Cruise Report: A13.5

(March 2024)

Highlights

Cruise Summary information

Section Designation	**A13.5**
Expedition designation (ExpoCode)	**33H320240201**
Chief Scientists	**Zachary Erickson / PMEL** **Jesse Anderson / ESR**
Dates	**2024 FEB 1 – 2024 MAR 23**
Ship	*R/V MARCUS G. LANGSETH*
Ports of call	Mindelo, Cabo Verde – Cape Town, South Africa
Geographic Boundaries	16.9°N 25.0°W 18.4°E 52°S
Stations	112
Core Argo Floats Deployed	4
Deep Argo Floats Deployed	1
Biogeochemical Argo Floats Deployed	11
EM-Apex Floats Deployed	7
Surface Drifters Deployed	18

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GO-SHIP A13.5 Cruise Report

R/V Marcus G. Langseth
01 February 2024 – 23 March 2024
Mindelo, Cabo Verde – Cape Town, South Africa

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NOAA / PMEL

Co-Chief Scientist:
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Preliminary CTD data submitted by:
Zachary K. Erickson
NOAA / PMEL

Preliminary bottle data submitted by:
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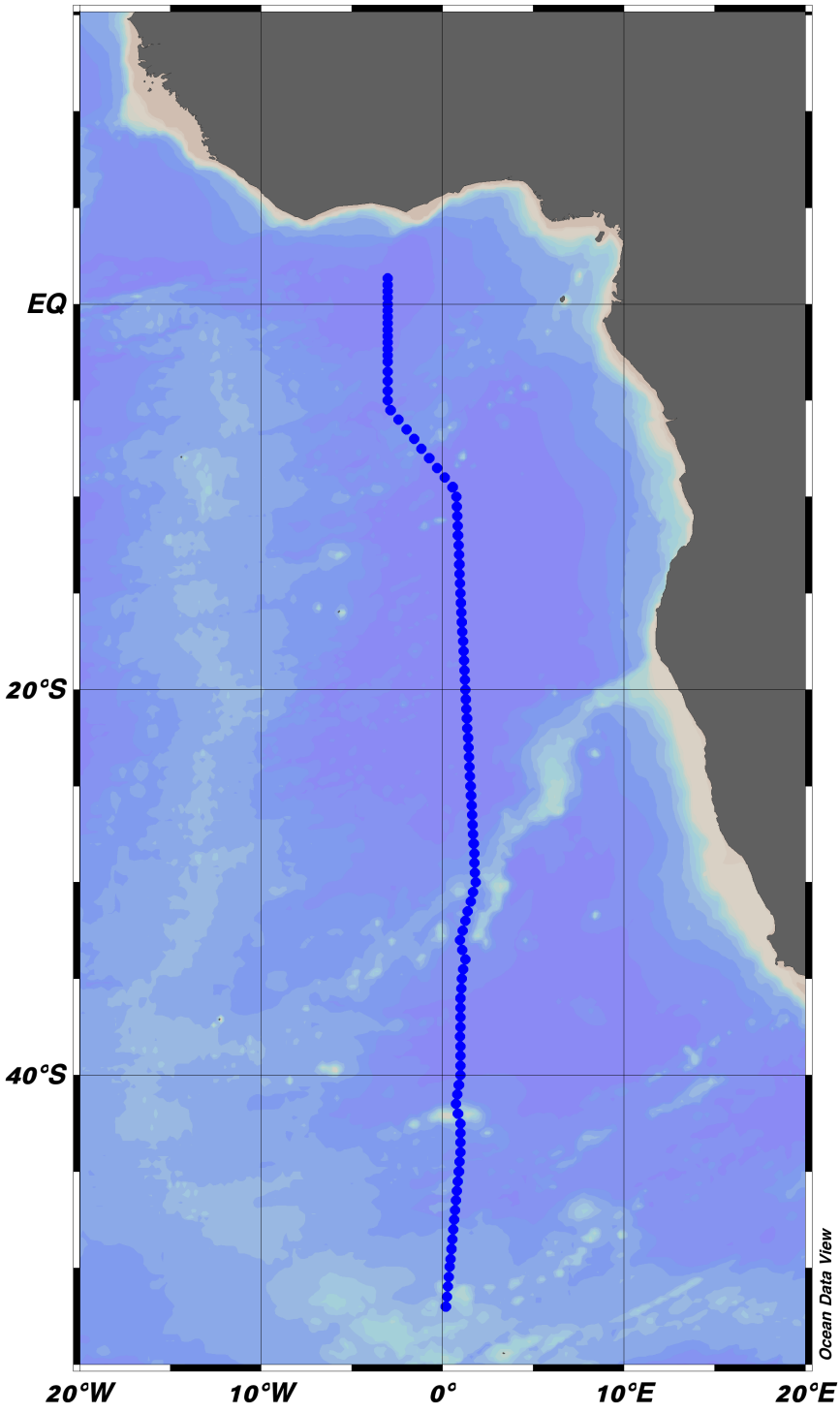

Figure 1. Station locations (blue dots) for A13.5.

1. Introduction

1.1 Summary

Hydrographic measurements were carried out along transect A13.5 in the Atlantic Ocean on the *R/V Marcus G. Langseth* in support of the Global Ocean Ship-based Hydrographic Investigation Program (GO-SHIP), funded primarily by NOAA and NSF. The goals of this program are to occupy a set of hydrographic transects, such as A13.5, at approximately decadal resolution with full water column measurements to study physical, hydrographic, and chemical changes over time. 112 stations were accomplished during this cruise, with latitudes between 1°20'N and 54°S and longitudes between 3°W and 2°E. Another station, north of 1°20'N, was initially measured but is not provided in the data submission due to a revocation of our license to sample in Ghanaian waters. Spacing between stations from 1°20'N to 3°S was 1/3° in latitude, and between 3°S and 52°S was ½°. Measurements from approximately 2,680 bottles were taken as part of this transect, analyzing a variety of parameters including salinity, dissolved oxygen, chlorofluorocarbons, sulfur hexafluoride, dissolved inorganic carbon, dissolved organic carbon, total alkalinity, and pH. This cruise is a re-occupation of the A13.5 line, with previous transects in 1983 and 2010.

Underway measurements were also made throughout the cruise of horizontal velocities through a ship-board ADCP, sea surface temperature, salinity, and pCO2 from the ship's underway clean water intake, and bathymetry data, except when the ship was within exclusive economic zones (EEZs). We were permitted to make these measurements within Norway's EEZ, surrounding Bouvet Island at 54.4°S, 3.3°E, as well as in South African waters. While we were originally granted similar access in Ghanaian waters, this permission was revoked during the cruise. Therefore, no data from within the Ghanaian EEZ will be published from this cruise. Discrete underway sampling was also performed three times per day for environmental DNA and particulate organic carbon, phosphorous, and nitrogen. During the first three days of the final transit from the final CTD station at 52°S, 0.2°E, discrete underway sampling of several parameters was also performed every 4 hours.

The A13.5 track line approximately follows the prime meridian, but deviates by up to 3° in longitude to best sample different oceanographic features, combining elements of WOCE lines A13 and A14. From north to south, this transect samples the Guinea Basin (to about 8°S) traverses over the Guinea Rise at ~9°S, transects the Agulhas Basin from 10-29°S, crosses the Walvis Ridge from 29-33°S, crosses the eastern edge of the Cape Basin from 33-48°S, and then encounters the southern part of the mid-Atlantic Ridge until its ending point, nominally at 54°S. Due to weather and ship delays, on this transect the southern terminus was 52°S. During crossing of the Walvis Ridge and also a mountainous feature in the Cape Basin, the transect path was configured to best pass through deep features, in order to maximize measurements of deep ocean properties. The A13.5 2024 transect therefore traces the following path:

- Follow 3°W from the northern terminus to 5°S
- Move from 3°W to 1°E through 5-15°S
- Move from 1°E to 1.833°E through 15-30°S

- Move from 1.833°E to 0.980°E through 30-33°S
- Move from 0.980°E to 1.218°E through 33-34°S
- Move from 1.218°E to 1°E through 34-36.5°S
- Follow 1°E from 36.5°S to 40°S
- Move from 1°E to 0.75°E through 40-41.5°S
- Move from 0.75°E to 1°E through 41.5-42.5°S
- Follow 1°E from 42.5°S to 44°S
- Move from 1°E to 0°E through 44°S to 54°S (note: stopped at 0.2°E, 52°S).
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1.2 GO-SHIP A13.5 2024 Participating Institutions

Abbreviation	Institution
AOML	Atlantic Oceanographic and Meteorological Laboratory
CICOES	Cooperative Institute for Climate, Ocean, and Ecosystem Studies
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
ESR	Earth and Space Research
LDEO	Lamont-Doherty Earth Observatory/Columbia University
LLO	Large Lakes Observatory/University of Minnesota - Duluth
NGI	Northern Gulf Institute
NOAA	National Oceanic and Atmospheric Administration
Princeton	Princeton University
PMEL	Pacific Marine Environmental Laboratory
RSMAS	Rosenstiel School of Marine and Atmospheric Science/U. Miami
SIO	Scripps Institute of Oceanography/University of California San Diego
TAMU	Texas A&M University
U. Abomey Calavi	University of Abomey-Calavi
UCI	University of California Irvine
UCSB	University of California Santa Barbara
U. Del.	University of Delaware
UH	University of Hawaii
UiO	Universitatet i Oslo
ULB	University of Liege - Belgium
URI	University of Rhode Island
UTTyler	University of Texas at Tyler
UW	University of Washington
WHOI	Woods Hole Oceanographic Institution

1.3 GO-SHIP A13.5 2024 Principal Investigators

Parameter	Lead PI(s)	Affiliation(s)	Email Address(es)
SADCP	Jules Hummon Eric Firing	U. Hawaii U. Hawaii	hummon@hawaii.edu efiring@hawaii.edu
pCO_2 (underway)	Denis Pierrot Rik Wanninkhof	AOML AOML	denis.pierrot@noaa.gov rik.wanninkhof@noaa.gov
CTD/O_2	Zachary Erickson Rick Lumpkin	PMEL AOML	zachary.k.erickson@noaa.gov rick.lumpkin@noaa.gov
LADCP	Andreas Thurnherr	LDEO	ant@ldeo.columbia.edu
CFCs/SF_6	Zachary Erickson	PMEL	zachary.k.erickson@noaa.gov
Dissolved O_2	Chris Langdon	RSMAS	clangdon@earth.miami.edu
fCO_2 (discrete)	Rik Wanninkhof	AOML	rik.wanninkhof@noaa.gov
pH	Chris Langdon	RSMAS	clangdon@earth.miami.edu
Alkalinity	Chris Langdon	RSMAS	clangdon@earth.miami.edu
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Seawater isotopes	Alexander Haumann	AWI	alexander.haumann@awi.de
Nutrients	Calvin Mordy Jia-Zhong Zhang	PMEL/CICOES AOML	calvin.w.mordy@noaa.gov jia-zhong.zhang@noaa.gov
Salinity (discrete)	Rick Lumpkin Zachary Erickson	AOML PMEL	rick.lumpkin@noaa.gov zachary.k.erickson@noaa.gov
Bio	Adam Martiny Luke Thompson	UCI AOML	amartiny@uci.edu luke.thompson@noaa.gov
Microplastics	Franck Lejzerowicz	UiO	f.l.p.lejzerowicz@ibv.uio.no
Core Argo floats & Deep Argo float	Susan Wijffels Steve Jayne Pelle Robbins	WHOI WHOI WHOI	swijffels@whoi.edu sjayne@whoi.edu probbins@whoi.edu
GO-BGC floats	David Nicholson Susan Wijffels	WHOI WHOI	dnicholson@whoi.edu swijffels@whoi.edu
EM-Apex floats	James Girton Zoli Szuts Ren-chieh Lien	UW/APL UW/APL UW/APL	girton@uw.edu zszuts@apl.washington.edu rcl@uw.edu
SVP/SVPB Drifters	Shaun Dolk Rick Lumpkin Luca Centurioni	AOML AOML UCSD/SIO	shaun.dolk@noaa.gov rick.lumpkin@noaa.gov lcenturioni@ucsd.edu

1.4 GO-SHIP A13.5 2024 Scientific Participants

Position	Name	Affiliation
Chief scientist	Zachary Erickson	NOAA/PMEL
Co-chief scientist	Jesse Anderson	ESR
CTD processing	Kristy McTaggart	NOAA/PMEL
CTD Watchstander	Teresa Kennedy	URI/UT Tyler
CTD Watchstander	Daniel Sandborn	LLO
Salts/CTD/LADCP	Jay Hooper	AOML/CIMAS
Salts/CTD/LADCP	Christian Saiz	AOML/CIMAS
Nutrients	Eric Wisegarver	NOAA/PMEL
Nutrients	Ian Smith	AOML/CIMAS
Dissolved O_2	Rachel Cohn	RSMAS
Dissolved O_2	Jennifer Aicher	RSMAS
CFCs	David Cooper	CICOES
CFCs	Anna Bruno	CICOES
CFCs	Isabel Schaal	WHOI
pCO_2	Patrick Mears	AOML/CIMAS
$pCO_2/d^{13}C$	Yifan Li	UDel
DIC	Chuck Featherstone	NOAA/AOML
DIC	Evan Josza	CICOES
Alkalinity/pH	Bo Yang	RSMAS
pH	Eva Jundt	RSMAS
pH	Clara Haughey-Gramazio	RSMAS
DOC	Max Pacatte	UCSB
LADCP	Adeola Dabunsi	U. Abomey Calavi
Bio	Kristian Furnes	UiO

1.5 GO-SHIP A13.5 2024 Crew

Department	Position	Name
Bridge	Master	Breckenridge Crum
Bridge	Chief Mate	David Wolford
Bridge	Second Mate	Joselyn White
Bridge	Third Mate	Thomas Wakley Jr.
Technician	Chief Science Technician	Todd Jensvold
Technician	Chief Mechanic	Joshua Kasinger
Technician	Science Technician	Koray Ergun
Technician	Science Technician	Aaron Martin
Deck	Bosun	Geroge Cereno
Deck	AB	Gerald Mclamon III
Deck	AB	Derek Johnson
Deck	AB	Venise Spears
Deck	OS	Lindsay Daniels
Deck	OS	Matrik Stein
Steward	Steward	Brian Jones
Steward	Cook	Jun Martires
Engineering	Chief Engineer	Samuel Romeuy
Engineering	First Engineer	Sean Sullivan
Engineering	Second Engineer	Sarah Wright
Engineering	Third Engineer	Mitchel Paul
Engineering	Electrician	Michael Hill
Engineering	Oiler	Rodolfo Florendo
Engineering	Oiler	David Hall
Engineering	Oiler	Malcolm Baker

2. Cruise Narrative

2.1 Domestic cruise mobilization in Norfolk, VA

Mobilization for this cruise occurred primarily in Norfolk, VA during January 8-12, 2024. Scientists from several represented institutions arrived to load and set up instrumentation within the different laboratory spaces on the ship. In addition to setting up laboratory spaces inside the ship, 3 vans were brought on board. One of these vans was for storage, and the other two were laboratory vans for dissolved inorganic carbon extraction and transient tracers such as chlorofluorocarbons (DICE and CFC vans, respectively). Due to the expected rough nature of seas in the Southern Ocean, these vans were not actively used as laboratory spaces for this cruise. Instead, equipment from the DICE and CFC vans were moved into the ship's port lab. The DICE van remained on the main deck along with the storage van, while the CFC van was moved onto an upper deck. Throughout the cruise, the DICE van was used to store and use hazardous chemicals.

The *Langseth* has five main laboratory spaces (Figure 2). The main level contains the port lab, the wet lab, and the dry lab. The port lab was occupied by the CFC group and the dissolved inorganic carbon (DIC) group; the wet lab had LADCP and CTD equipment, Bio-GO-SHIP, microplastics, carbon, nitrate, and seawater isotopes, and dissolved organic carbon (DOC); and the dry lab had nutrients, oxygen, pH, and TA. The wet lab also had the ship's underway seawater line. Upstairs from the port lab is the bird lab, which contained fCO2. Downstairs from the port lab was the computer lab, which was where the CTD console was set up. A small side room attached to the computer lab was used as the salts room.

Along with laboratory set-ups, in Norfolk two other systems were installed. The first was the rail system, which was attached to the main deck (Figure 3). This system was used to place the CTD between casts. A platform, set up by the AOML-based CTD team in Cabo Verde and on the first days of the transit to our fist station, was subsequently set on the rail system to support the CTD rosette. Ropes and a winch were used to move the CTD rosette along the rails between the ship's railing, from where it was deployed, and inboard underneath a sheltered area, where sampling occurred. Second, a pCO2 system was installed in the wet lab by Denis Pierrot; see Section 3.2 for more details.

Figure 2. Diagram of laboratory set-ups on the Langseth*. From top left: wet lab, salt room, port lab, bird lab, and dry lab. Note that the right side of the port lab was "open" and included a staircase up to the bird lab as well as a door to the outside. Bird lab was on second level; main, dry, and port labs were on the main deck; and the salt room was one floor down.*

Figure 3. CTD rosette set-up shown during a recovery. The platform and tracks allowed the CTD rosette to be brought inboard on the main deck for sampling. Shown from left to right are Ian Smith (AOML/CIMAS), Koray Ergun (Langseth technician), and Christian Saiz (AOML/CIMAS); in rough weather a third tagline was added to help stabilize the package.

2.2 A13.5 transect

The *R/V Marcus G. Langseth* departed from Mindelo, Cabo Verde on February 1st to begin an 8.5 day transit to the beginning of the A13.5 line, which is along 3°W near the Ghanaian coast. A relatively last-minute change of starting port from Praia to Mindelo increased our transit time by approximately one full day. In order to preserve time for the main transect, the ship took the shortest path to our initial station, which necessitating transiting through several African country's exclusive economic zones (EEZs) in which we did not have clearance to take measurements. Therefore, no coordinated underway sampling occurred during this initial transit, although pCO2 and the Bio-GO-SHIP groups did make underway measurements during days when the ship was within international waters. Along this initial transect three test CTD stations were performed to test sensors and provide water for groups to practice sampling.

Our first completed station, Station 1, was completed on February 8th and was located within the Ghanaian EEZ. After a lengthy delay and a revocation of our ability to sample within the Ghana EEZ (see Section 2.3), Station 2 was completed 345 kilometers due south of Station 1, at 1°20'S and 3°W, on February 10th. Station 2 forms the northernmost point of the data submitted as part of this cruise.

Stations 2-10 were completed with no significant issues. On Station 11, we were not able to fire all bottles due to bad communication with the CTD rosette. Upon further inspection, similar errors in communication were also seen to have occurred on Station 10, even though the bottles ultimately still did close. After much troubleshooting, the issue was traced to the cable, which had several tens of meters of rust. Approximately 150 m of cable were cut off and the end was reterminated. During this troubleshooting process, the CTD was also connected to the secondary winch. This cast could not be completed; for more on issues concerning the secondary winch during this cruise see Section 2.4.

From the beginning of our line to about 8°S we had calm seas and no significant weather. Starting at around Station 25 (8°S), winds began to pick up and we ran into significant currents, which often acted to cause the ship to drift over the CTD cable during CTD casts. While this was mostly able to be mitigated by the bridge, on several stations CTD casts needed to be momentarily stopped due to contact between the ship hull and the CTD cable while the ship adjusted position. In particular, casts were stopped on Stations 28 and three times on 72. For Station 72, the first stop was on the downcast, at 112 dbar. After the ship adjusted position and the wire angle improved, the package was lifted about 10 m so that the cable could be inspected. The second two casts on this cast also occurred on the downcast, and the cable was not lifted. On Station 74, a rogue wave hit the ship shortly after deployment, when the CTD package was still near the surface. Shortly thereafter, on Station 76, an incident occurred during deployment where one of the three taglines used to deploy the CTD got caught in a gap in the ship's railing, preventing the CTD from deploying. While attempting to remove the rope in wavy seas, the CTD swung against the side of the ship and hit the railing. The CTD was immediately recovered and inspected for damages. While no damage was evident from the contact with the ship, a sharp bend was discovered in the cable several tens of meters out from the package. We surmise that this could have occurred either during the rogue wave on cast 74 or during an unrelated wind event during a transit between stations, which could have rotated one of the blocks on which the CTD cable went through. Following this discovery, 100 m of cable were cut off, thereby removing the bend in the wire and also several other places in which there was light abrasion on the cable from contact with the ship's hull in previous casts. After retermination, the CTD was again ready to deploy. Following this cast, there were no further significant issues with wire angle.

On Station 48, at 19.5°S on February 24th, the altimeter stopped registering the bottom at the end of the bottom approach. We were unable to determine the issue of fix the problem, but did realize that the testing done by Seabird before selling the altimeter was only to 100 bar, far shy of the 600 bar pressure rating on the altimeter. A back-up Valeport altimeter also did not work, so we were unable, past Station 48, to descend to within 10 m of the ocean bottom. We used the ship's multibeam altimeter to gauge bottom depth, and stopped at 80 m off of the bottom, modifying that deeper – to about 50 m – by the end of the cruise.

We ran into our first significant weather event on Monday, March 4th, at 35°S, when high winds gusting to 40 knots, prevented deployment of the CTD on Station 79. These high winds were part of a low pressure system moving through the region, which necessitated an approximately

40 hour delay in operations while waiting for the winds and the associated swell to die down. On Tuesday, March 12th we also stood down from operations at Station 101 (46°S) for about 16 hours due to high winds and rough seas. Following this station, speeds on the transit were reduced while sampling in order to prevent large waves from washing out the deck.

At approximately 48°S we started encountering icebergs, which reduced transit speeds at nighttime. Speeds were severely reduced during foggy conditions, which occurred during several mornings. This dramatically increased transit times between stations, with the longest transit taking 6 hours (compared with a normal transit time of 3 hours). Due to these weather and iceberg-related delays, the final four stations were not able to be completed, and the cruise ended on Station 113 at 52°S, 20:00 GMT on March 16th.

