-sampling consisted of a 163km west-to-east VPR tow followed by a 203km east-to-west CTD section. Heavy seas forced us to cancel the west-most CTD station. The ship then proceeded to the north eddy station with all weather decks secured. Again, heavy sea states made deployment of the VPR impossible, so we performed the north-to-south CTD section but had to call off some of the middle CTDs from that section due to heavy seas. The drogue had spiraled about 100km from the eddy center by this point, so the ship broke from the N-S line to recover it, after which the interior eddy stations (that had been skipped due to weather) were re-sampled under safer sea states, finally arriving at the southern eddy station, #71 at 1853h on 2/24/20. At this point, the VPR could finally be redeployed to tow the entire south-to-north eddy survey transect. Two productivity/trace-metal stations were run in the eddy at stations 56 and 70. (The carboy experiment was sampled at station 56. Measurements of photosynthetic variables were made underway and at stations 54, 56, 58, 60, 62, 64, 66, 68, 70 and 71. FTF preparations were made for semi-quantitative microscopy viewing at stations 56 (east eddy interior) and 70 (eddy center). Barite precipitation measurements were performed at station 56 in this feature. We performed a deep, 24-bottle, cast for nutrients, oxygen, and dissolved inorganic carbon chemistry 183km NE of the eddy (34.42°S x 38.04°E; depth 5217m), sampled to 5200m. The last station of the cruise was a 24-bottle deep cast at 27° 24.5'S 049°, 49.33'E for freons, nutrients, temperature, salinity, PIC, POC, biogenic silica, coccolithophore and coccolith abundance, dissolved oxygen and dissolved inorganic carbon chemistry. The purpose of this cast was to examine water ages of SAMW, examine the stoichiometry of the changes in the chemistry from assumed preformed levels, and to provide comparative values for the meridional transect to be performed in the following cruise on R/V Revelle.

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Project Information

Collaborative Research: Biogeochemical and Physical Conditioning of Sub-Antarctic Mode Water in the Southern Ocean (Conditioning_SAMW)

NSF Award Abstract:
Cold surface water in the southern Indian Ocean sinks to about 500 meters and travels in the dark for thousands of miles before it resurfaces some 40 years later near the equator in the other ocean basins. This

major water mass is named the Sub-Antarctic Mode Water (SAMW). Nutrients it contains when it warms and rises into the sunlit subtropical and tropical waters are estimated to fuel up to 75% of the microscopic plant growth there. Before it sinks, the chemical properties of the SAMW are modified by the growth and distinct physiology of two common phytoplankton; diatoms with shells made of silica, and coccolithophores with carbonate shells. Local physical dynamics influence where and how fast these two phytoplankton classes grow. Consequently, differing nutrient and trace chemical fingerprints are established at the point of SAMW formation. This project is an exceptionally detailed field and modeling effort that will document and quantify the remarkable, interconnected processes that chemically connect two important oceanic ecosystems half a world apart. The scientists leading the project will study the complexity of the biological and chemical conditioning of the SAMW and thus provide critical data about the large-scale oceanic controls of the biological carbon pump that removes atmospheric carbon dioxide to the deep ocean over millennial timescales. Scientific impact from this project will stem from significant peer-reviewed publications and improved predictive models. Societal benefits will develop from training of a range of scholars, including high school, undergraduate, and graduate students, as well as technical and post-doctoral participants. A high school teacher and science communication specialist will go to sea with the project and share experiences from the ship with students on shore via social media and scheduled web interactions.

To examine how SAMW formation and subduction controls the productivity of global waters well to the north, two January expeditions to the SE Indian Ocean will identify, track, and study the unique mesoscale eddies that serve as discrete water parcels supporting rich populations of either coccolithophores or diatoms plus their associated microbial communities. The eddies will be tracked with Lagrangian Argo drifters and observations will be made of exactly how SAMW is chemically conditioned (i.e. Si, N, P, Fe, and carbonate chemistry) over time scales of months. Using data obtained on the feedback between ecological processes and nutrient, trace metal, and carbonate chemistry in these eddies and on related transect cruises, the project will have three main goals: (1) determine the rates at which SAMW coccolithophores and diatoms condition the carbonate chemistry plus nutrient and trace metal concentrations, as well as assess taxonomic and physiological diversity in the study area with traditional methods plus next-generation sequence DNA/RNA profiling, (2) explore growth limitations by iron, silicate and/or nitrate in controlling algal assemblages and genetic diversity, and (3) combine these findings with the Ekman- and eddy-driven subduction of SAMW to examine biogeochemical impact on a basin scale, using both observations and global numerical models. A meridional survey from 30 to 60 degrees south latitude will be used to characterize the larger-scale variability of carbonate chemistry, nutrient distributions, productivity, genetics and biomass of various plankton groups as SAMW is subducted and proceeds northward.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1735664
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NSF Division of Ocean Sciences (NSF OCE)	OCE-1736375
NSF Division of Ocean Sciences (NSF OCE)	OCE-1735436

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