The transit from the final station to Cape Town, South Africa took approximately 6.5 days. During the first 3 days (March 16-18), underway samples were taken using the ship's underway system every four hours, for 18 samples total, from DIC, pH, TA, fCO2, carbon isotopes, and nutrients. The final 3 days were used for finishing sample analysis and packing up laboratory spaces.

2.3 Issues concerning sampling in Ghanaian waters

On February 8th we entered the Ghanaian EEZ, in which we had planned our first 12 stations. These stations were on the 3°W line of longitude, with 3 close to the shelf (at 250, 1000, and 1750 m isobaths), an additional 4 at increased spacing resolution and the rest at 1/3° latitude intervals starting at 3.33°S. Prior to the cruise departure, the ship had received permission from the Ghanaian Ministry of Foreign Affairs and Ministry of Environment, Science, Technology, and Innovation to sample in Ghanaian waters.

Upon entering Ghanaian waters we proceeded to our first station, which was the third from the closest to land (2500 m isobath). We picked this starting point primarily due to piracy concerns; this station was far enough from land to have minimal pirate risk, and we would practice operations so that the station closest to land would happen as quickly as possible. Starting at this more southerly station also meant we would get to the Ghanaian coast during the daytime, rather than near midnight, which was advantageous because several online sources suggested that piracy occurs more frequently in the evening than in the early morning. Following this cast, we steamed to Station 2. Our transit took us between two oil/gas platforms. As we neared the station, we were hailed by the Ghanaian Navy and told to stand down from science operations. We transmitted our clearance and waited for several hours, before being ordered to return with the Navy ship to Accra, Ghana. We declined to follow, and requested assistance from the U.S. State Department. After several more hours, we were allowed to leave Ghanaian waters with an escort from a different Ghana Navy ship and were informed that our permission to sample in the Ghanaian EEZ was revoked. We steamed due west and left the Ghanaian EEZ, entering instead the Ivory Coast EEZ, 18:48 on February 9th. Our second station was therefore the farthest north station along 3°W that was outside of Ghanaian waters, at 1.33°N. The total delay was 18 hours. Following this incident, we were informed that the Ghanaian Navy had been

hired by oil and gas platforms in the area to provide security, and that our credentials from the Ministry of Foreign Affairs were not valid unless they had been signed off on by the Navy. Despite undergoing a dedicated search to find a clearly communicated demarcation of an area of heightened security around these oil and gas platforms, we were unsuccessful at determining where exactly this boundary existed.

2.4 Issues concerning the secondary winch

Per GO-SHIP regulations, two winches and cables are required for GO-SHIP cruises, with the secondary winch and cable used as a backup if the primary becomes inoperable during a cruise. Even for cases where the primary can be fixed, having a working secondary system set up ensures that troubleshooting on the primary winch or cable can be completed with minimal delays, as the secondary system can be used in the meantime.

The *Langseth* only has one winch suitable for CTD operations permanently installed. A Desh5 NOAA CTD winch was located at Markey, with cable that appeared to have been unused since 2014. The cable had last been inspected by Rochester Wire and Cable LLC in 6/25/15 and found to be 32,902 ft (10,029 m) long. The winch and cable were delivered to the *Langseth* during the domestic mobilization in Norfolk, VA.

During the cruise, the secondary winch wire was reterminated to be able to connect with the CTD. This involves cutting off small amounts of cable. The ticker tape in the cable identified the wire length as 5750 m, or approximately half the length we had expected based on the last known inspection. Given that our deepest depth was expected to be almost 6,000 m, it was clear that this cable would not be suitable for deep casts along our line.

The first instance using the cable was on Station 11, at 1.67°S on February 13, 2024 following issues with the primary cable connection. On the downcast at approximately 160 dbar there was an issue with the secondary winch which required a temporary halt. After getting the winch working again, the motor failed at 395 dbar. The package was able to be lifted partway using slow winch speeds before the motor failed again, and the CTD was left in the water for approximately two more hours until a secondary system to bring it out of the water was rigged up by the crew using a different winch system on the ship. Upon troubleshooting the winch, the primary problem was found to be associated with the variable frequency drive (VFD), which converts a constant voltage being supplied by the ship into varying voltages to control the speed of the winch. An issue was found with the encoder device, which provides feedback to the VFD on how fast the winch is running, allowing the VFD to properly regulate speed. The encoder appeared to be faulty, with the end result being that at speeds higher than about 1 m/min, the encoder would give incorrect information to the VFD, causing it to stop and display errors and – once started up again – kick into overdrive before again halting with an error. Fortunately, the ship had a spare encoder and was able to make the repair. Additional problems with the tension/payout hookup and winch AC installation were also fixed in the process. The secondary winch was tested by running for several hours on deck and deemed operable on February 19th. During a stoppage of work following Station 76 on March 13th, a weight was attached to the

secondary and it was tested in the water, and deemed fully operational, albeit with a shortened cable. Neither the secondary winch nor cable were ever successfully used with a CTD on this cruise.

3. Underway Data Acquisition

3.1 Acoustic Doppler Current Profiler (ADCP) Measurements

Principal Investigators: Jules Hummon (U. Hawaii) and Eric Firing (U. Hawaii)

The R/V *Marcus G. Langseth* has a permanently mounted 75 kHz acoustic Doppler current profiler ("ADCP" Teledyne RDI) for measuring ocean velocity in the upper water column. The ADCP is a Phased Array instrument, capable of pinging in broadband mode (for higher resolution), narrowband mode (lower resolution, deeper penetration), or interleaved mode (alternating). On this cruise, data were collected with 8 m broadband pings and 16 m narrowband pings. The data were collected for the entire duration of A13.5 except when in a foreign nation's EEZ – with an exception for Norway (Bouvet Island) and South Africa, for which we were granted a permit to continue to take measurements.

The shipboard ADCP data are acquired and processed by specialized software developed at the University of Hawaii and installed on the *Langseth*. The acquisition system ("UHDAS", University of Hawaii Data Acquisition System) acquires data from the ADCPs, gyro heading (for reliability), position and orientation systems for marine vessels (POSMV) headings (for increased accuracy), and GPS positions from various sensors. Single-ping ADCP data are automatically edited and combined with ancillary feeds, averaged, and disseminated via the ship's web, as regularly-updated figures on a web page and as Matlab and netCDF files.

3.2 Underway pCO_2 Analyses

Principal Investigators: Denis Pierrot (AOML), Rik Wanninkhof (AOML)
Analyst: N. Patrick Mears (AOML/CIMAS)

An automated underway pCO_2 system from AOML was situated in the wet lab aboard the R/V *Marcus Langseth*. The design of the instrumental system is based on Wanninkhof and Thoning (1993), and Feely et al. (1998), while the details of the instrument and of the data processing are described in Pierrot, et.al. (2009).

The repeating cycle of the system includes 5 gas standards, 5 ambient air samples, and 66 headspace samples from its equilibrator within 3.3 hours. The concentrations of the standards range from 240 to 576 ppm CO_2 in compressed natural air. They were purchased from NOAA/ESRL in Boulder and are directly traceable to the WMO scale. An ultra-high purity nitrogen (UHP N_2) provided a zero standard.

The system includes an equilibrator where approximately 0.6 liters of constantly refreshed surface seawater from the bow intake is equilibrated with 0.8 liters of gaseous headspace. The water flow rate through the equilibrator was 1.8-2.0 liters/min.

The equilibrator headspace is circulated through a non-dispersive infrared analyzer (IR), a LI-COR™ 6262, and then returned to the equilibrator. When ambient air or standard gas is analyzed, the gas leaving the analyzer is vented to the lab. A KNF pump constantly draws 6-8 liter/min of marine air through 100 m of 0.95 cm (= 3/8") OD Dekoron™ tubing from an intake on the bow mast. The intake has a rain guard and a filter of glass wool to prevent water and larger particles from reaching the pump. The headspace and marine air gases are dried before flushing the IR analyzer.

A custom program developed using LabView™ controls the system and graphically displays the air and water results. The program records the output of the infrared analyzer, the GPS position, water and gas flows, water and air temperatures, internal and external pressures, and a variety of other sensors. The program records all of this data for each analysis.

Since the beginning of the cruise, a non-functioning 3-way solenoid caused standard and atmospheric gas measurements analyzed by the LI-COR™ to be returned to the headspace gas of the equilibrator via the equilibrator return line instead venting out of the system. This results in several data points collected from the headspace gas being discarded when taken directly after standard and atmospheric sample analysis. In addition, this causes an excess of salt crystals to form in the return line that required cleaning to prevent restricted gas flow.

On February 8th upon powering on the GO board and initializing the program an error occurred with the VICI electric actuator or the multi-position valve that resulted in a mismatched port, where the port number displayed was incorrectly connected to a port, 4 positions past, ie, port 1 displayed connected to port 5. This was circumvented by reprogramming the port numbers to the correct ports, this allowed for the correct connection to the correct ports for different analysis and standards.

Further issues arose from this error where certain sequences would lose flow. These sequences were where the actuator moved forward to a port and then moved backward. The ATM analysis after the first measurement is lost as well as a STD5 zero measurement after a STD4s measurement. As the cruise progressed, the EQU lost flow for entire sections between standard measurements and returned to flowing conditions after another set of standards.

Standard Gas Cylinders

Cylinder#	ppm CO_2
CC309839	240.72
CC505452	369.42
CC310075	408.21
CC749973	576.07
N2	0

References

Pierrot, D., C. Neill, K. Sullivan, R. Castle, R.Wanninkhof, H. Luger, T. Johannessen, A. Olsen, R.A. Feely, C.E. Cosca, 2009: Recommendations for autonomous underway pCO2 measuring systems and data-reduction routines. Deep-Sea Res., II, v. 56, pp. 512-522.

Feely, R.A., R. Wanninkhof, H.B. Milburn, C.E. Cosca, M. Stapp, and P.P. Murphy, 1998: A new automated underway system for making high precision pCO_2 measurements onboard research ships. Analytica Chim. Acta, v. 377, pp. 185-191.

Wanninkhof, R., and K. Thoning, 1993: Measurement of fugacity of CO_2 in surface water using continuous and discrete sampling methods. Mar. Chem., v. 44, no. 2-4, pp. 189-205.

4. Stations

4.1 CTD deployment and Niskin locations

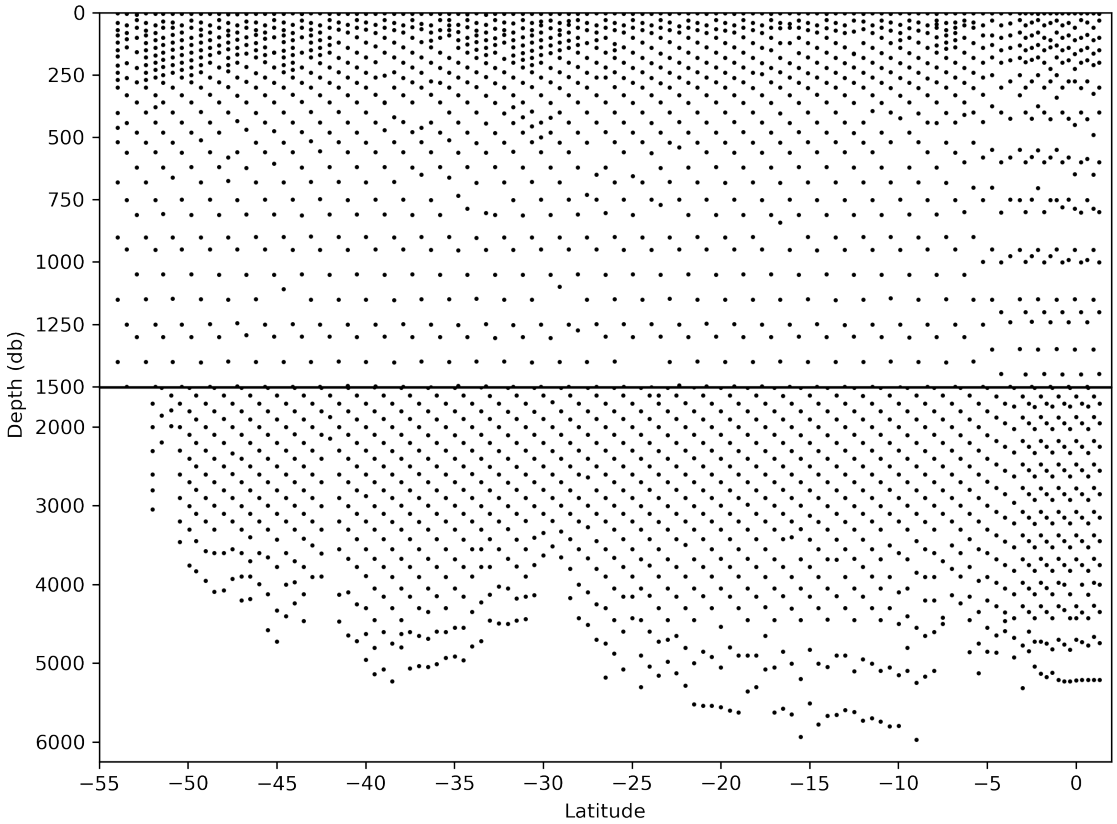


Figure 4. Bottle firing depths from transect.

The CTD/rosette system was deployed off the starboard side of the *Langseth*. Science personnel were responsible for the deployment and recovery of the CTD/rosette. Communications with the winch and bridge were facilitated by the ship's science technician lead. During deployment and recovery, the CTD/rosette package was controlled by hooks and lines and safely lowered onto a custom cart and rail system that allowed the CTD/rosette package to be safely brought inboard for sampling. A PMEL 24-position rosette system with 12-liter Bullister bottles was used for all CTD/rosette stations 1-113.

Stations were distributed at regular intervals of latitude, every 1/3° from 1°20'N-3°S, and every ½° from 3°S-54°S, for a total of 75 stations occupied. On the upcast, 24 Bullister bottles were fired. (Note that elsewhere in this report, these bottles are referred to as Niskins.) The first was always at the deepest depth, 10-15 m above the sea floor while the altimeter was working and 40-80 m above afterwards (see Section 4.2), and the last was always at the surface, at 3-5 m depth. The rest were arranged throughout the water column (see Figure 4), always with about

half in the upper 1000 m. Starting at Station 19 (5°S), the following rotation of bottle depths was used, where depth is measured in decibars.

Niskin	Schema		
#	A	B	C
1	deep	deep	deep
2	halfway	halfway	halfway
3	4450	4300	4150
4	4050	3900	3775
5	3675	3550	3420
6	3300	3200	3100
7	3000	2900	2800
8	2700	2600	2500
9	2400	2300	2200
10	2100	2000	1900
11	1800	1700	1600
12	1500	1400	1300

Niskin	Schema		
#	A	B	C
13	1250	1150	1050
14	950	900	810
15	750	680	620
16	560	520	480
17	440	400	360
18	330	300	280
19	260	240	220
20	200	180	160
21	140	120	100
22	80	70	60
23	50	40	30
24	surface	surface	surface

Bottle depths were sometimes modified slightly in order to capture water mass features in the water column. This was generally done when extrema in either temperature, salinity, or oxygen were observed in the CTD downcast, and those extrema were not captured by the values given above. However, in cases where features were present through multiple transects (e.g., the Antarctic Intermediate Water salinity minimum), bottles were generally not shifted in depth to capture the core signal, as the feature would still be present in future stations at approximately the same depth. In addition, on stations with bottom depths that were shallower than about 5000 m, bottles in the above scheme that were too deep were eliminated and moved towards shallower depths – generally splitting the difference between two bottles in the upper 500 m. For example, in Scheme A the depths 110, 170, 230, and 290 dbar might be added to shallower stations. If the station depth was under about 2500 m, only 16 Niskins were closed, rather than the full 24.

At the end of each rosette deployment water samples were drawn from the rosette bottles in the following order:

- Chlorofluorocarbons (CFCs) and SF_6
- Oxygen
- fCO_2
- pH/Total Alkalinity (TA)
- Dissolved Inorganic Carbon (DIC)
- ^{13}C DIC
- Nitrate and seawater isotopes
- Dissolved Organic Carbon (DOC)
- Nutrients
- Salinity
- Phytoplankton pigments (HPLC) and particulate organic carbon (POC)

In general, all measurements were drawn from all bottles unless there was a mistrip or some other exception, except for:

- ^{13}C DIC, which was collected at all depths at every other station (full degrees, except for within the equatorial region)
- Nitrate isotopes, which were collected at all depths at every fourth station
- Seawater isotopes, which were collected from 10 bottles at XX stations throughout the cruise, consolidated primarily within the southern part of the transect. At two stations, samples were taken from all 24 bottles.
- DOC, which was collected at all depths at every other station (full degrees, except for within the equatorial region) and only at the surface bottle at other stations
- HPLC and POC samples, which were only taken at the surface and estimated deep chlorophyll maximum at 11 sites aligned with BGC Argo deployments.

The correspondence between individual sample containers and the rosette bottle position (1-24) from which the sample was drawn was recorded on the sample log for the cast. This log also included any comments or anomalous conditions noted about the rosette and bottles. One member of the sampling team was designated the sample cop, whose sole responsibility was to maintain this log and ensure that sampling progressed in the proper drawing order. Normal sampling practice included opening the drain valve and then the air vent on the bottle, indicating an air leak if water escaped. This observation together with other diagnostic comments (e.g., 'lanyard caught in lid', 'valve left open'') that might later prove useful in determining sample integrity were routinely noted on the sample log. Drawing oxygen samples also involved taking the draw temperature from the bottle. The temperature was noted on the sample log and was sometimes useful in determining leaking or mis-tripped bottles.

4.2 CTD Data Acquisition

Principal Investigators: Zachary Erickson (PMEL) and Rick Lumpkin (AOML)
Analytical Personnel: Kristy McTaggart (PMEL)
Console Operators: Kristy McTaggart (PMEL), Teresa Kennedy (UT Tyler/URI), and Daniel Sandborn (LLO)

The CTD data acquisition system consisted of the ship's SBE-11*plus* (V2) deck unit s/n 11P111660 and a networked PMEL Dell Optiplex 7040 Windows 10 laptop running SBE Seasave V7 version 7.26.7.107 software. NMEA GPS data were received through the deck unit. The workstation was used for data acquisition and to close bottles on the rosette. Raw data files were archived immediately after each cast onto the laptop as well as onto the wireless science network. No real-time data were lost during this cruise.

CTD deployments were initiated by the deck crew and the CTD console operator once the Bridge advised that the ship was on station. Between each station the CTD sensors were kept clean and wet using a very dilute Triton-X deionized water solution. The computer console operator maintained a CTD Cast log recording position and depth information at the surface,

bottom, and end of each cast as well as a record of every attempt to close a bottle, and any pertinent comments.

After the underwater package entered the water, the winch operator lowered it to 20 meters. After a 60-second startup delay, the pumps turned on. The console operator watched the CTD data for reasonable values, waited three minutes at the soak depth for sensors to stabilize, instructed the winch operator to bring the package to the surface, paused for 30 seconds, and began the descent to a target depth approximately 10-15 meters above the sea floor. The descent rate was nominally 30 m/min to 50 m, 45 m/min to 200 m, and 60 m/min deeper than 200 m. These rates could vary depending on sea cable tension and sea state.

The console operator monitored the progress of the deployment and quality of the CTD data through interactive graphics and operational displays. The chief or co-chief scientist created a sample log for the cast that would be used to record the water samples taken from each Bullister bottle. The altimeter, CTD depth, wire-out, and multibeam echo sounder depth were all monitored to determine the distance of the package from the bottom. Following the altimeter trace within 100 m of the bottom, the CTD was stopped at 10 m above the bottom (casts 1-51). Without a working altimeter (casts 52-113), the CTD was stopped at 80 m above the bottom using the ship's multibeam echo sounder measure of depth.

Bottles were closed on the upcast through the software. Each bottle was tripped 30 seconds after the winch stopped at each sample depth to allow the rosette wake to dissipate and the bottles to flush. The winch operator was instructed to proceed to the next bottle stop 15 seconds after closing a bottle to ensure that stable CTD and reference temperature data were associated with the trip.

Near the surface, the console operator directed the winch to stop the rosette just beneath the surface. After the surface bottle was closed, the package was recovered. Once on deck, the console operator stopped data acquisition and turned off the deck unit.

At the end of each cast, primary and secondary CTD/O_2 sensors were flushed with a very dilute Triton-X and de-ionized water solution using syringes fitted with tubing. The syringes were left attached to the temperature ducts between casts, with the temperature and conductivity sensors immersed in the rinse solution to guard against airborne contaminants. The oxygen sensors were flushed with solution but not stored with solution. The rosette carousel was rinsed with warm freshwater.

PMEL purple frame components and calibration dates

Manufacturer / Model	Serial Number	Calibration Date	Station/Casts Used
Sea-Bird 9plus CTD	1548	28-Aug-23	0011-1131
Sea-Bird 3Plus primary temperature	4341	05-Aug-23	0011-1131
Sea-Bird 4C primary conductivity	4600	12-Sep-23	0011-1131
Sea-Bird 43 primary oxygen	315	29-Aug-23	0011-0031
Sea-Bird 43 primary oxygen	313		0041-1131
Sea-Bird 5T primary pump	8794	n/a	0011-1131
Sea-Bird 3Plus secondary temperature	6358	02-Aug-23	0011-1131
Sea-Bird 4C secondary conductivity	2887	13-Oct-23	0011-0031
Sea-Bird 4C secondary conductivity	3068	27-Apr-22	0041
Sea-Bird 4C secondary conductivity	2882	12-Sep-23	0051-1131
Sea-Bird 43 secondary oxygen	4471	14-Oct-23	0011-1131
Sea-Bird 5T secondary pump	8774	n/a	0011-1131
Sea-Bird 35 reference temperature	72	13-Mar-24	0011-1131
Sea-Bird 32 24-position carousel (AOML)	500	n/a	0011-1131
Valeport VA500 altimeter	88210	10-Jun-23	0011-0501

4.3 CTD Data Processing

Principal Investigators: Zachary Erickson (PMEL) and Rick Lumpkin (AOML)
Analytical Personnel: Kristy McTaggart (PMEL)

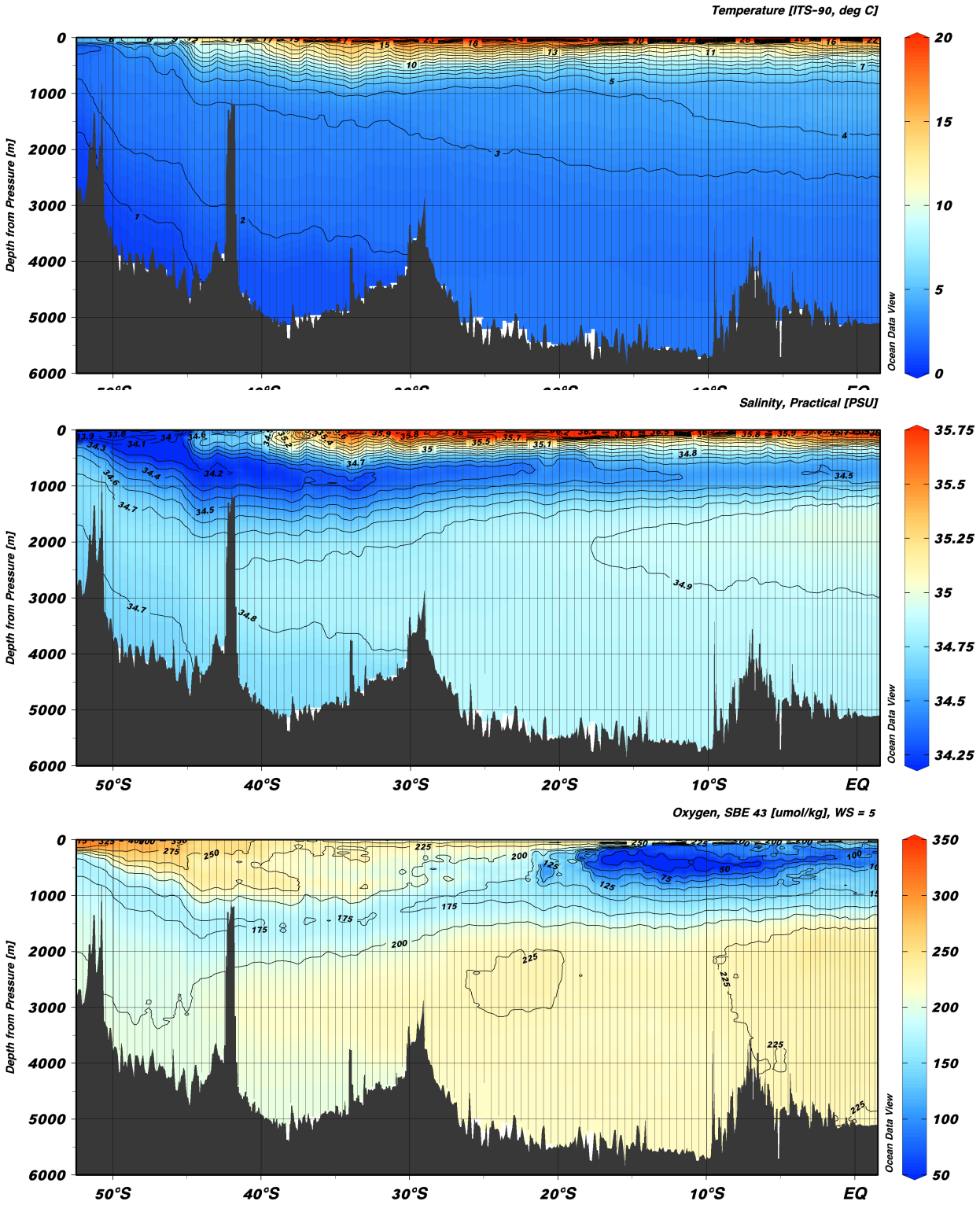


Figure 5. From top to bottom, temperature (ITS-90, in deg C), salinity (PSU), and oxygen (µmol/kg) using preliminary data from the primary sensors on the CTD.

The reduction of profile data began with a standard suite of processing modules using Sea-Bird Data Processing Version 7.26.7.121 software in the following order:
DATCNV converts raw data into engineering units and creates a ROS bottle file. Both down and up casts were processed for scan, elapsed time(s), pressure, t0, t1, c0, c1, oxvo1, oxvo2, ox1 and ox2. MARKSCAN was used to skip over scans acquired on deck and while priming the system under water.

ALIGNCTD aligns temperature, conductivity, and oxygen measurements in time relative to pressure to ensure that derived parameters are made using measurements from the same parcel of water. Primary and secondary conductivity were automatically advanced in the V2 deck unit by 0.073 seconds. No further alignment was warranted. It was not necessary to align temperature or oxygen.

BOTTLESUM averages burst data over an 8-second interval (within ± 4 seconds of the confirm bit) and derives both primary and secondary salinity, potential temperature (θ), and potential density anomaly (σ_θ). Primary and secondary oxygen in µmol/kg were derived in DATCNV and averaged in BOTTLESUM, as recommended by Sea-Bird.

WILDEDIT makes two passes through the data in 100 scan bins. The first pass flags points greater than 2 standard deviations; the second pass removes points greater than 20 standard deviations from the mean with the flagged points excluded. Data were kept within 0.005 of the mean.

FILTER applies a low pass filter to pressure with a time constant of 0.15 seconds. In order to produce zero phase (no time shift) the filter is first run forward and backwards through the file.

CELLTM uses a recursive filter to remove conductivity cell thermal mass effects from measured conductivity. In areas with steep temperature gradients the thermal mass correction is on the order of 0.005 PSS-78. In other areas the correction is negligible. Nominal values of 0.03 and 7.0 s were used for the thermal anomaly amplitude (α) and the thermal anomaly time constant (β^{-1}), respectively, as suggested by Sea-Bird.

LOOPEDIT removes scans associated with pressure slowdowns and reversals. If the CTD velocity is less than 0.25 m/sec[1] or the pressure is not greater than the previous maximum scan, the scan is omitted.

DERIVE uses 1-dbar averaged pressure, temperature, and conductivity to compute primary and secondary salinity, as well as more accurate oxygen values.

BINAVG averages the data into 1-dbar bins. Each bin is centered on an integer pressure value, e.g. the 1-dbar bin averages scans where pressure is between 0.5 dbar and 1.5 dbar. There is no surface bin. The number of points averaged in each bin is included in the data file.

STRIP removes oxygen that was derived in DATCNV.

TRANS converts the binary data file to ASCII format.

Package slowdowns and reversals owing to ship roll can move mixed water in tow to in front of the CTD sensors and create artificial density inversions and other artifacts. In addition to Seasoft module LOOPEDIT, MATLAB program deloop.m computes values of density locally referenced between every 1 dbar of pressure to compute the square of the buoyancy frequency, N2, and linearly interpolates temperature, conductivity, and oxygen voltage over those records where N2 is less than or equal to -1 × 10-5 s-2. Some profiles failed the criteria near the surface. These data were retained and will be flagged as questionable in the final CCHDO formatted .CSV files.

Program calctd.m reads the delooped data files and applies calibrations to pressure, temperature, conductivity, and oxygen; and computes calibrated salinity. Calibrations will be finalized and applied post-cruise.

5. Cruise Measurements

5.1 Lowered Acoustic Doppler Current Profiler (LADCP)

Principal Investigator: Andreas Thurnherr (LDEO)
Technicians: Adeola Dahunsi (U. Abomey-Calavi), Christian Saiz (AOML/CIMAS), and Jay Hooper (AOML/CIMAS)

Pre-station setup

After mobilization on February 1st 2024, the LADCP system was set-up for reliable communication with the LADCP computer installed in the wet lab. Prior to the test casts, two ADCPs provided by the Lamont-Doherty Earth Observatory (LDEO) were installed on the CTD rosette and linked together using a star cable which also supplies power from the NOAA/AOML provided battery. In a bid to acquire the entire water column depth profiles of both horizontal and vertical velocities, one ADCP was installed facing upwards (uplooker; UL), while the other was positioned beneath it facing downwards (downlooker; DL). This set-up approach is necessary for post-processing as the DL is expected to improve the bottom tracking ability of the ADCPs while the UL validates surface data acquired through the ship-mounted ADCP. This setup was done during the ship loading in Norfolk earlier in January and validated upon arrival of the ship in Mindelo to be sure the star cable was well anchored to the rosette in order to reduce shaking inside the water during deployment/recovery.

At this stage, the communication with the acquisition computer as well as the charging of the battery were done through the NOAA/AOML provided deck cable. A permanently connected voltage meter was placed between the deck cable and the power source to monitor the level of depletion of the battery and how well it is charged. In order to reduce the chance of damage to this cable due to constant movement, this deck cable was routed as close as possible to the resting location of the CTD rosette whenever it is on deck (Figure 6). During communication with the ADCPs, the deck cables were consistently linked to the acquisition computer through RS232-to-USB adapters, forming a permanent connection as shown in Figure 7. Several on-deck test casts were run to validate the consistency of this setup and to identify the required information for the CRUISE_SETUP.expect where the USB corresponding to the UL and DL are set accordingly. The issue of misconnection of the cables was sometimes noted at the stage and was rectified by properly labelling each cable and USB adaptor to aid easy identification by every technician involved in the LADCP data acquisition.

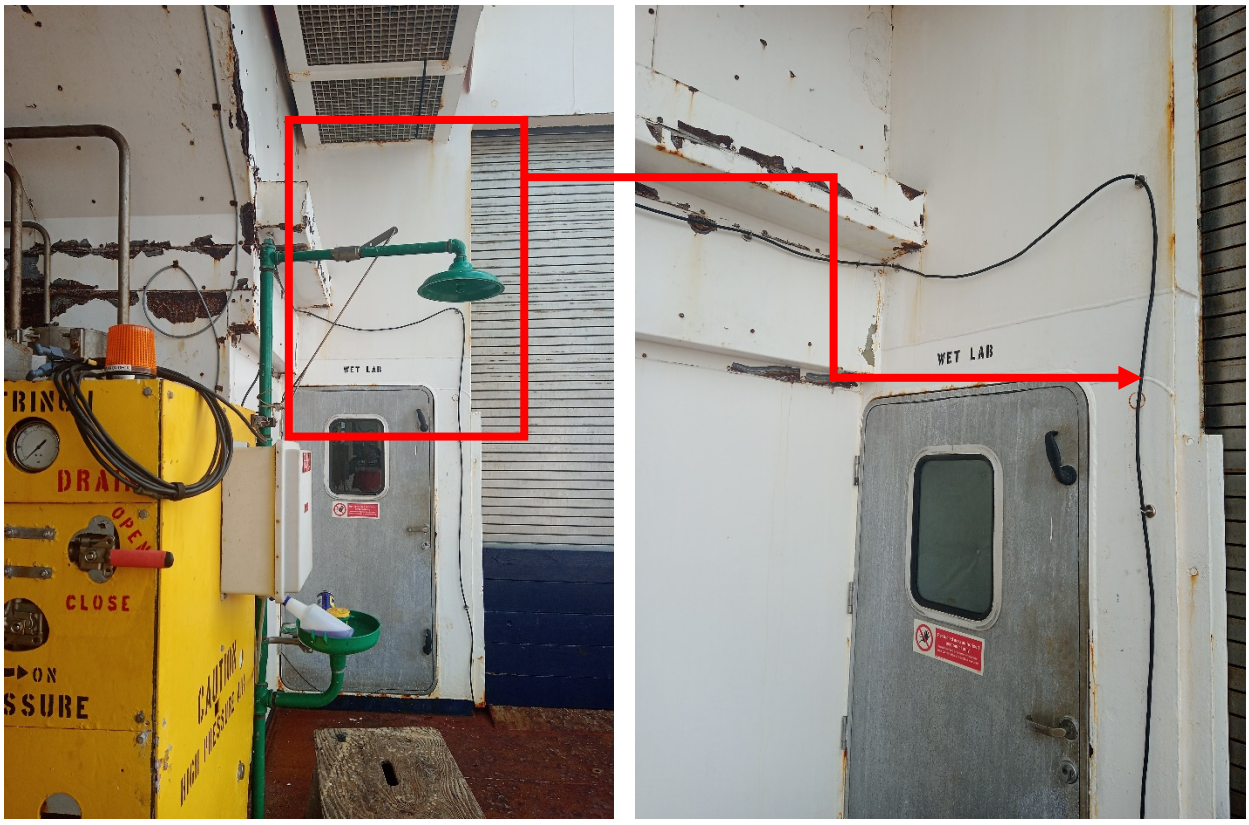


Figure 6. Left: Picture of the deck cable routed through the wet lab exit door to the closes point to the CTD rosette. Right: Closer version of the deck cable pinned on the wall into the wet lab.

In order to aid backing up of acquired LADCP data and to access the data from CTD and Shipboard ADCP (SADCP), which are needed for processing after every cast, the acquisition computer was connected to the ship's network drive. The path to the backup folder on the shared drive was subsequently added in the CRUISE_SETUP.expect to aid regular backing up after every data download or running the "lcheck" command. It was noted that the backup folder name whose directory path is to be defined should not contain spaces as this throws an error during backup. This connection to the ship's network was also necessary to aid correct synchronization of the ship's time server so LADCP, CTD and SADCP can agree in terms of acquisition time. Afterwards, the "rsync" command was tested to be sure it sends the right data regularly for onshore backup and data quality assessment. This is done from the

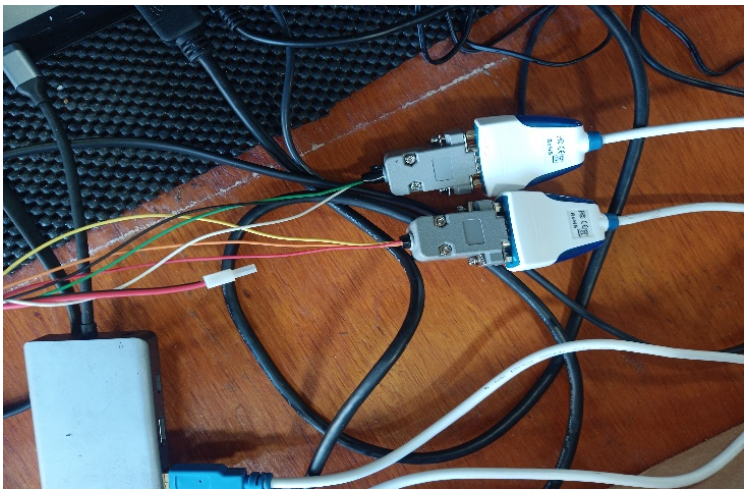


Figure 7. Connection of the NOAA/AOML deck cable to two RS232-to-USB adapters.

top working directory using the command: **rsync -avz –size-only ./Data <<receiving address>>:**. At the conclusion of this set-up, the watch LADCP technicians onboard agreed on the approaches for LADCP deployment, recovery, downloading, and logsheet completion. Pending arrival at the first test cast station, regular on-deck tests were done to confirm the whole set-up worked uninterrupted. An issue was suspected with the NOAA/AOML provided deck cable at this stage. Most times, the LADCP system fails to start, throwing the typical error "No deck power?". Every time, this issue was solved by swapping the UL-UL to UL-DL and DL-DL to DL-UL connections between the deck cable and the USB adapters, which means wrong connection, and running the "**ldir**" or "**lstart**" command again. The swapping was reversed to UL-UL and DL-DL and it seemed to solve the problem temporarily until the next cast. This approach was maintained for the new several casts. It was noted that with the wrong connections, the UL file contain DL data and vice versa. This was checked with "**listEns <data file name> | less**". This was because the two USB adapters with the identifiers "FTANPWMZ" and "FTANPW05" have been defined as the master (primary) and slave (secondary) in the CRUISE_SETUP.expect file. Hence, any swapping results in wrong naming of files as well. It is worthy of mention that these identifiers are used to wake up each ADCP separately during troubleshooting using the **TRDIterm /dev/cu.*** where * is either **usbserial-FTANPWMZ** or **usbserial-FTANPW05**.

Test and Station casts

Similar to the approach for on-deck test casts, the working directory was set by running **cd Desktop/A13.5/Acquire/** in the Terminal before every cast. The backup folder on the ship shared network drive is verified to be mounted using the command:

ls /Volumes/MGL2402/public/science/LADCP/raw_backup/

If not connected, the connection is done by using the Finder menu to connect to server. The deployment of the ADCP is done about 10 minutes prior to arriving at the station in order to rectify any issues before the cast. The ADCPs connections are verified to be correct in terms of color matching (yellow: master-downlooker and green: slave-uplooker). Afterwards, either the previous "TRDIterm" or "ldir" command is used to see if communication to both LADCPs works. Since the previous data would be deleted during deployment, the ADCPs memory is checked for previous cast record by running "lcheck" and logging the **zmax** and **zend** in the corresponding logsheet.

For the deployment, the "lstart" command is used after which the station and cast number in the from 001.1 is entered where "001" corresponds to the station number and "1" is the first cast in that station. If there is any reason to repeat a cast at the same station, the number takes the form "001.2" in that order. Afterwards, the system prompts to either delete or retain previous data by entering "y" -yes or "n"- no. With two ADCPs deployed, one sees the two systems started with different colours (red and blue) ended by a "done" message. This signifies the point at which one can disconnect the deck cable from the star cable on the CTD rosette and the four ends (two males from the star cable and two females on the deck cables) are secured with dummy plugs.

After recovery, the still-dummied end of the star cables on the CTD are rinsed with deionized water, then cleaned with tissue papers before connecting to the deck cable. Upon return to the computer station in the wet lab, the power switch is turned on to charge the battery after which the acquired data is download using the “ldownload” command. After successful download, the “lcheck” command is run to generate the soft link which is needed by MATLAB for the horizontal velocity processing as well as to log the “zmax” and “zend” in the logsheet.

The first test cast tagged 99901 was done on February 4, 2024. The deployment worked correctly but there was issue with data download during recovery due to the UL file having a bigger size than the DL file. This was resolved by downloading sequentially using the “ldownload_sequential” command instead of the usual parallel approach with “ldownload”. It was after discovered that the UL pinged twice as much as the DL during this cast. In a bid to diagnose this problem, for the second test cast, it was suggested to use the UL as the primary. This was done by making the following changes to CRUISE_SETUP.expect:

- Swapping the values of PRIMARY_COMMS and SECONDARY_COMMS
- Swapping the values of PRIMARY_FILE_LBL and SECONDARY_FILE_LBL

Data Preprocessing for Quality Control (QC)

Regular processing of the acquired data was done throughout the cruise to quickly resolve issues as they arose. For this, the vertical velocity as well as the horizontal velocity are processed separately using different tools. The two procedures for this are detailed in the two manuals below:

1. How to Process LADCP Data For Vertical Velocity (w) and Derive Parameterized Estimates for Turbulent Kinetic Energy Dissipation using LADCP w Software V2.2 by A.M. Thurnherr, December 6, 2022.
2. How To Process LADCP Data With the LDEO Software (Version IX.14) by A.M. Thurnherr, June 29, 2021.

Summarily, in order to process the vertical velocity, the following procedures are followed:

- **Create a 6Hz time series file from the 24hz CTD cnv file**: This file is used to derive the 6Hz file using the LADCP_w_CTD tool; for example, **LADCP_w_CTD -mi99901 rh19991.cnv**.
- **Process the DL file**: Prior to this step, one must create the folder /Data/ LADCP_w and the file **ProcessingParams** in the LADCP_w processing directory with the following content:
  $out_basename = sprintf('%05d',$ID); # use 5-digit station/cast numbers
  $CTD_file = sprintf('../Data/CTD/%05d.6Hz',$ID); # CTD 6Hz time series file
  $LADCP_file = sprintf('../Data/raw/%05d_%s.PD0',$ID,$RUN); # LADCP data file (UL or DL).
  After the creation of the needed file, the command “**LADCP_w_ocean 99901 DL**" where 99901 corresponds to the station/cast ID for the first test cast. This will create the LADCP_w/DL output directory (if it does not exist already) and write its output there.

The log file should be examined as well as the processing output figures which needs to be converted from .ps to .pdf using the command:
ps2pdf 99901_bin_residuals.ps; ps2pdf 99901_residual_profs.ps; ps2pdf 99901_time_lags.ps; ps2pdf 99901_wprof.ps

- **Process the UL file:** If everything worked for the DL processing, one can process the UL data with **"LADCP_w_ocean -h DL/99901.wprof 99901 UL"**. The **"-h DL/99901.wprof"** causes the software to look for the water depth in that file. (A warning will appear for non-full-depth casts.) The output from this processing run is the UL subdirectory.
- **Combine the DL/UL output to create a combination profile**: In order to combine the data from the two ADCPs, one uses LADCP_w_postproc with the DL and UL .wsamp files as input. In this case the command **"LADCP_w_postproc DL/99901.wsamp UL/99901.wsamp"** will create the combo profile and a diagnostic plot in the processing directory. (Note that one can also type "**LADCP_w_postproc ?L/99901.wsamp"**.)
- **Apply the VKE parameterization**: In order to apply the VKE parameterization, one runs **"LADCP_VKE ?L/99901.wprof"**, which will create an output profile and diagnostic plot.

For the horizontal velocity processing which is done using MATLAB, the processing is more straightforward once “set_cast_params.m” is run to include all the necessary information such as the location of the SADCP and CTD data. In order to make sure the most up-to-date version of the SADCP data is used for every cast processing, this line was added to the “set_cast_params.m” as well: **mkSADCP('../Data/SADCP','../Data/SADCP/SADCP.mat')**.

First one has to create 1Hz CTD data files from the 24 Hz CNV files from the ship’s shared network drive using the LADCP_w_CTD tool. For example, for profile 99901 one will have to run "LADCP_w_CTD -i 99901 -d 5 -s 1 rh19991.cnv". This command will generate the following three files: 99901.1Hz, 99901_sspd.ps, and 99901_w_CTD.ps. It is the file "99901.1Hz” that would be used for the horizontal velocity processing. Afterwards, the processing is done by simply running the command “**process_cast (99901)**” in MATLAB from the directory containing the “set_cast_params.m”.

The combined zonal and meridional velocities plotted for all stations from surface to the seabed are shown in Figure 8.

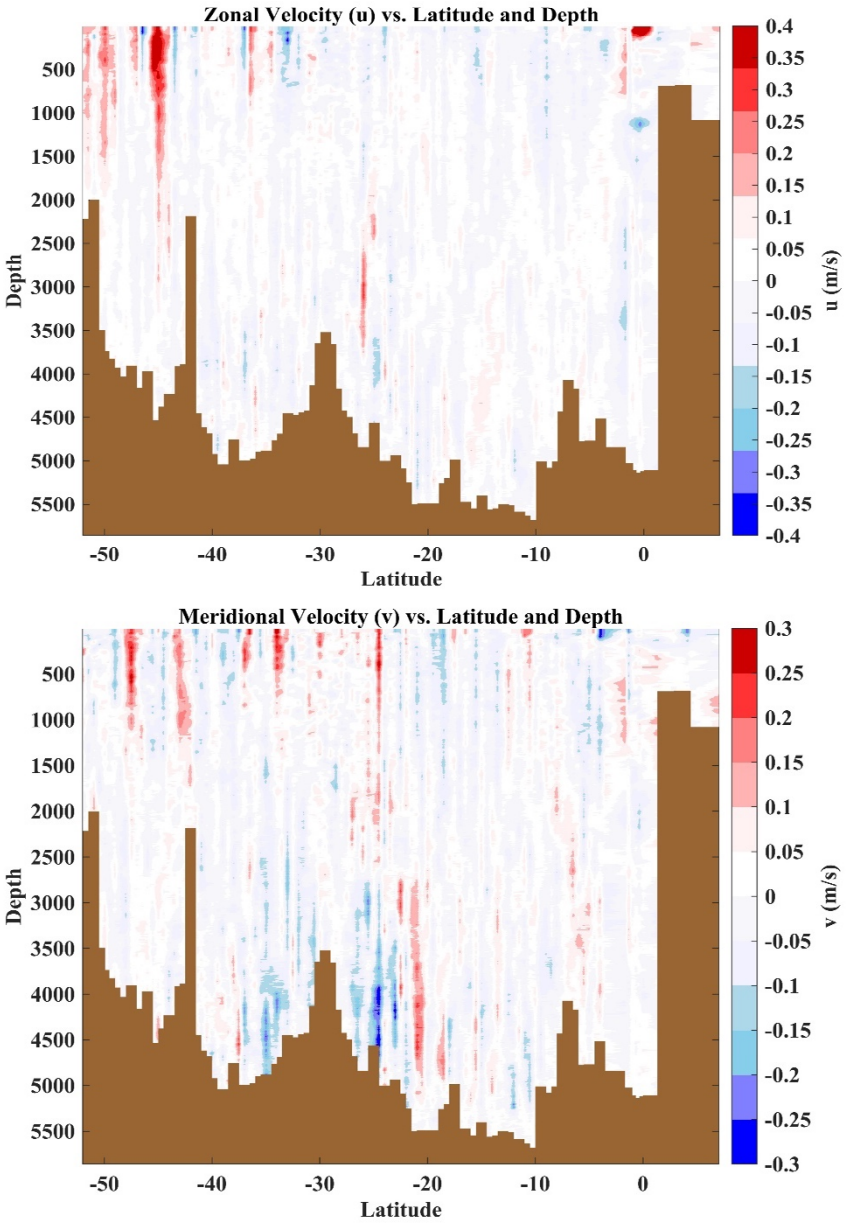


Figure 8. Upper-Lower panel: Zonal velocity (u-) and meridional velocity (v-) components of acquired LADCP data for A13.5 (Bad data showing velocity maxima beyond surface will be rectified at post- processing).

General Issues Encountered

1. After recovery from the first test cast (99901), the battery was discovered too low for data download. It was later found out that the UL pinged twice for every DL ping as well which cause large disparity in the data files. Hence ldownload_sequential was used.
2. Before the second test cast (99801), the UL was made the primary and vice versa in the CRUISE_SETUP.expect. There was issue starting the ADCPs until the deck cable - USB adapter connections were swapped and reversed. This issue persisted throughout the use of the NOAA/AOML deck cable.
3. Bad battery affected the casts in stations 00301-00501 until new battery was installed in 00601.
4. The DL used in 01201 was found dead upon recovery which prevented LADCP deployment in 01301. The DL was replaced with the spare ADCP and Star Cable was changed for the cast at 01401 but the DL also came back dead. Therefore, both 01201 and 01401 had only UL data. Same for 01501 where only UL was deployed because there were no extra ADCP after losing the two DLs. Details of the ADCPs used at different stations and their deployment position are given in Table 1.
5. It can be observed in Figure 8 that many of the profiles from the Angola basin have meridional velocities that are very likely bad. Essentially all the profiles with velocity maxima either in mid-water or in the lower half of the water column. These will be corrected during another thorough post-cruise quality control that will be carried out before archiving of cruise data.

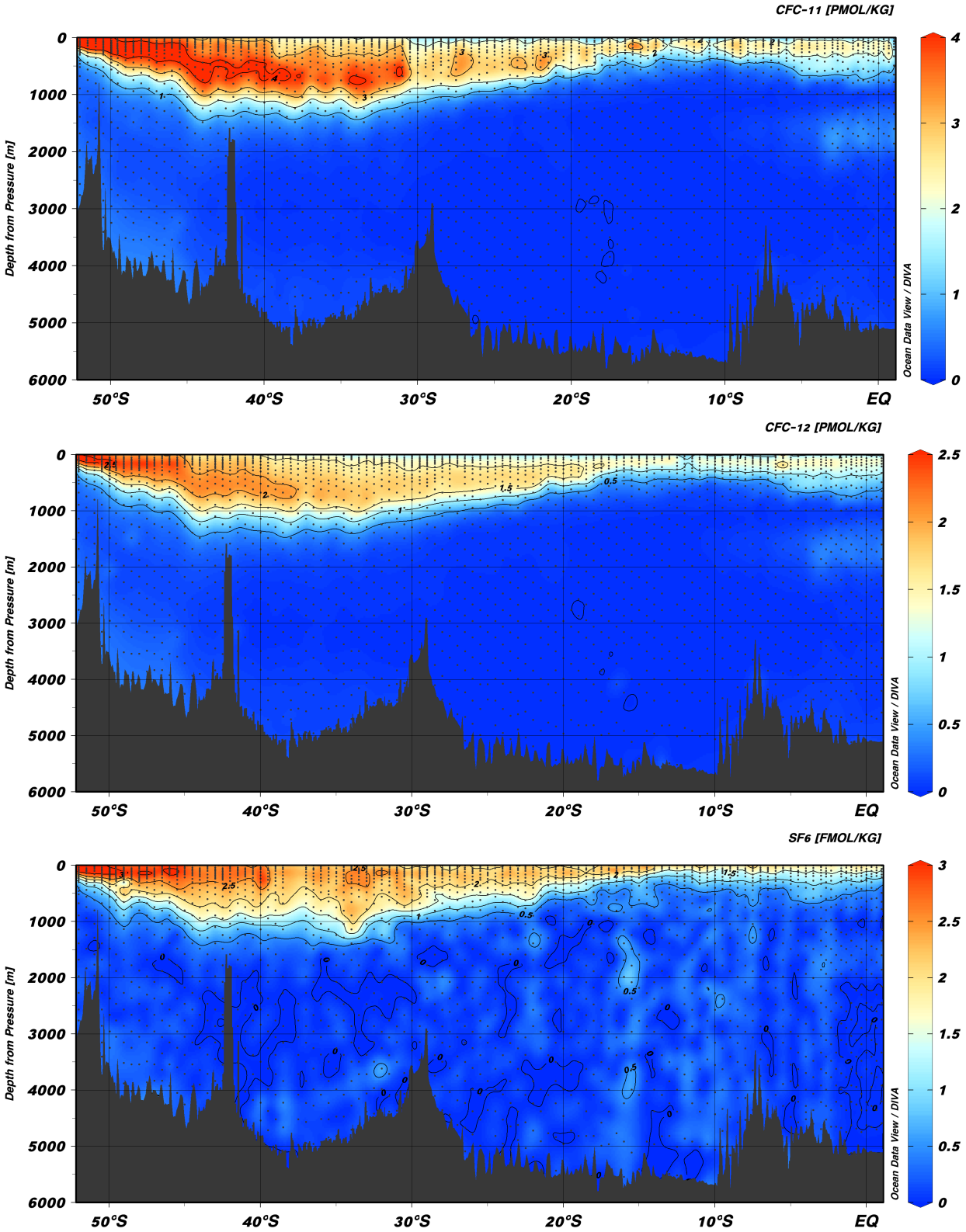
Table 1: ADCP Systems used during A13.5 cruise

Model	Serial Number	Stations used
Teledyne RDI WHM300	150	1- 12 (DL)
Teledyne RDI WHM300	12243	14 (DL)
Teledyne RDI WHM300	149	1-16 (UL), 17-113 (DL)

DL = downlooker UL = uplooker.

5.2 Chlorofluorocarbons (CFCs), sulfur hexafluoride (SF_6), and nitrous oxide (N_2O)

Principal Investigator: Zachary Erickson (NOAA/PMEL)
Analysts: David Cooper (CICOES), Anna Bruno (CICOES), and Isabel Schaal (WHOI)



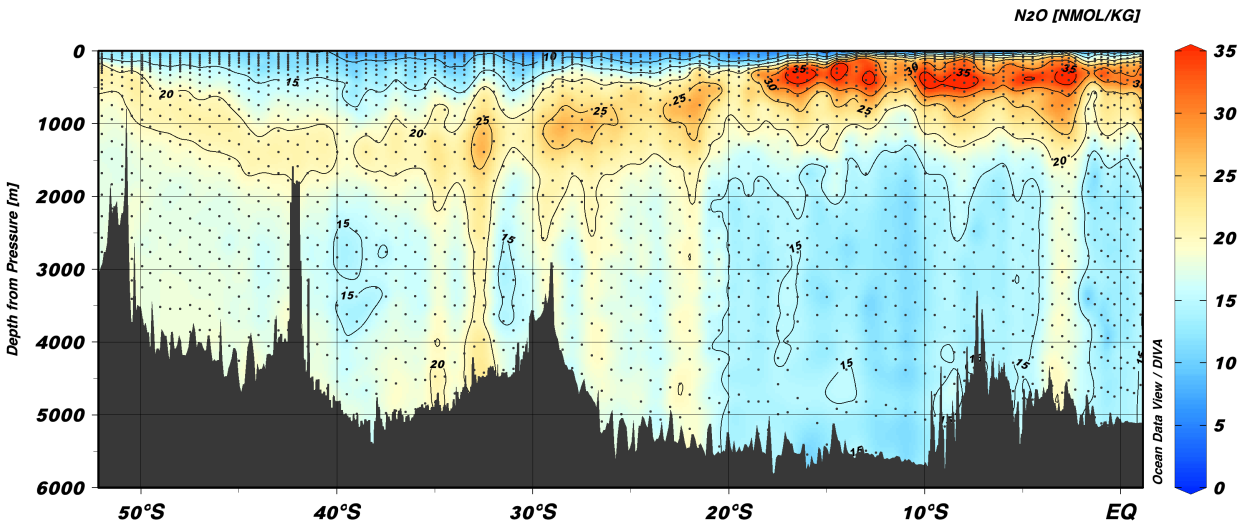


Figure 9. From top to bottom, CFC-11 (pmol/kg), CFC-12 (pmol/kg), SF6 (fmol/kg), and N2O (nmol/kg) from preliminary bottle file.

Samples for the chlorofluorocarbons (CFCs) CFF-11 and CFF-12, sulfur hexafluoride (SF_6), and nitrous oxide (N_2O) were collected and analyzed. Seawater samples were taken from all casts, with full profiles taken from most casts and strategically determined bottles sampled from the remaining casts. These measurements are complemented by periodic measurements of air samples.

Seawater samples were drawn from Niskin bottles. These samples were the first ones drawn, taking care to check the integrity of the sample and coordinate the sampling analysts to minimize any time between the initial opening of each bottle and the completion of sample drawing. To minimize contact with air, the CFC samples were drawn directly through the stopcocks of the Niskin bottles into 250 ml precision glass syringes. Syringes were rinsed and filled via three-way plastic stopcocks. The syringes were subsequently held at 0-5 degrees C until 30 minutes before being analyzed. At that time, the syringe was placed in a bath of water heated to approximately 30 degrees C.

For atmospheric sampling, a approximately 80 m length of 3/8" OD Dekaron tubing was run from the forward tower on the bow of the ship. A flow of air was drawn through this line into the analytical van using an air-cadet pump. The air was compressed in the pump, with the downstream pressure held at approximately 1.4 atm using a backpressure regulator. A tee allowed a flow (100 mL min^{-1}) of the compressed air to be directed to the gas sample valve of the CFC analytical system, while the bulk flow of the air (>7 L min^{-1}) was vented through the backpressure regulator. Analysis of bow air was performed at several locations along the cruise track. Approximately five measurements were made at each location to increase the precision. Atmospheric data were not submitted to the database, but were found to be in excellent agreement with current global databases.

Concentrations of CFC-11, CFC-12, SF_6 and N_2O in air samples, seawater samples, and gas standards were measured by shipboard electron capture gas chromatography (ECD-GC) using

techniques described by Bullister and Wisegarver (2008). This method has been modified with the addition of an extra ECD to accommodate N_2O analysis. For seawater analyses, water was transferred from a glass syringe to a glass sparging chamber (~200 mL). The dissolved gases in the seawater sample were extracted by passing a supply of CFC-free purge gas through the sparging chamber for a period of 6 minutes at 140 - 150 ml/min. Water vapor was removed from the purge gas by passage through a Nafion drier, backed up by a 18 cm long, 3/8" diameter glass tube packed with the desiccant magnesium perchlorate. This tube also contained a short length of Ascarite to remove carbon dioxide, a potential interferent in N_2O analysis. The sample gases were concentrated on a cold-trap consisting of a 1/16" OD stainless steel tube with a ~5 cm section packed tightly with Porapak Q (60-80 mesh), a 22 cm section packed with Carboxen 1004 and a 2.5 cm section packed with molecular sieve MS5A. A Neslab cryocool was used to cool the trap, to approximately -60°C. After 6 minutes of purging, the trap was isolated, and it was heated electrically to ~170°C. The sample gases held in the trap were then injected onto a precolumn (~60 cm of 1/8" O.D. stainless steel tubing packed with 80-100 mesh Porasil B, held at 80°C) for the initial separation of CFC-12 and CFC-11 from later eluting peaks. After the F12 had passed from the pre-column through the second pre-column (22 cm of 1/8" O.D. Stainless steel tubing packed with Molecular Sieve 5A, 100/120 mesh) and into the analytical column #1 (~170 cm of 1/8" OD stainless steel tubing packed with MS5A and held at 80°C) the outflow from the first precolumn was diverted to the second analytical column (~150 cm 1/8" OD stainless steel tubing packed with Carbograph 1AC, 80-100 mesh, held at 80°C). After F11 had passed through the first precolumn, the flow was diverted to a third analytical column (1/8" stainless steel tube with 30cm Molecular Sieve 5A, 60/80 mesh) for N_2O analysis. The first pre-column was then backflushed and vented. The first two analytical columns and precolumn 1 were held isothermal at 80°C in Shimadzu GC-8A gas chromatographs with electron capture detectors (250°C). The third analytical column and second pre-column were held at 160C in a Shimadzu GC-8A gas chromatogram, with the detector held at 250°C.

The analytical system was calibrated using a blended standard gas (seawater ratio, PMEL 35063), with available further reference to a second atmospheric ratio standard. Gas sample loops of known volume were thoroughly flushed with standard gas and injected into the system. The temperature and pressure were recorded so that the amount of gas injected could be calculated. The procedures used to transfer the standard gas to the trap, precolumn, main chromatographic column, and EC detector were similar to those used for analyzing water samples. Four sizes of gas sample loops were used. Multiple injections of these loop volumes could be made to allow the system to be calibrated over a relatively wide range of concentrations. Air samples and system blanks (injections of loops of CFC-free gas) were injected and analyzed in a similar manner. The typical analysis time for seawater, air, standard or blank samples was ~12 minutes. Concentrations of the CFCs in air, seawater samples, and gas standards are reported relative to the SIO98 calibration scale (e.g., Bullister and Tanhua, 2010). Concentrations in air and standard gas are reported in units of mole fraction CFC in dry gas, and are typically in the parts per trillion (ppt) range. Dissolved F11 and F12 concentrations are given in units of picomoles per kilogram seawater (pmol kg^{-1}), SF_6 concentrations are given in femtomoles per kilogram of seawater (fmol kg^{-1}). N_2O concentrations are given in nanomoles per kilogram of seawater (nmol kg^{-1}). The analytical system was calibrated by fitting their

chromatographic peak areas to multi-point calibration curves, generated by injecting multiple sample loops of gas from the working standard into the analytical instrument. The response of the detector remained relatively constant during the cruise. Single injections of a fixed volume of standard gas at one atmosphere were run much more frequently (at intervals of ~90 minutes) to monitor and normalize short-term changes in detector sensitivity.

The purging efficiency of the stripper was estimated by re-purging a water sample in the upper concentration range and measuring the residual signal. At a flow rate of 150 cc/min for 6 minutes, the purging efficiency for SF_6 and F12 was greater than 99% and the efficiency for F11 was about 99%. The purging efficiency for N_2O was about 92%, but subject to some degree of variability due to changes in flow rate and purging temperature. Correction is made for this variability, together with correction for any measured stripper blank value.

Results of 2670 seawater samples have been submitted from 113 stations. Duplicates were successfully analyzed from 109 stations to estimate precision and variability. These duplicates are divided between lower level CFC/SF_6 samples from deeper water (F11 or F12 < 0.5 pmol/kg) and higher level samples taken from the upper water column (F11 or F12 > 0.5 pmol/kg). N_2O samples were not divided in this manner due to its ubiquity in the water column. From the higher level samples, we calculate the average deviation to be 4.4%, 0.8%, 2.9% and 2.3% from the mean of the pairs for SF_6, F12, F11 and N2O measurements, respectively. Deviation from the mean of pairs from the lower concentration samples averaged less than 9% from the mean for F12, and less than 8% from the mean for F11. The exceedingly low levels of SF_6 present in deeper water, frequently at or below the limit of detection (approximately 0.02 fmol/kg) do not allow for similar calculation. Due to current software limitations and interference from the ship rolling in heavier seas, many of the extremely low SF_6 data were unresolved from baseline noise.

The precision of measurements during A13.5 was lower than typically observed due to various analytical or system issues during this cruise. The response to standard gas was a major factor, with significantly more variability than normal. This was most notable for N_2O standards. Continued post-cruise analysis of the data will require additional attention to station-to-station variability of the preliminary submitted values, an artifact of the standard variability. Data from station 79 to the end of the cruise are of higher quality than from preceding stations, after a new sample trap was packed and installed. The initial data from Stations 1-12 was also mostly free from analytical issues.

Atmospheric samples were run whenever time permitted, often during CTD sampling. Data are limited for this reason, but serve as a check for our system by comparing with the global database, and as a basis for calculating the surface saturation state in future analysis of our water data. In summary, our measured atmospheric data agree reasonably well with the expected global data set (current data in parentheses), with mean concentrations of 335 ppb N_2O (337 ppt), 216 ppt CFC11 (216 ppt), 502 ppt CFC12 (484 ppt) and 9.6 ppt SF_6 (11.7 ppt).

A small number of water samples had anomalous SF_6 or CFC concentrations relative to adjacent samples. These samples occurred sporadically during the cruise, were not clearly associated

with other features in the water column (e.g., anomalous dissolved oxygen, salinity, or temperature features), and are omitted from the reported data.

References

Bullister, J.L. and T. Tanhua. 2010. Sampling and Measurement of Chlorofluorocarbons and Sulfur Hexafluoride in Seawater. In: The GO-SHIP Repeat Hydrography Manual: A Collection of Expert Reports and Guidelines. IOCCP Report No. 14, ICPO Publication series No. 134, Version 1.

Bullister, J.L. and D.P. Wisegarver. 2008. The shipboard analysis of trace levels of sulfur hexafluoride, chlorofluorocarbon-11 and chlorofluorocarbon-12 in seawater. Deep-Sea Res. I, v. 55, pp. 1063-1074.

5.3 Dissolved Oxygen

Principal Investigator: Chris Langdon (RSMAS)
Analysts: Rachel Cohn (RSMAS) and Jennifer Aicher (RSMAS)

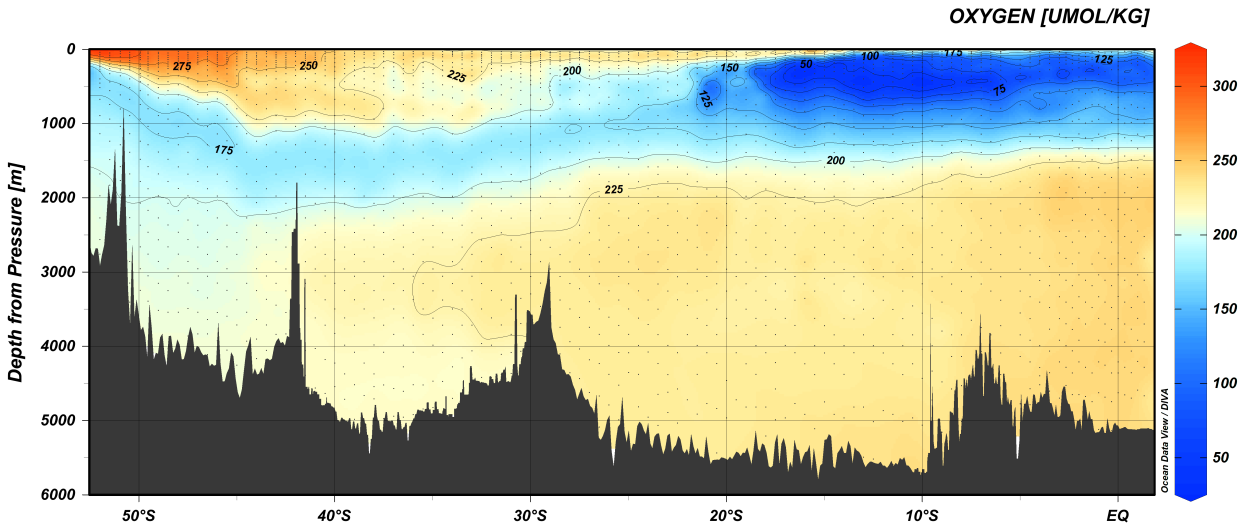


Figure 10. Dissolved oxygen (µmol/kg) from preliminary bottle file.

Equipment and Techniques

Dissolved oxygen analyses were performed with an automated titrator using amperometric end-point detection [Langdon, 2012]. Sample titration, data logging, and graphical display were performed with a Windows PC running a LabView program written by Ulises Rivero at NOAA AOML. Lab temperature was maintained at 20.1-27.5°C. The temperature-corrected molarity of the thiosulfate titrant was determined as given by Dickson [1994]. Thiosulfate was dispensed by a 2 ml Kloehn syringe driven with a stepper motor controlled by the titrator. The whole-bottle titration technique of Carpenter [1965], with modifications by Culberson et al. [1991], was used. Four to five replicate 10 ml iodate standards were run every 4-6 days (Average SD = 0.54uL)

when the thiosulfate titrant was replaced. The reagent blank calculated as the difference between V1 and V2, the volumes of thiosulfate required to titrate 1-ml aliquots of the iodate standard. It was determined during mobilization and setup in Norfolk, VA. All reagents and standards were made prior to the cruise at UM RSMAS by the PI, with the exception of the thiosulfate titrant, which was made fresh at sea every 4-6 days. The iodate standard was tested against an iodate standard of the same concentration produced by OSIL.

Sampling and Data Processing

Dissolved oxygen samples were drawn from Niskin bottles into calibrated 125-150 ml iodine titration flasks using silicon tubing to avoid contamination of DOC samples. The flasks were sample rinsed and then samples were drawn by counting while the flask was allowed to fill at full flow from the Niskin. This count was then tripled and repeated thereby allowing the flask to be overflowed by three flask volumes. At this point the silicone tubing was pinched to reduce the flow to a trickle. This was continued until a stable draw temperature was obtained on the Digi-sense Thermistor Meter. Draw temperatures were used to calculate µmol/kg concentrations and provide a diagnostic check of Niskin bottle integrity. 1 ml of MnCl2 and 1 ml of NaOH/NaI were added immediately after drawing the sample using SOCOREX Calibrex 520 dispensers. The flasks were then stoppered and shaken well. Deionized water was added to the neck of each flask to create a water seal. For stations deeper than 2000m, 24 samples and 2 duplicate samples were drawn from the rosette (26 flasks per station). For stations shallower than 2000m, not all Niskins were fired and the number of samples drawn were 16 plus two duplicates at the minimum (18 flasks). The samples were stored in the lab in plastic totes at room temperature for 1-2 hours before analysis. The data were incorporated into the cruise database shortly after analysis. Thiosulfate normality was calculated for each standardization and corrected to the laboratory temperature. This temperature ranged between 21.1 and 27.5 °C, getting progressively colder as the ship traveled south of the equator. Reagent blanks were run during mobilization in Norfolk, VA (1.75±0.8 uL). The total number of samples drawn for the cruise was 2,899.

Volumetric Calibration

The dispenser used for the iodate standard solution (SOCOREX Calibrex 520) and the burette were calibrated gravimetrically just before the cruise. Oxygen flask volumes were determined gravimetrically with degassed deionized water at NOAA AOML and UM RSMAES. The correction for buoyancy was applied. Flask volumes were corrected to the draw temperature.

Duplicate Samples

For each station, two duplicate samples were drawn from different Niskins on each cast. The Niskins selected for duplicates were alternated each station in order to take duplicate samples from the full range of depths and Niskin bottles over the course of the cruise. A total of 226 pairs of duplicates were drawn.

There were eight circumstances in which only value was reported instead of the average of the duplicates. These were due to situations when a bad titration produced an endpoint of 0 (station 30, 34, 77), a bubble from the tubing deposited into the sample during titration (station

57), sampling error (station 72, 77), poorly calibrated bottle volume (station 93), and an overshot endpoint (station 100).

The average the standard deviations between duplicates is 0.37 umol/kg; the median standard deviation is 0.22 umol/kg.

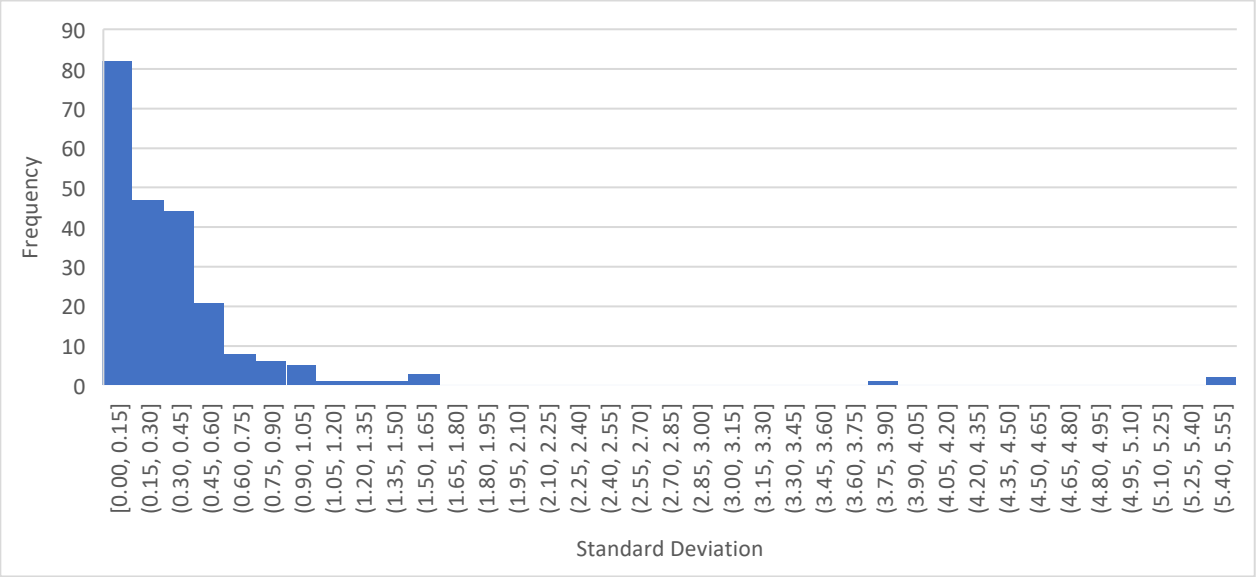


Figure 11. Standard deviation of duplicate oxygen analyses performed during A13.5 2023. Average is 0.37 umol/kg, median is 0.22 umol/kg, IQR is 0.44- 0.09 = 0.35 umol/kg, and n = 222.

Quality Coding

Preliminary quality code flags have been assigned to the oxygen data following the WOCE flag protocol. A summary of the quality coding can be found in Table 1. Samples were flagged as acceptable (2) if there was no sampling error and no issues during the preparation. Samples were flagged as questionable (3) if there was suspected error during sampling or titration (i.e. few titration points and a bad plot). Samples were flagged as known bad (4) if there was sampling error (i.e. a bubble in the sample flask) or if titration issues resulted in a zero endpoint to be calculated (see problems section). Samples were flagged as not reported (5) if the titration endpoint was overshot and no endpoint was calculated (see problems section). Duplicate samples were averaged and flagged as such (6). Samples were flagged as a missing value (9) if they were not taken (i.e. Niskin misfires and leaks).

Discrete oxygen QC flag statistics for A13.5 2024.

QC Flag	Number of Samples	Description
2	2303	Acceptable
3	101	Questionable
4	30	Known bad

5	21	Not reported
6	218	Median of duplicates
9	8	Missing value – sample not taken

Problems

NaI/NaOH dispenser

The NaI/NaOH dispenser got stuck during sampling at station 20. In order to not hold up sampling, a 1000uL pipette (Eppendorf Research s/n 1331007) was used to dispense NaI/NaOH for station 20. The entire station was flagged as questionable (3) under further review can be conducted. After the station, the dispenser was taken apart and thoroughly rinsed with deionized water. In order to prevent the same problem from occurring in the future, the dispenser was rinsed with deionized water every few days.

Burette Bubbles/O-ring

Starting around station 25, bubbles started to form under the base of the burette syringe and then slowly creep up into the burette. The bubbles were noted during analysis and cleared from the burette and tubing as necessary. Over the next few stations, these bubbles began to increase in size, causing additional concern. In consultation with the PI, it was determined that there may be an issue with the O-ring seal on the burette. The burette was disassembled, the O-ring inspected and greased with silicone grease, and reassembled on 02/24/2024, prior to station 46. This O-ring maintenance resolved the bubble issue. There is a possibility that disassembling and reassembling the burette could change its calibration, but the factor of change is estimated to be negligible. Once the equipment has returned to land, a calibration will be performed on the burette for quality control.

Overshot Endpoints

There were 22 total samples that exceeded the number of data points during the titration (n>30), and no endpoint was calculated. One of these samples was part of a duplicate pair (station 100, Niskin 4); in this circumstance the one acceptable sample was reported instead of the duplicate average. The other 21 samples were flagged as not reported (5) since no endpoint could be calculated by the software. For the majority of these samples, the number of data points was exceeded very close to the end of the titration. There is the potential to determine an endpoint via linear regression and calculate the oxygen concentration during the next level of QC at the PI's discretion.

When a sample exceeded the number of data points during titration, the slope was increased by 0.5 for the next sample in order to reduce the number of data points, if the next sample was predicted to be a similar oxygen concentration to the previous one.

Too few data points

There were 22 total samples where there were too few data points in the titration, resulting in the software to calculate an endpoint of -0.00 and an oxygen concentration of around -0.9

umol/kg. Since there was an oxygen concentration calculated, albeit obviously incorrect, these calculated concentrations were reported and flagged as known bad (4). Three of these samples were part of a duplicate pair (station 30, Niskin 23; station 34, Niskin 7; station 77, Niskin 10). In this circumstance the one acceptable sample of the pair was reported instead of the duplicate average.

For 9 samples, this was caused by a large spike in the detector current, resulting in an over addition of thiosulfate, essentially ending the titration. This issue was encountered during mobilization in Norfolk, VA as well, and as a result, the titrator was plugged into a UPS provided by the R/V Langseth for clean power during the cruise. Although the titrator was connected to the UPS for the entirety of the cruise, these few current spikes did occur. The exact cause has not been determined and is something to investigate and remedy before the next cruise. For the other 13 samples, this was caused by an over addition of thiosulfate based on the slope setting. This occurred primarily when m = 4.0 or greater. This increased slope was due to avoiding overshooting the endpoint (see above section), but in turn could cause too few data points. To remedy this, PI Chris Langdon wrote a firmware update to limit the amount of thiosulfate added when the detector current is greater than 250 µA. This allowed for an increased slope to not overshoot the endpoint, but reduced the chance of an over addition of thiosulfate. This firmware update was implemented at station 79 and solved the issue. All instances of too few data points after station 79 were due to a large current spike.

Broken flasks

Flask 2: broken during test cast; replaced from spare calibrated flasks

Flask 12: bottle neck found broken upon arrival; replaced from spare calibrated flasks

Flask 7: dropped during sampling; replaced with flask 78

Flask 24: crack in bottle neck; replaced with flask 34

Flask 34: broken after opening at station 106

Flask issues

Flask 1: not stoppering well; replaced with flask 77

Flask 6: not stoppering/sealing well; replaced with flask 36

Flask 40: flask volume questionable; recommended for recalibration

5.4 fCO2

Principal Investigator: Rik Wanninkhof (AOML)
Analysts: N. Patrick Mears (AOML/CIMAS), Yifan Li (U. Del)

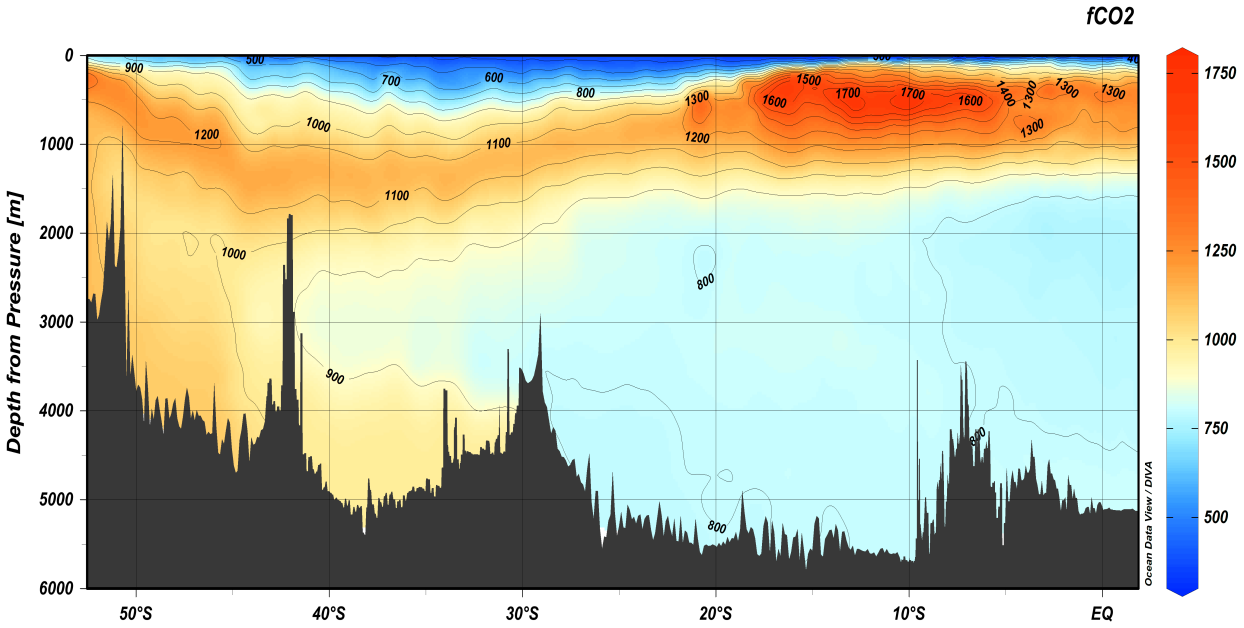


Figure 12. fCO_2 (µatm) from preliminary bottle file.

Sampling:

Samples were drawn from 11-L Niskin bottles into 500 ml glass bottles using nylon tubing with a Silicone adapter that fit over the drain cock. Bottles were first rinsed three times with ~25 ml of water. They were then filled from the bottom, overflowing a bottle volume while taking care not to entrain any bubbles. About 5 ml of water was withdrawn to allow for expansion of the water as it warms and to provide space for the stopper and tubing of the analytical system. Saturated mercuric chloride solution (0.24 ml) was added as a preservative. The sample bottles were sealed with glass stoppers lightly covered with grease and were stored at room temperature for a maximum of seven hours prior to being run.

The analyses for pCO_2 were done with discrete samples at 20°C. A primary water bath was kept within 0.02°C of the analytical temperature; a secondary bath was kept within 0.3°C of the analytical temperature. Most of the samples were analyzed in batches of twelve bottles, which took approximately 3.5 hours including the six standard gases. When twelve bottles were moved into the primary water bath for analyses, the next twelve bottles were moved into the secondary water bath. No sample bottle spent less than two hours in the secondary water bath prior to being moved to the analytical water bath. Duplicate samples from the same Niskin were drawn to check the precision of the sampling and analysis.

Two thousand six hundred and ninety-seven unique samples were drawn from 113 CTD casts covering 99.6% of all unique depths. There were 146 sets of duplicates drawn at numerous depths, 124 were determined to be good and used in statistics. The average relative standard error was 0.06%, while the relative standard deviation was 0.08%. The average difference between duplicates was 0.95 uatm.

Five CRMs from Batch 210 were measured over the course of the cruise to assess the accuracy of the disc pCO2 system. The fCO2 of the CRMs were calculated using CO2sys and the certified values of Total Carbon, Total Alkalinity and the salinity for the batch. The average difference between the measured fCO2 value and the calculated fCO2 value (578.8 uatm) was 0.34 uatm (n=5).

There was very noticeable outgassing in samples during the first 10 stations through the Equatorial region as a result of the poor temperature control in the lab space where the discrete pCO2 equipment was located. The lab stayed only ~0.5C cooler than outside air temperature. We began utilizing the air-conditioned van located on the starboard side of the ship to store samples while they were waiting to be analyzed until the inside lab temperature reached ~20C.

On station 9 and 10 sections of data were not recorded in the average file because it was left open. These samples were recalculated using the raw data files and are flagged 3 until reviewed.

During the analysis of station 24 one of the standards did not run correctly resulting in data being flagged 3 until it is reviewed.

Underway Sampling

Underway samples were collected every 4 hours from the underway seawater line located in the wet lab that is connected to the same seawater line as the underway pCO2 system located in the same space. The seawater is pumped from a bow seawater inlet located approximately 5 meters below the waterline through a sea chest where instruments measure and record temperature and salinity.

A total of 18 underway stations were collected with duplicate samples collected every 4 stations during the transit from the end of CTD sampling at [-51.62º, 0.68º] to [-42.74 º, 10.13 º] in transit to Cape Town, South Africa.

Analyzer Description:

The principles of the discrete pCO2 system are described in Wanninkhof and Thoning (1993) and Chipman et al. (1993). The major difference in the current system is the method of equilibrating the sample water with the constantly circulating gas phase. This system uses miniature membrane contactors (Micromodules from Memrana, Inc.), which contain bundles of hydrophobic micro-porous tubes in polycarbonate shells (2.5 x 2.5 x 0.5 cm). The sample water

is pumped over the outside of the tubing bundles in two contactors in series at approximately 25 ml/min and to a drain. The gas is recirculated in a vented loop, which includes the tubing bundles and a non-dispersive infrared analyzer (LI-COR™ model 840) at approximately 27 ml/min.

The flow rates of the water and gas are chosen with consideration of competing concerns. Faster water and gas flows yield faster equilibration. A slower water flow would allow collection of smaller sample volume; plus, a slower gas flow would minimize the pressure increase in the contactor. Additionally, the flow rates are chosen so that the two fluids generate equal pressures at the micro-pores in the tubes to avoid leakage into or out of the tubes. A significant advantage of this instrumental design is the complete immersion of the miniature contactors in the constant temperature bath. Also in the water bath are coils of stainless steel tubing before the contactors that ensure the water and gas enter the contactors at the known equilibration temperature.

The instrumental system employs a large, insulated cooler (Igloo Inc.) that accommodates twelve sample bottles, the miniature contactors, a water circulation pump, a copper coil connected to a refrigerated circulating water bath, an immersion heater, a 12-position sample distribution valve, two thermistors, and two miniature pumps. The immersion heater works in opposition to the cooler water passing through the copper coil. One thermistor is immersed in the water bath, while the second thermistor is in a sample flow cell after the second contactor. The difference between the two thermistor readings was consistently less than 0.02°C during sample analyses. In a separate enclosure are the 8-port gas distribution valve, the infrared analyzer, a barometer, and other electronic components. The gas distribution valve is connected to the gas pump and to six standard gas cylinders.

To ensure analytical accuracy, a set of six gas standards (ranging from 288 to 1534 ppm) was run through the analyzer before and after every sample batch. The standards were obtained from Scott-Marin and referenced against primary standards purchased from C.D. Keeling in 1991, which are on the WMO-78 scale.

A custom program developed using LabView™ controls the system and graphically displays the CO2 concentration as well as the temperatures, pressures and gas flow during the 10-minute equilibration. The CO2 in the gas phase changes greatly within the first minute of a new sample and then goes through nearly two more oscillations. The oscillations dampen quickly as the concentration asymptotically approaches equilibrium. The flows are stopped, and the program records an average of ten readings from the infrared analyzer along with other sensor readings. The data files from the discrete pCO2 program are reformatted so that a Matlab program designed for processing data from the continuous pCO2 systems can be used to calculate the fugacity of the discrete samples at 20°C. The details of the data reduction are described in Pierrot et al. (2009).

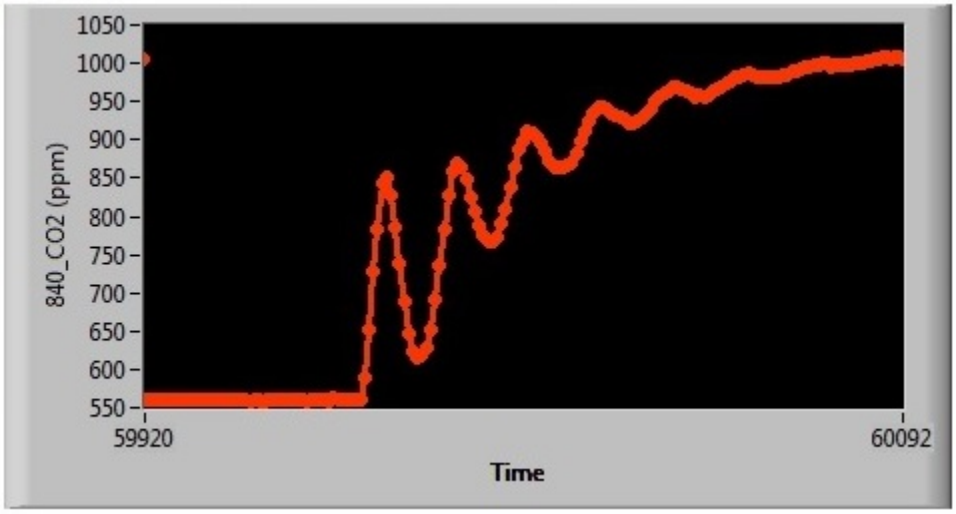


Figure 13. CO2 oscillations during start of first sample in set of twelve.

The instrumental system was originally designed and built by Tim Newberger and was supported by C. Sweeney and T. Takahashi. Their skill and generosity have been essential to the successful use and modification of this instrumental system.

Standard Gas Cylinders:

Cylinder#	ppm CO_2
JB03282	288.55
JB03268	384.30
CB11243	591.87
CA05980	792.51
CA05984	1036.95
CA05940	1533.7

References

Chipman, D.W., J. Marra, and T. Takahashi, 1993: Primary production at 47°N and 20°W in the North Atlantic Ocean: A comparison between the 14C incubation method and mixed layer carbon budget observations. Deep-Sea Res., II, v. 40, pp. 151-169.

Wanninkhof, R., and K. Thoning, 1993: Measurement of fugacity of CO_2 in surface water using continuous and discrete sampling methods. Mar. Chem., v. 44, no. 2-4, pp. 189-205

Pierrot, D., C. Neill, K. Sullivan, R. Castle, R.Wanninkhof, H. Luger, T. Johannessen, A. Olsen, R.A. Feely, C.E. Cosca, 2009: Recommendations for autonomous underway pCO2 measuring systems and data-reduction routines . Deep-Sea Res., II, v. 56, pp. 512-522.

5.5 pH

PI: Chris Langdon (RSMAS)
Analysts: Clara Haughey-Gramazio (RSMAS) and EvaLynn Jundt (TAMU)

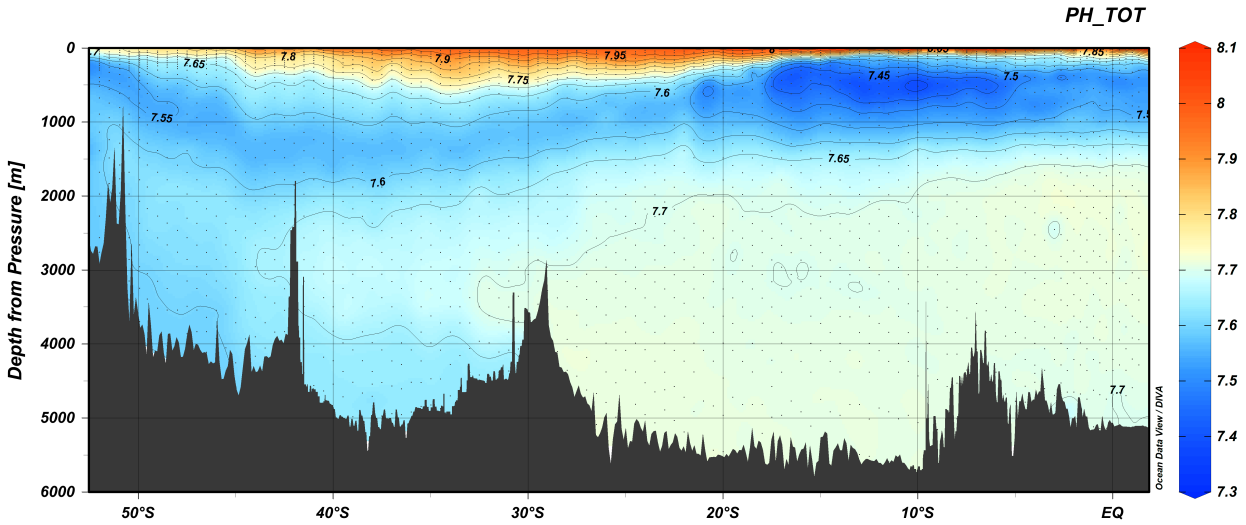


Figure 14. pH from preliminary bottle file.

Sampling

Samples were collected in 250 mL narrow mouth borosilicate glass bottles using silicone tubing. Bottles were rinsed with sample and overflowed by the bottle's volume. Samples were sealed using a glass stopper with no headspace left. A plastic over-cap was used to secure the glass stopper. Samples were warmed to 25.0˚C before the measurement. Two duplicates were collected from most stations. The same bottle of sample was used for total alkalinity measurement after pH was measured.

Analysis

pH (total scale) was measured spectrophotometrically using a semi-automatic analyzer with purified meta-cresol purple (mCP). The semi-automatic analyzer (similar to the instrument reported by Carter et al., 2013) consists of a HP8453 spectrophotometer, a Kloehn 6-port syringe pump with 10 ml burette, a Starna 10 cm flow cell (type 585.3) with water jacket, and a Hart Scientific FLUKE 1523 reference thermometer. A Thermo Scientific Haake SC150 water bath maintained the spectrophotometric cell temperature at 25.0ºC. The absorbance of light (A) was measured at four different wavelengths (434 nm, 578 nm, 730 nm, and 488 nm). The absorbance ratio (R-ratio) of A_{578} and A_{434} was used for pH calculation (together with temperature and salinity), with A_{730} as a reference to correct any disturbances ($R = (A_{578}-A_{730})/(A_{434}-A_{730})$). Details of the calculation can be found in Liu et al. (2011). The absorbance at 488 nm (A_{488}) was used to ensure that a constant amount of dye was added to the sample. Salinity data were obtained from the conductivity and temperature sensors on the CTD.

Perturbation from mCP addition was corrected using the 'double dye' method (Clayton and Byrne, 1993; Dickson et. al, 2007).

Reagents

Purified mCP indicator was obtained from Dr. Robert Byrne's lab at the University of South Florida, and prepared as 2 mM solution with ion strength of 0.7 M (ion strength adjusted using NaCl).

Data Processing

pH was calculated using R-ratio, temperature, and salinity with equations from Liu et al. (2011). mCP perturbation correction was performed using the 'double dye' method (Clayton and Byrne, 1993; Dickson et. al, 2007). Briefly, for each station we chose 1-2 samples with different pH and measured R-ratio twice (with the dye addition doubled at the 2nd time) to get the difference in R-ratio (ΔR). And then the mCP perturbation can be corrected with a linear regression between R-ratio and ΔR.

Overall, 2658 pH samples were analyzed. Repeat measurements on duplicate samples showed a difference between pH duplicates (sample 2 – sample 1) of -0.0003 ± 0.0042 (*n* = 196).

References

Carter, B. R., Radich, J. A., Doyle, H. L., & Dickson, A. G. (2013). An automated system for spectrophotometric seawater pH measurements. Limnology and Oceanography: Methods, 11(1), 16-27.

Clayton, T.D. and Byrne, R.H., (1993). Spectrophotometric seawater pH measurements: total hydrogen ion concentration scale calibration of m-cresol purple and at-sea results. Deep Sea Research (Part I, Oceanographic Research Papers), 40(10): 2115-2129.

Dickson, A.G.; Sabine, C.L. and Christian, J.R. (eds) (2007) Guide to best practices for ocean CO2 measurement. Sidney, British Columbia, North Pacific Marine Science Organization, 191pp. (PICES Special Publication 3; IOCCP Report 8). DOI: https://doi.org/10.25607/OBP-1342

Liu, X., Patsavas, M. C., & Byrne, R. H. (2011). Purification and characterization of meta-cresol purple for spectrophotometric seawater pH measurements. Environmental science & technology, 45(11), 4862-4868.

5.6 Total Alkalinity (TA)

Principal Investigators: Chris Langdon (RSMAS)
Analyst: Bo Yang (RSMAS)

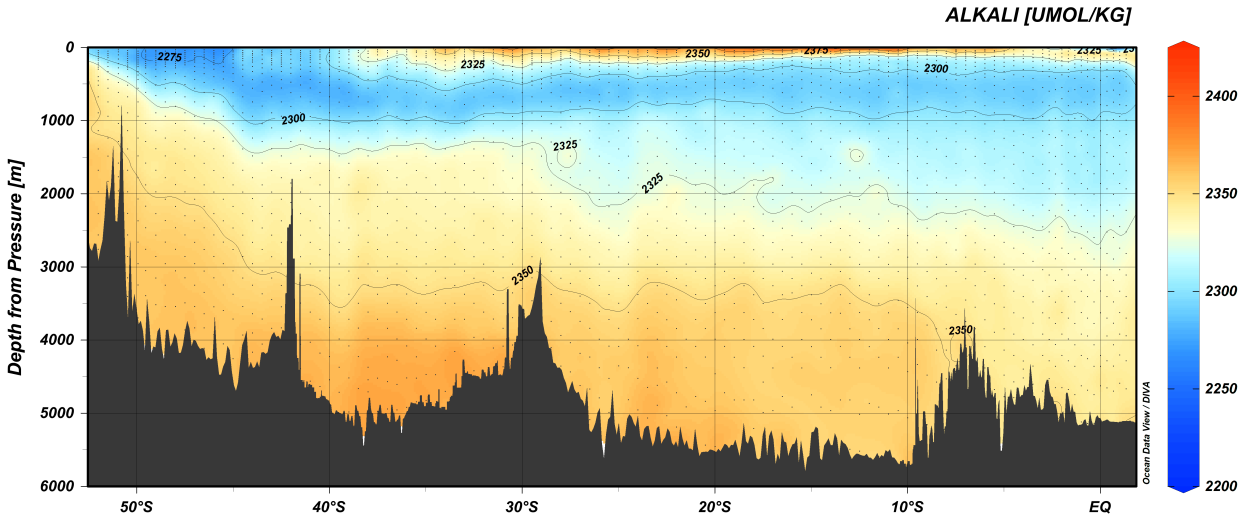


Figure 15. Total alkalinity (TA; µmol/kg) from preliminary bottle file.

Sampling

We used the leftover sampled seawater from pH measurements for TA analysis. A custom-made sample dispenser with a glass pipette was used to volumetrically measure out an accurate amount (95.976 ml at 25°C) of sample for titration.

Analysis

An automatic open-cell titration system built by Dr. Andrew Dickson's lab was used for the TA measurements, which consists of a Metrohm 876 Dosimat titrator (controlled by a PC via a NI USB-6501 digital I/O), a Keysight DAQ970A data acquisition system, a pH Metrohm glass electrode (6.0262.100), a Sierra SmartTrak 50 mass flow controller, a Tetra air pump, and a custom-made amplifier (powered by two 9v batteries). A custom-made LabView software was used for system control and TA calculation.

During the titration, an initial aliquot of approximately 2.5-2.6 mL of standardized hydrochloric acid solution (~0.1M HCl in ~0.6M NaCl solution) is first delivered and the sample is stirred and purged (with air) for 5 minutes at a rate of 200 scc/m to remove any CO_2 generated during this process. After that, a series of aliquots of 0.05 ml HCl solution were added and the pH was measured after each addition by the pH glass electrode. The total alkalinity is computed from the titrant volume and pH values using a non-linear least-squares approach over the pH range of 3.5 to 3.0 (Dickson 2007). Salinity data from CTD was used for TA calculation.

Reagents

Hydrochloric acid (~ 0.1 M) prepared in ~0.6 M NaCl solution was used for titration.

Standardization

HCl solution was standardized in the lab before the cruise using the certified reference material (CRM) Batch 197 from Dr. Andrew Dickson's lab at UCSD. During the cruise, the acid concentration was checked several times by measuring CRM Batch 210 (leftover from DIC measurements).

Data Processing

A custom-made LabView software was used for system control and TA calculation, which automatically calculated the TA. Briefly, TA is computed with the sample's mass (measured volumetrically), salinity, the mass of HCl added, the HCl concentration (standardized with CRM), and the cell temperature. A non-linear least square fitting is used to get the end point of the titration and the TA of the sample (see the details in section 7.3 of SOP 3b from Dickson et al., 2007).

Overall, 2672 TA samples were analyzed. Repeat measurements on duplicate samples showed a difference between TA duplicates (sample 2 – sample 1) of -0.13 ± 1.68 µmol kg^{-1} (*n* = 122).

An internal consistency check was performed using measured TA, pH, and preliminary dissolved inorganic carbon (DIC) data (only good data points with quality flag 2 or 6 were used, *n* = 2645). The mean difference between measured TA and TA calculated from the pH-DIC pair is -1.33 ± 3.88 µmol kg^{-1} (Figure 16).

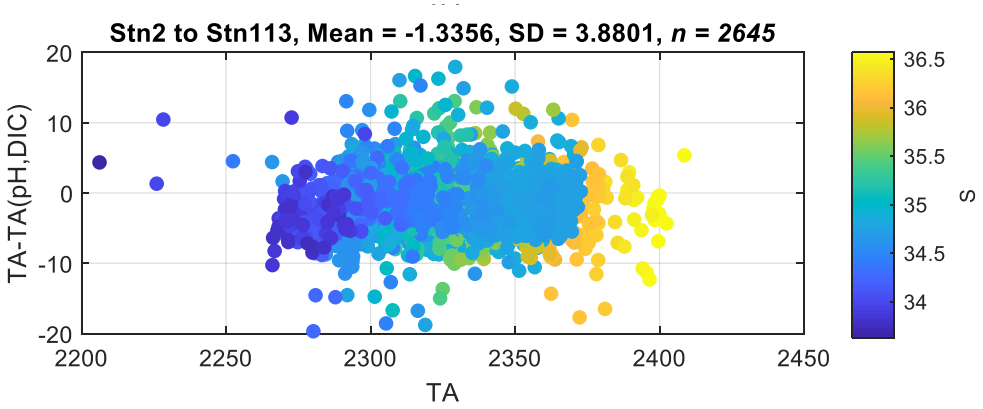


Figure 16. Difference between measured TA and TA calculated from pH-DIC pair, as a function of measured TA (with salinity in PSU in color).

Reference

Dickson, A.G.; Sabine, C.L. and Christian, J.R. (eds) (2007) Guide to best practices for ocean CO2 measurement. Sidney, British Columbia, North Pacific Marine Science Organization, 191pp. (PICES Special Publication 3; IOCCP Report 8). DOI: https://doi.org/10.25607/OBP-1342

5.7 Dissolved Inorganic Carbon (DIC)

Principal Investigators: Rik Wanninkhof (AOML), Richard Feely (PMEL)
Technicians: Charles Featherstone (AOML) and Evan Josza (CICOES)

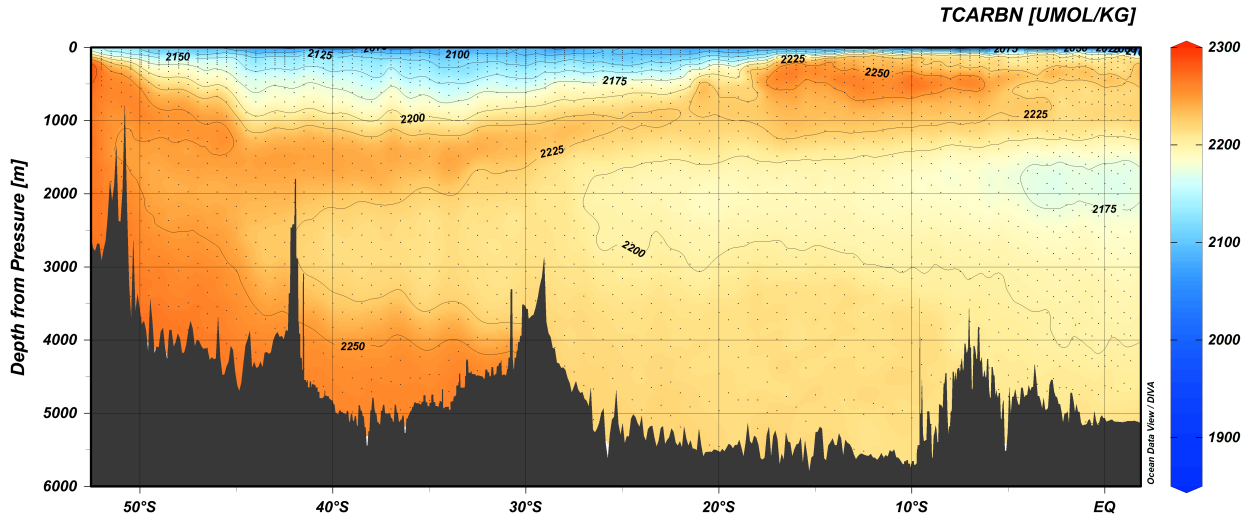


Figure 17. Dissolved Inorganic Carbon (DIC; µmol/kg), referred to in CCHDO bottle files as TCARBN, from the preliminary bottle file.

Sample collection:

Samples for DIC measurements were drawn (according to procedures outlined in the PICES Publication, *Guide to Best Practices for Ocean CO2 Measurements*) from Niskin bottles into 294 ml borosilicate glass bottles using silicone tubing. The flasks were rinsed twice and filled from the bottom with care not to entrain any bubbles, overflowing by at least one-half volume. The sample tube was pinched off and withdrawn, creating a 6 ml headspace, followed by 0.12 ml of saturated $HgCl_2$ solution which was added as a preservative. The sample bottles were then sealed with glass stoppers lightly covered with Apiezon-L grease and were stored at room temperature for a maximum of 12 hours.

Equipment:

The analysis was done by coulometry with two analytical systems (AOML 3 and AOML 4) used simultaneously on the cruise. Each system consisted of a coulometer (CM5015 UIC Inc) coupled with a Dissolved Inorganic Carbon Extractor (DICE). The DICE system was developed by Esa

Peltola and Denis Pierrot of NOAA/AOML and Dana Greeley of NOAA/PMEL to modernize a carbon extractor called SOMMA (Johnson et al. 1985, 1987, 1993, and 1999; Johnson 1992). The two DICE systems (AOML 3 and AOML 4) were removed from the AOML DIC laboratory van and set up inside the *R/V Marcus Langseth* in the Port Lab.

DIC Analysis:

In coulometric analysis of DIC, all carbonate species are converted to CO_2 (gas) by addition of excess hydrogen ion (acid) to the seawater sample, and the evolved CO_2 gas is swept into the titration cell of the coulometer with pure air or compressed nitrogen, where it reacts quantitatively with a proprietary reagent based on ethanolamine to generate hydrogen ions. In this process, the solution changes from blue to colorless, triggering a current through the cell and causing coulometric generation of OH^- ions at the anode. The OH^- ions react with the H^+, and the solution turns blue again. A beam of light is shone through the solution, and a photometric detector at the opposite side of the cell senses the change in transmission. Once the percent transmission reaches its original value, the coulometric titration is stopped, and the amount of CO_2 that enters the cell is determined by integrating the total change during the titration.

DIC Calculation:

Calculation of the amount of CO_2 injected was according to the CO_2 handbook (DOE 1994). The concentration of CO_2 *($[CO_2]$)* in the samples was determined according to:

$$[CO_2] = \text{Cal. Factor} * \frac{(\text{Counts} - \text{Blank} * \text{Run Time}) * K\ \mu\text{mol/count}}{\text{pipette volume} * \text{density of sample}}$$

where *Cal. Factor* is the calibration factor, *Counts* is the instrument reading at the end of the analysis, *Blank* is the counts/minute determined from blank runs performed at least once for each cell solution, *Run Time* is the length of coulometric titration (in minutes), and *K* is the conversion factor from counts to micromoles.

All DIC values were recalculated to a molar weight (µmol/kg) using density obtained from the CTD's salinity. The DIC values were corrected for dilution due to the addition of 0.12 ml of saturated $HgCl_2$ used for sample preservation. The total water volume of the sample bottles was 294 ml (calibrated by Esa Peltola, AOML). The correction factor used for dilution was 1.0004. A correction was also applied for the offset from the CRM. This additive correction was applied for each cell using the CRM value obtained at the beginning of the cell run. The average correction was 2.70 µmol/kg for AOML 3 and 1.15 µmol/kg for AOML 4 (CRM Batch 210).

The coulometer cell solution was replaced after 24 – 28 mg of carbon was titrated, typically after 9 – 12 hours of continuous use. The blanks ranged from 12 to 31.

Calibration, Accuracy, and Precision:

The stability of each coulometer cell solution was confirmed three different ways.

1) Gas loops were run at the beginning of each cell
2) CRMs supplied by Dr. A. Dickson of SIO, were analyzed at the beginning of the cell before sample analysis.
3) Duplicate samples from the same Niskin were measured near the beginning, middle, and end of each cell.

Each coulometer was calibrated by injecting aliquots of pure CO_2 (99.999%) by means of an 8-port valve (*Wilke et al., 1993*) outfitted with two calibrated sample loops of different sizes (~1ml and ~2ml). The instruments were each separately calibrated at the beginning of each cell with a minimum of two sets of these gas loop injections.

The accuracy of the DICE measurement is determined with the use of standards (Certified Reference Materials (CRMs) consisting of filtered and UV irradiated seawater) supplied by Dr. A. Dickson of Scripps Institution of Oceanography (SIO). The CRM accuracy is determined manometrically on land in San Diego. The DIC data reported to the data base have been corrected to batch 210 CRM values. The CRM certified value for batch 210 is 2046.37 µmol/kg.

The precision of the two DICE systems can be demonstrated via the replicate samples. Approximately 11% of the Niskins sampled were duplicates taken as a check of our precision. These replicate samples were interspersed throughout station analysis for quality assurance and integrity of the coulometer cell solutions. The average absolute difference from the mean of these replicates is 1.28 µmol/kg for AOML 3 and 1.17 µmol/kg for AOML 4. No major systematic differences between the replicates were observed.

The pipette volume was determined by taking aliquots of distilled water from volumes at known temperatures. The weights with the appropriate densities were used to determine the volume of the pipettes.

Calibration data during this cruise:

UNIT	Ave L Loop Cal Factor	Ave S Loop Cal Factor	Pipette	Ave CRM	STDEV	AVG Dupes	STDEV Dupes
AOML 3	1.004489	1.004221	26.757 ml	Batch 210: 2049.05, N= 59	2.70	1.28	0.91
AOML 4	1.003783	1.004555	29.391 ml	Batch 210: 2047.19, N = 56	1.15	1.17	0.83

Underway DIC Samples

Underway samples were collected from the flow thru system in the Wet-Lab onboard the *R/V Marcus Langseth* during the first 3 days of transit from the last CTD station. Discrete DIC

samples were collected approximately every 4 hours with duplicates every fifth sample. A total of 21 discrete DIC samples including duplicates were collected while underway.

Summary:

The overall performance of the analytical equipment was good, but several issues did arise during the cruise. At the beginning of the cruise the lamp bulb was changed on both coulometers and the voltage was adjusted to 2.475V as per manufacturer's recommendation. A cell with cathode solution was placed in each coulometer and run cell setup selected. The reading should be between 2700-4000. For optimal performance the coulometer should read between 3800 to 3900; both coulometers were set to 3850. The pipette on AOML 3 had issues filling in time, so valve 4 and 13 were replaced. The tubing from the catchment bulb to the bottom of the stripper was replaced due to a small hole, which was causing high counts during the clear and ready check for AOML 3. Valve 13 was replaced on AOML 4 due to slow filling of the pipette. A section of the sample line from the sample bottle to AOML 4 was removed and replaced due to a small leak (hole) in the tubing. Both systems had problems with the cell caps popping off due to a build-up of pressure in the cell. The narrow vent line from the cell cap was getting clogged and was replaced with a wider tubing and the issue was resolved.

Including the duplicates, 3003 samples were analyzed from 113 CTD casts for dissolved inorganic carbon (DIC) which means there is a DIC value for approximately 99.8% of the Niskins tripped. The DIC data reported to the database directly from the ship are to be considered preliminary until a more thorough quality assurance can be completed shore side.

References:

DOE (U.S. Department of Energy). (1994). *Handbook of Methods for the Analysis of the Various Parameters of the Carbon Dioxide System in Seawater*. Version 2.0. ORNL/CDIAC-74. Ed. A. G. Dickson and C. Goyet. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.), (2007): Guide to Best Practices for Ocean CO_2 Measurements. PICES Special Publication 3, 191 pp.

Feely, R.A., R. Wanninkhof, H.B. Milburn, C.E. Cosca, M. Stapp, and P.P. Murphy (1998): "A new automated underway system for making high precision pCO2 measurements aboard research ships." Anal. Chim. Acta, 377, 185-191.

Johnson, K.M., A.E. King, and J. McN. Sieburth (1985): "Coulometric DIC analyses for marine studies: An introduction." Mar. Chem., 16, 61-82.

Johnson, K.M., P.J. Williams, L. Brandstrom, and J. McN. Sieburth (1987): "Coulometric total carbon analysis for marine studies: Automation and calibration." Mar. Chem., 21, 117-133.

Johnson, K.M. (1992): Operator's manual: "Single operator multiparameter metabolic analyzer (SOMMA) for total carbon dioxide (CT) with coulometric detection." Brookhaven National Laboratory, Brookhaven, N.Y., 70 pp.

Johnson, K.M., K.D. Wills, D.B. Butler, W.K. Johnson, and C.S. Wong (1993): "Coulometric total carbon dioxide analysis for marine studies: Maximizing the performance of an automated continuous gas extraction system and coulometric detector." Mar. Chem., 44, 167-189.

Johnson, K.M., Körtzinger, A.; Mintrop, L.; Duinker, J.C.; and Wallace, D.W.R. (1999). *Coulometric total carbon dioxide analysis for marine studies: Measurement and internal consistency of underway surface TCO2 concentrations*. Marine Chemistry 67:123–44.

Lewis, E. and D. W. R. Wallace (1998) Program developed for CO2 system calculations. Oak Ridge, Oak Ridge National Laboratory. http://cdiac.ornl.gov/oceans/co2rprt.html

Wilke, R.J., D.W.R. Wallace, and K.M. Johnson (1993): "Water-based gravimetric method for the determination of gas loop volume." Anal. Chem. 65, 2403-2406

5.8 Carbon Isotopes ($\delta^{13}C$)

Principal Investigators: Wei-jun Cai (U. Delaware)
Samplers: Yifan Li (U. Del), N. Patrick Mears (AOML/CIMAS), Zachary Erickson (NOAA/PMEL), and Jesse Anderson (ESR)

Sampling

Samples for $\delta^{13}C$ -DIC measurements were drawn according to procedures outlined in the PICES Special Publication, Guide to Best Practices for Ocean CO_2 Measurements, from the rosette sample bottles into cleaned 250 mL borosilicate glass bottles using silicone tubing. Bottles were first rinsed three time and then filled from the bottom, overflowing at least twice the bottle's volume, before slowly withdrawing the tube to prevent bubble entrapment. After samples were taken back to the lab, 2 ml of each sample was pipetted out to allow thermal expansion, and then 0.1 mL of saturated mercuric chloride solution was added as a preservative. Bottles were sealed with glass stoppers, coated with Apiezon-L grease, secured with rubber bands and clips, and stored in coolers. All samples were stored on an upper level deck (the "streamer deck") until the end of the cruise, after which they were stored inside the ship for approximately 2 months until the *Langseth* arrived back in the U.S., where they will be transported to the University of Delaware for analysis.

$\delta^{13}C$-DIC samples were collected from every rosette sample bottle at every other station until station 107, at which point they were collected at every station. A total of 1644 samples were collected from 61 stations, including 218 duplicate samples. These duplicates were collected from bottles at the surface, middle and bottom layers. At stations 43 and 101, duplicates were collected from all bottles. The two sets of duplicates from station 43 were stored on the streamer deck and in the wet lab, respectively, during the cruise. The two sets of duplicates from station 101 were sampled by borosilicate glass bottles of different brands.

Underway discrete samples were taken every 4 hours for 3 days during the transit to Cape Town, South Africa, all with duplicates.

5.9 Dissolved Organic Carbon and Total Dissolved Nitrogen

Principal Investigators: Craig Carlson (UCSB)
Sampler: Max Pacatte (UCSB)

The goal of this measurement is to provide high-resolution, long-term monitoring of Dissolved Organic Carbon (DOC) and Total Dissolved Nitrogen (TDN) distributions throughout the water column, in order to help better understand biogeochemical cycling in global oceans. DOC/TDN was sampled at every other station. Two duplicates randomly selected for a total of 26 samples collected per cast. At intermediate stations a single surface sample was collected (in replicate) to increase surface resolution across this section.

DOC/TDN was sampled at 57 stations for full depth profiles, and another 56 surface sample only stations were also collected. In total 1,637 individual samples were collected for future laboratory analysis.

During sampling, seawater was passed through an inline filter holding a combusted GF/F filter attached directly to the Niskin for samples above 500 m of each cast. This was done to eliminate particles larger than 0.7 µm from the sample. Samples from deeper depths were not filtered. Previous work has demonstrated that there is no resolvable difference between filtered and unfiltered samples in waters below the upper 500 m at the µmol kg^{-1} resolution. To avoid contamination, nitrile gloves were used when handling all sampling equipment and clean lab surfaces were used for processing samples. After each station, all equipment used for sampling was rinsed with 5-10% hydrochloric acid and MilliQ water in preparatioon for the following station. All samples were rinsed 3 times with ~5 mL of seawater and collected into 40 mL glass EPA vials.

Sample vials were prepared in advance for this cruise by combusting at 450°C for 4 hours to remove any organic matter. Vial caps were cleaned by soaking in 10% hydrochloric acid, followed by a soak in Nanopure water overnight, followed by a 3 times rinse with Nanopure water and left out to dry. Samples were fixed with 50 µL of 4N hydrochloric acid and stored upright in well- sealed pelican coolers at room temperature on board. Samples were never frozen. Samples will be shipped back to UCSB for analysis via high temperature combustion on Shimadzu TOC-V or TOC L analyzers.

DOC samples will be analyzed via high temperature combustion using a Shimadzu TOC-V or Shimadzu TOC-L in a shore-based laboratory at the University of California, Santa Barbara. The operating conditions of the Shimadzu TOC-V have been slightly modified from the manufacturer's model system. These methods have been added to the GO SHIP Practices collection and are fully detailed in Halewood et al. (2022), and previously Carlson (2010), Hansell (2005), and Hansell (1998). Final results will be reported in units of µmol kg^{-1}. Where possible, direct measures of sample salinity and analytical temperature will be used to calculate average seawater density. In practice, we have found that applying an average seawater density of 1,027 kg m^{-3} to open ocean water column samples, compared to direct measure of sample

density, results in a difference of less than 0.01 µmol kg^{-1}; i.e., less than analytical precision. However, when salinity and an average analytical lab temperature are available or in regions where salinity varies strongly, a more accurate density correction is determined and applied for each sample. Each parameter includes a field for quality control flags.

References

Halewood E, Opalk K, Custals L, Carey M, Hansell D.A. and Carlson, C.A. (2022) Determination of dissolved organic carbon and total dissolved nitrogen in seawater using High Temperature Combustion Analysis. Front. Mar. Sci. 9:1061646. doi: 10.3389/fmars.2022.1061646.

Carlson, C. A., D. A. Hansell, N. B. Nelson, D. A. Siegel, W. M. Smethie, S. Khatiwala, M. M. Meyers and E. Halewood 2010. Dissolved organic carbon export and subsequent remineralization in the mesopelagic and bathypelagic realms of the North Atlantic basin. Deep Sea Research II, 57: 1433-1445.

Hansell, D.A. and C.A. Carlson 1998. Deep ocean gradients in the concentration of dissolved organic carbon. Nature, 395: 263-266.

Hansell, D.A. 2005 Dissolved Organic Carbon Reference Material Program. EOS, 35:318-319.

Walsh, T.W., 1989. Total dissolved nitrogen in seawater: a new high- temperature combustion method and a comparison with photo-oxidation. Mar. Chem., 26:295-311.

5.10 Nitrate isotopes ($\delta^{15}N$ and $\delta^{18}O$)

Principal Investigators: François Fripiat (ULB) and Daniel Sigman (Princeton)
Samplers: Teresa Kennedy (UT Tyler/URI) and Daniel Sandborn (LLO)

Seawater samples were obtained from 28 casts for later analyses of the isotopic composition of nitrate (NO3-) isotopes $\delta^{15}N$ and $\delta^{18}O$. Samples were recorded on a log sheet as either sampled (flag 1) or not sampled (flag 9). One sample was omitted on station 13 (sample bottle 71) due to Niskin bottle 23 identified as inoperable. Duplicate sample were obtained on station 41 (samples 220 and 221) due to a leak on Niskin bottles 4, where no samples were obtained. One sample was omitted on station 101 due to lack of water in Niskin bottle 14 (sample 582).

One sample was obtained for each Niskin bottle on the rosette for select casts (stations 5, 9, 13, 17, 21, 25, 29, 33, 37, 41, 45, 49, 53, 57, 61, 65, 69, 73, 77, 81, 85, 88, 93, 97, 101, 105, 109, 113), and recorded on a log sheet. Nitrile gloves were worn during sampling into pre-labeled and pre-rinsed 60 mL HDPE Nalgene screw-top bottles.

Seawater was sampled from Niskin bottles by opening the petcock, rinsing 3 times by filling with approximately 20 mL of seawater, capping, and shaking, then filled to approximately 40 mL total volume. Bottles were tightly capped, transferred to cardboard boxes, and stored in a freezer kept at -20°C.

After the cruise, samples were transferred to the University of Cape Town, where they will later be shipped to the Université Libre de Bruxelles for analysis.

5.11 Seawater isotopes (δD and $\delta^{18}O$)

Principal Investigator: Alexander Haumann (AWI)
Samplers: Teresa Kennedy (UT Tyler/URI) and Daniel Sandborn (LLO)

Seawater samples were obtained from 24 casts for later analyses of the isotopic composition of water isotopes $\delta^{18}O$ and δD. Samples were recorded on a log sheet as either sampled (flag 1) or not sampled (flag 9). No duplicate samples were obtained. All isotope samples have a corresponding salinity sample, taken and analyzed immediately after.

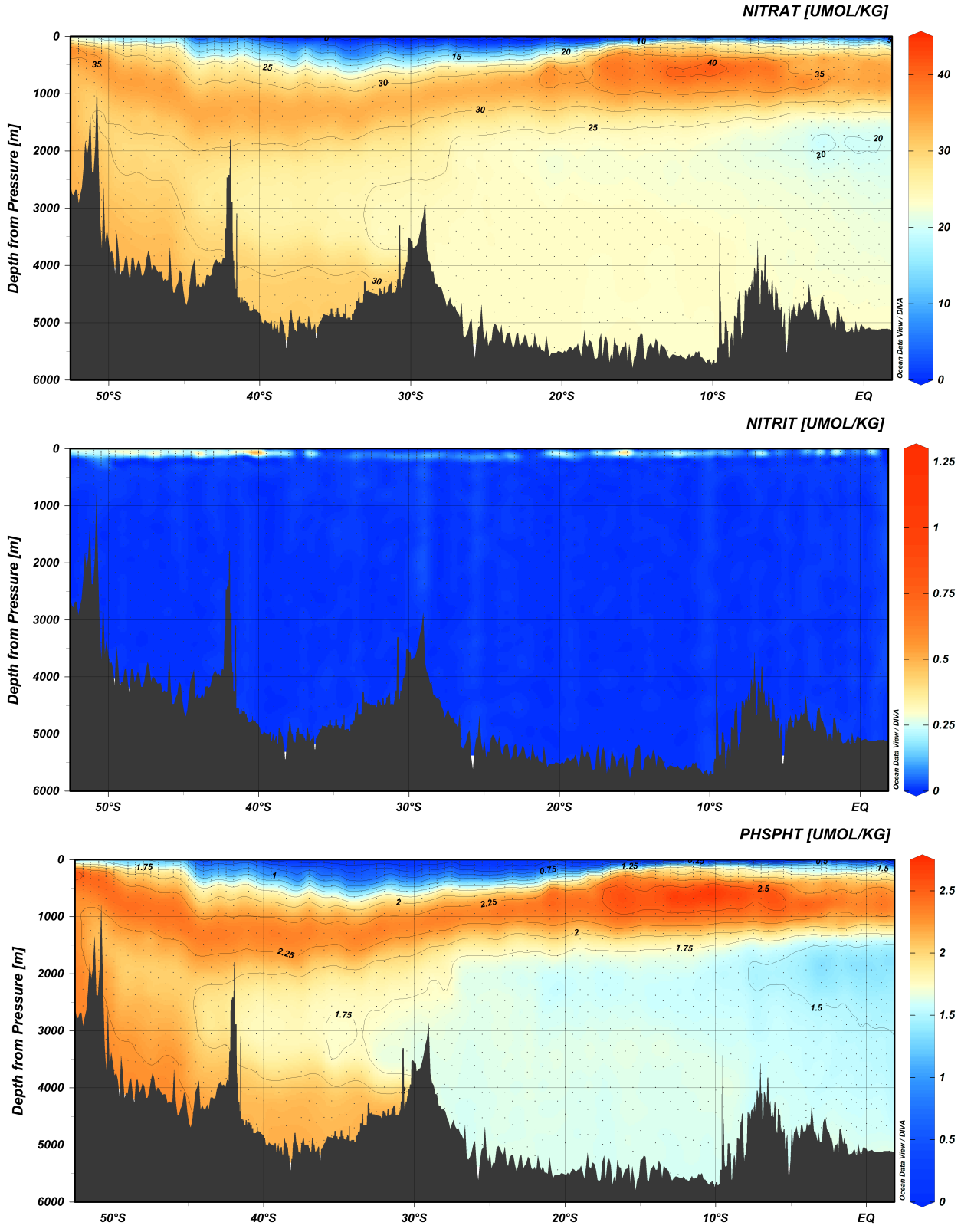
One sample was obtained for a selection of 10 Niskin bottles (stations 5, 17, 29, 41, 49, 56, 58, 69, 73, 77, 81, 85, 88, 93, 97, 101, 103, 105, 107, 109, 111, 112). The sampling strategy attempted to cover all water masses present in the profile, and when necessary, selected suggested depth levels provided by the PI (5, 15, 75, 100, 150, 200, 500, 1000, 1500, 3000). All 24 Niskins were sampled on stations 57 (24°S) and 113 (52°S).

Nitrile gloves were worn during sampling into 30 mL LDPE narrow-mouth screw-top bottles (Vitlab no. 138293). Seawater was sampled from Niskin bottles by opening the petcock, rinsing bottles and caps 1-3 times by filling with approximately 5 mL of seawater, capping, and shaking, then filled with no headspace and a minimum of air bubbles. Bottles were tightly capped and transferred to a plastic bag in a refrigerator kept at 4°C.

Samples were left on board R/V *Marcus G. Langseth* in a refrigerator for later retrieval and analysis.

5.12 Nutrients

Principal Investigators: Jia-Zhong Zhang (NOAA/AOML) and Calvin Mordy (CICOES/PMEL)
Analysts: Eric Wisegarver (NOAA/PMEL) and Ian Smith (AOML/CIMAS)



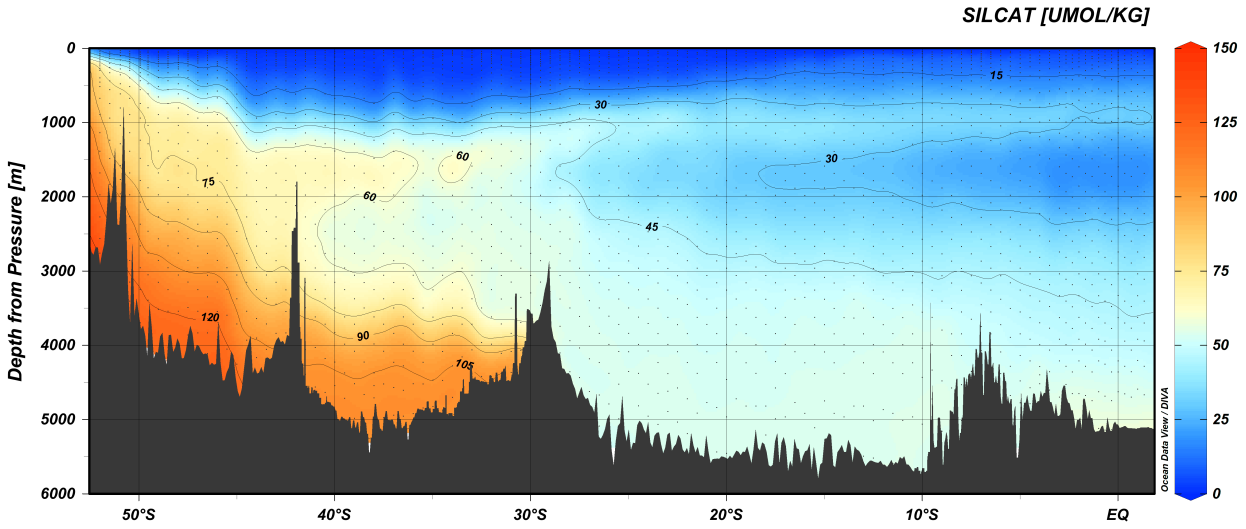


Figure 18. From top to bottom, nitrate (µmol/kg), nitrite (µmol/kg), phosphate (µmol/kg), and silicate (µmol/kg) from preliminary bottle file.

Equipment and Techniques

Dissolved nutrients (phosphate, silicate, nitrate, and nitrite) were measured by using a Seal Analytical AA3 HR automated continuous flow analytical system with segmented flow and colormetric detection.

Detailed methodologies are described by Gordon et al. (1992).

Silicic acid was analyzed using a modification of Armstrong et al. (1967). An acidic solution of ammonium molybdate was added to a seawater sample to produce silicomolybic acid. Oxalic acid was then added to inhibit a secondary reaction with phosphate. Finally, a reaction with ascorbic acid formed the blue compound silicomolybdous acid. The color formation was detected at 660 nm. The use of oxalic acid and ascorbic acid (instead of tartaric acid and stannous chloride by Gordon et al., 1993) were employed to reduce the toxicity of our waste steam.

Nitrate and Nitrite analysis was also a modification of Armstrong et al. (1967). Nitrate was reduced to nitrite via a copperized cadmium column to form a red azo dye by complexing nitrite with sulfanilamide and N-1-naphthylethylenediamine (NED). Color formation of nitrate + nitrite was detected at 520 nm. The same technique was used to measure nitrite (excluding the reduction step), and nitrate concentrations were determined by the difference of these two analyses.

Phosphate analysis was based on a technique by Bernhart and Wilhelms (1967). An acidic solution of ammonium molybdate was added to the sample to produce phosphomolybdate acid. This was reduced to the blue compound phosphomolybdous acid following the addition of hydrazine sulfate. The color formation was detected at 820 nm.

Sampling and Standards

Nutrient samples were drawn in 50 mL sample tubes that had been stored in 10% HCl. The bottles are rinsed 3-4 times with sample prior to filling. Samples were then brought to room temperature prior to analysis. Fresh mixed working standards were prepared before each analysis. In addition to the samples, each analysis consisted of a 4-point standard curve with each concentration run in duplicate at the beginning. Also, one mixed working standard from the previous analytical run was used at the beginning of the new run to determine differences between the two standards. Low Nutrient Seawater (LNSW) was used as a medium for the working standards.

The working standards were made by the addition of 3, 6, and 9 mL of a secondary nitrite standard and 3, 6, and 9 mL of a secondary mixed standard (containing silicic acid, nitrate, and phosphate) into a 250 mL calibrated volumetric flask of LNSW. Working standards were prepared twice daily.

Dry standards of a high purity were pre-weighed at PMEL. All standards were dissolved at sea. The secondary mixed standard was prepared by the addition of nitrate and phosphate primary standards to the silicic acid standard.

Nutrient concentrations were reported in micromoles per kilogram. Lab temperatures were recorded for each analytical run.

Approximately 2680 samples were analyzed.

References:

Armstrong, F.A.J., Stearns, C.R. and Strickland, J.D.H. (1967) The measurement of upwelling and subsequent biological processes by means of the Technicon AutoAnalyzer and associated equipment. Deep-Sea Res. 14:381-389.

Bernhard, H. and Wilhelms, A. (1967) The continuous determination of low level iron, soluble phosphate and total phosphate with AutoAnalyzer. Technicon Symposia, I. pp.385-389.

Gordon, L.I., Jennings Jr., J.C., Ross, A.A. and Krest, J.M. (1993) A suggested protocol for the continuous automated analysis of seawater nutrients (phosphate, nitrate, nitrite and silicic acid) in the WOCE Hydrographic program and the Joint Global Ocean Fluxes Study, WOCE Operations Manual, vol. 3: The Observational Programme, Section 3.2: WOCE Hydrograghic Programme, Part 3.1.3: WHP Operations and Methods. WHP Office Report WHPO 91-1; WOCE Report No. 68/91. November 1994, Revision 1, Woods Hole, MA., USA, 52 loose-leaf pages.

5.13 Salinity

Principal Investigators: Rick Lumpkin (NOAA/AOML), Zachary Erickson (NOAA/PMEL)
Analysts: Jay Hooper (AOML/CIMAS), Christian Saiz (AOML/CIMAS)
Samplers: Jay Hooper (AOML/CIMAS), Christian Saiz (AOML/CIMAS), Teresa Kennedy (UT Tyler/URI), Daniel Sandborn (LLO), Zachary Erickson (NOAA/PMEL), and Jesse Anderson (ESR)

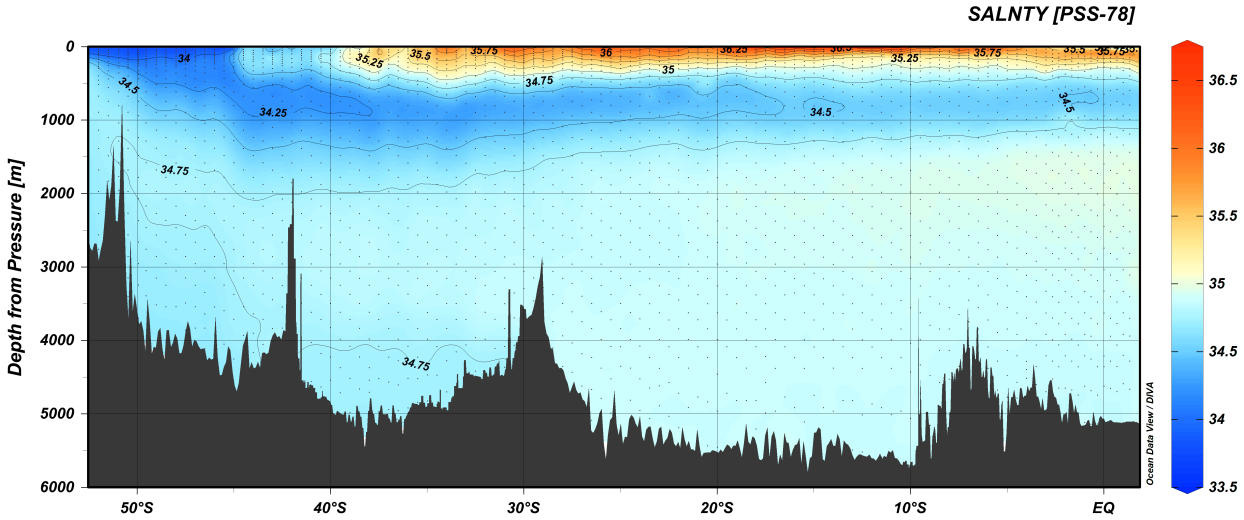


Figure 19. Discrete salinity (PSU) from preliminary bottle file.

A single Guildline Autosal, model 8400B salinometers (s/n 71464), located in the salinity analysis room (a cleared-out office room), was used for all salinity measurements. The Autosal was calibrated January 2014. The Autosal computer interface used was s/n 80070**.** The salinometer readings were logged on a computer using Ocean Scientific International's logging hardware and software. The Autosal's water bath temperature was set to 24°C, which the Autosal is designed to automatically maintain. The laboratory's temperature was also set and maintained to just below 24°C, to help further stabilize reading values and improve accuracy. In the colder latitudes the lab temperature was maintained closer to 25°C to help bring the samples to ambient temperature. Several digital thermometers were used to verify the stability of the room temperature, the Autosal water bath temperature, and when the water samples were ready to be run. Salinity analyses were performed after samples had equilibrated to the Autosal room temperature at least 12 hours, 18-24 hours in colder latitudes, after collection. The salinometer was standardized for each group of samples analyzed (usually 2 casts and up to 52 samples) using two bottles of standard seawater: one at the beginning and end of each set of measurements. The salinometer output was logged to a computer file. The software prompted the analyst to flush the instrument's cell and change samples when appropriate. Prior to each run a sub-standard flush, approximately 200 mL, of the conductivity cell was conducted to flush out the DI water used in between runs. For each calibration standard, the salinometer cell was initially flushed 6 times before several conductivity ratio reading was taken, usually 5-6 readings. For each sample, the salinometer cell was initially flushed at least 3 times before a set of conductivity ratio readings were taken. After each run the Autosal conductivity cell was flushed

with approximately 200 mL of a triton-DI water solution and then rinsed and stored with DI water until the net run.

IAPSO Standard Seawater Batch P-167 was used to standardize all casts.

The salinity samples were collected in 200 mL Kimax high-alumina borosilicate bottles that had been rinsed at least three times with sample water prior to filling. The bottles were sealed with custom-made plastic insert thimbles and Nalgene screw caps. This assembly provides very low container dissolution and sample evaporation. Prior to sample collection, inserts were inspected for proper fit and loose inserts replaced to insure an airtight seal. PSS-78 salinity [UNES81] was calculated for each sample from the measured conductivity ratios. The offset between the initial standard seawater value and its reference value was applied to each sample. Then the difference (if any) between the initial and final vials of standard seawater was applied to each sample as a linear function of elapsed run time. The corrected salinity data was then incorporated into the cruise database. When duplicate measurements were deemed to have been collected and run properly, they were averaged and submitted with a quality flag of 6. On A13.5, 2874 salinity measurements were taken, including 222 duplicates, and approximately 120 vials of standard seawater (SSW) were used. Two duplicate samples were drawn from each cast to determine total analytical precision.

The standard calibration values and duplicates are below in Figure 20 and Figure 21. The duplicates taken during the cruise showed a median precision of -0.0002+/- 0.007 psu.

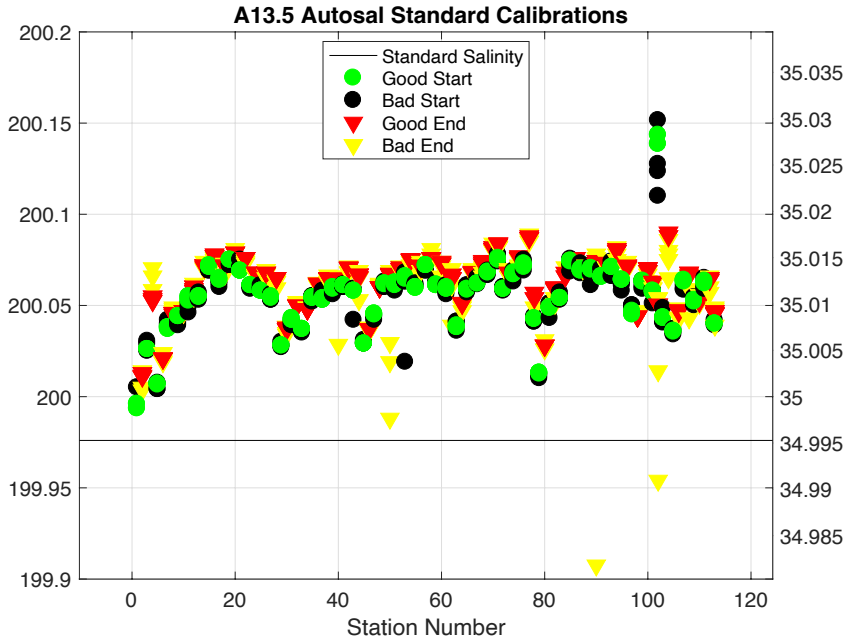


Figure 20. Standard vial calibrations throughout the cruise before and after each Autosal run. The green dots and red triangles are the good values used before and after each run to calculate salinity and drift corrections, respectively. The black dots and yellow triangles are the bad values not used. The left vertical axis is 200x the conductivity ration and the right axis is the corresponding salinity.

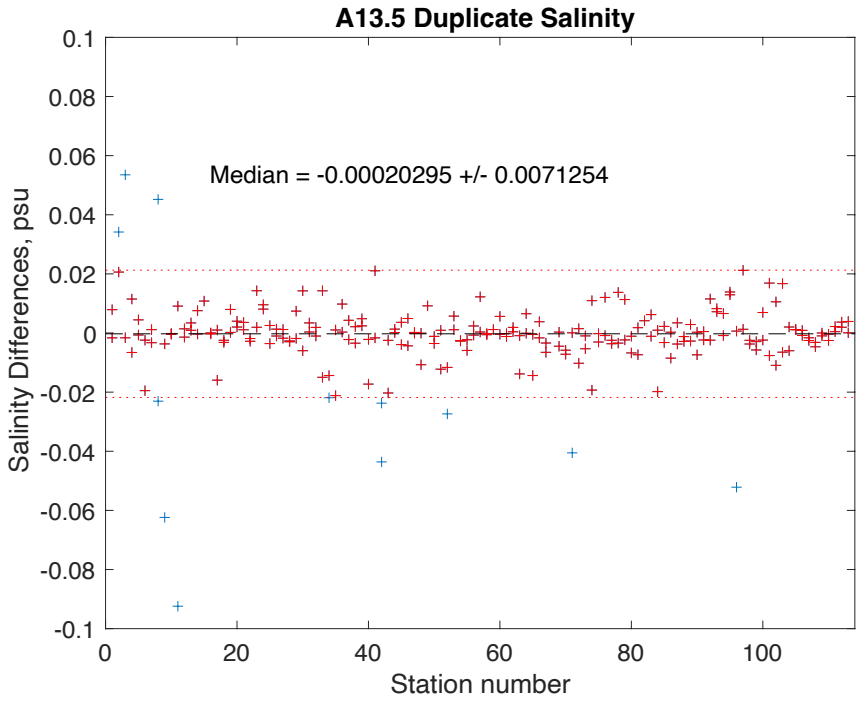


Figure 21. Salinity residuals of the duplicate samples.

5.14 Bio-GO-SHIP

PIs: Adam Martiny (UCI) and Luke Thompson (AOML)
Analyst: Kristian Furnes (UiO)

5.14.1 Continuous Inline Sampling

An underway system utilizing a diaphragm pump provided continuous flow from surface waters for eDNA, RNA, POP, POCN and HPLC filtration.

On February 23, it was discovered that the ship's inline system had not been cleaned for an unknown period. As such the evening operations were paused so that the system could be cleaned.

5.14.2 Underway Sampling

eDNA and large volume POM was collected at approximately 0600, 1200, and 2000 UTC via the underway tap. At 1200 RNA samples were also collected. Underway samplings were skipped if CTD rosette casts was set to be retrieved at the same time and the CTD had multiple niskins available for sampling. There were 6 underway sampling events throughout transit while sailing away from Cabo Verde and heading toward GO-SHIP station 1. These were collected whenever the ship was outside of any exclusive economic zone during transit. From station 1 to station 113, 106 underway sampling events were processed. Additionally, 9 underway sampling events were processed while transiting from station 113 to Cape Town.

5.14.3 eDNA and RNA

For underway sampling, 8-liter samples were gathered for eDNA at local time 0600, 1200, and 2000, and an 8-liter sample was gathered for RNA at 1200. Duplicates were collected every third day. Filtering took place immediately following Niskin or underway sampling. Nitrile gloves were worn for sample collection and processing. Prior to gathering sample water from Niskin or underway, each container was quickly rinsed three times with sample water. Following filtration protocols, each container was rinsed with DI water.

For filtration, clean tubing ran from each water sample, through a peristaltic pump with the ability to run two samples at a time, to separate measured containers to track volume filtered. Each sample line was first cleaned with sample water, and the end of each tubing was then secured with a Sterivex 0.22 µm filter cartridge. Approximately 8 liters of sample water ran through each filter. Following filtration, each filter was cleared of remaining liquid.

Using Sterivex filters, eDNA and RNA samples were prepped prior to filtering with pre-measured Zymo ZR BashingBeads and processed with 1000 µL of DNA/RNA Shield added to cartridge post filtration. All samples were labeled following protocol and stored at -80°C for later analysis. Sample lines were cleaned with 5% bleach solution and then DI water immediately following sampling at each depth. During transit from Cabo Verde to station 1, 7 samples were processed for eDNA underway sampling and 1 sample were processed for RNA underway sampling. From station 1 to station 113, 117 samples were processed for eDNA and 34 samples for RNA underway sampling. Finally, 10 samples eDNA and 3 RNA samples were collected while transiting from station 113 to Cape Town.

5.14.4 Large Volume Particulate Organic Matter (POM)

POM was comprised of two sample parameters, particulate organic carbon/nitrogen (POC/N) and particulate organic phosphorus (POP). For underway sampling, eight-liter triplicates were gathered for both POC and POP (24 total liters per parameter). Nitrile gloves were worn for sample collection and processing. Prior to gathering sample water from Niskin or underway, each container was quickly rinsed three times with sample water.

Filtering took place immediately following Niskin or underway sample collection. Each sample container, secured with a spigot at the bottom of the container, was filled to a pre-measured 8-liter mark. Hosing was connected to each spigot, which led to separate filter housings with precombusted, 25 mm GF/F filters. Tubing from the outflow of filter housings led to an aspirator pump that emptied into a sink. Following filtration, POP sample filters were rinsed with approximately 5 mL of Na2SO4 solution to remove traces of dissolved phosphorus from the filter. Each filter was removed with tweezers, folded into aluminum foil with the sample-side folded inwards, labeled according to protocol, and stored at -80°C for later analysis. During transit from Cabo Verde to station 1, 15 POP samples and 15 POCN samples were processed for underway sampling. From station 1 to station 113, 318 POP samples and 318 POCN samples were processed for underway sampling. Finally, 27 POP samples and 28 POCN samples were collected while transiting from station 113 to Cape Town.

5.14.5 High Performance Liquid Chromatography (HPLC)

HPLC samples were collected at 11 BGC float stations. At each station one underway sample, one underway duplicate, one chlorophyll max depth (c-max) sample, one wet blank (from duplicate) and one dry blank were collected. One to two liters were collected for each sample, based on water availability. Nitrile gloves were worn for sample collection and processing. Following filtration protocols, each container was rinsed with filtered sea water.

Filtering took place immediately following Niskin and underway sampling. Water samples were filtered through pre-combusted, 25 mm GF/F filters secured on a filtration manifold attached to a vacuum pump. Filters were folded in half sample-side inwards, labeled following protocol, and stored at -80°C for later analysis. In total, 10 underway samples, 10 underway duplicate samples, 10 c-max samples, 10 wet blanks (from duplicate) and 10 dry blanks were collected. Due to miscommunication during float station 4, surface samples were collected instead of underway, and the 35 m depth was collected instead of c-max.

5.14.6 Particulate Organic Carbon (POC)

POC samples were collected at 11 BGC float stations. At each station one surface sample, one surface duplicate, one chlorophyll max depth (c-max) sample, one wet blank (from duplicate) and one dry blank was collected. One to two liters were collected for each sample, based on water availability. Nitrile gloves were worn for sample collection and processing. Following filtration protocols, each container was rinsed with filtered sea water.

Filtering took place immediately following Niskin sampling. Water samples were filtered through pre-combusted, 25 mm GF/F filters secured on a filtration manifold attached to a vacuum pump. Filters were folded in half sample-side inwards, labeled following protocol, and stored at -80°C for later analysis. In total, 10 surface samples, 10 surface duplicate samples, 10 c-max samples, 10 wet blanks (from duplicate) and 10 dry blanks were collected. Due to miscommunication during float station 4, 35 m depth was collected instead of surface, and another c-max sample was collected instead of surface duplicate.

5.15 Microplastics

PI: Franck Laurent Patrick Lejzerowicz (UiO)
Analyst: Kristian Have Furnes (UiO)

The microcosm experiment was set-up in the form of twelve jars. The jars were split up into four groups of PE (polyethylene), PLA (polylactic acid), PET (polyethylene terephthalate) and rocks (control). Each jar was filled with grains of substrates corresponding to its group. On the 7th of February 2024, the jars were filled with water from the ships underway system. Over the next month the water was exchanged once a week, using a funnel to make sure none of the substrate was lost. During these exchanges the latitude, longitude, time, and air temperature was documented. Each jar was covered by a petri dish to isolate it and prevent contamination. At the end of the experiment the samples were collected in different falcon tubes and frozen to -20°C.

6. Deployments

A total of 41 deployments took place during the 2024 A13.5 hydrographic survey. This included 23 profiling floats of 4 different types and 18 surface drifters of 2 different types. Floats deployed were 4 Core Argo floats (https://argo.ucsd.edu/), 7 Global Ocean Biogeochemical Array (GO-BGC; https://www.go-bgc.org/) floats, 1 Deep Argo float (https://argo.ucsd.edu/expansion/deep-argo-mission/), and 7 EM-APEX Floats for Sampling QUantitative Internal-wave Distributions (SQUID; https://nopp-giw.ucsd.edu/teams/girton/). Drifters deployed included 10 Surface Velocity Program (SVP) and 8 Surface Velocity Program Barometer (SVPB) drifters. Since the *Langseth* commonly has a wet main deck due to ship design for seismic work, all deployments were stored on the streamer deck and/or in the CFC van on the paravane deck until deployment. This required hand carrying each deployment down a steep, narrow staircase immediately before deployment. Langseth marine technicians, Todd Jensvold, Joshua Kasinger, Koray Ergun, and Aaron Martin assisted with moving the floats and all deployments. Details for each deployment type follow.

6.1 Core Argo Floats

Principal Investigators: Susan Wijffels (WHOI), Steven Jayne (WHOI) and Pelle Robbins (WHOI), Shipboard personnel: Jesse Anderson (ESR)

A total of 4 WHOI Core Argo floats were deployed during the transit into Cape Town, South Africa after the end of the A13.5 hydrographic line. All floats deployed were MRV Systems Solo II (S2-A) floats equipped with Seabird SBE41/41CP CTD and Iridium Antennas. Parameters measured are temperature, salinity, and pressure. These floats were readied for deployment during mobilization in Norfolk, VA by Deb West-Mack (WHOI) and Aidan Thayer (WHOI) who also provided deployment instructions. Deployment locations were targeted to fill in spatial gaps in the Argo network. All floats were boxed and wrapped in plastic (wrap and bag) to protect the cardboard deployment box and cornstarch release harness. At sea, the plastic layers were removed just before deployment.

On the first deployment, after rigging up the boxed float deployment bridal on the ships boom on the port stern, we discovered that the water release had prematurely triggered due to water exposure. The float was instead lowered using the sling method with two ropes. It was then discovered that the remaining floats had signs of water exposure while in storage on the streamer deck. On the second float deployment, after removing the plastic, the float deployment box was dry on the bottom and the water release was intact, so we attached the deployment bridal to the ships boom and lowered the box into the water. The water release did not trigger after ~1 min, so the float was brought back aboard and lowered instead by the sling method. The decision was made to use the sling method for subsequent deployments. All deployments occurred from the port side stern while the ship steamed towards port at between 3-11kts.

All floats will complete standard Argo missions. The floats will drift at 1,000 m then dive to 2,000 m before collecting data on the way back up to the surface every 10 days. Data is publicly available via the Argo program GDACs (https://argo.ucsd.edu/data/).

	Serial #	Latitude	Longitude	Date and Time (GMT)	Depth	Station	Comments
1	7737	-50.498	1.868	3/17/24 12:40	3770	N/A	water release prematurely triggered, sling deployment
2	7797	-47.496	5.253	3/18/24 11:50	4454	N/A	water release did not release, sling deployment
3	7833	-44.485	8.402	3/19/24 09:25	4578	N/A	sling deployment
4	7788	-41.506	11.336	3/20/24 07:30	4628	N/A	sling deployment

6.2 Biogeochemical Argo Floats

Principal Investigators: David Nicholson (WHOI) and Susan Wijffels (WHOI)
Shipboard personnel: Jesse Anderson (ESR), Zachary Erickson (PMEL), Kristian Furnes (UiO), Max Pacatte (UCSB), and Teresa Kennedy(URI/UT Tyler)

11 floats were deployed for the Global Ocean Biogeochemistry Array (GO-BGC) following CTD stations on the A13.5 hydrographic line. All floats deployed were Seabird Navis Argo floats equipped with an SBE 41/41CP CTD to measure temperature, salinity, and pressure. Additional BGC sensors varied by float but include sensors for optical dissolved oxygen (SBS 83 or SBE63), backscattering and fluorescence (MCOMS), nitrate (SUNA), and pH. These floats were readied for deployment during mobilization in Norfolk, VA by Deb West-Mack (WHOI) and Aidan Thayer (WHOI) who also provided deployment instructions. Deployment locations were targeted to uniformly populate the South Atlantic with BGC-Floats – some of the first deployments in the region for the expanding GO-BGC Array. Deployed floats were all adopted by schools around the USA through the GO-BGC Adopt-A-Float Program. The floats were decorated at sea by members of the A13.5 science party and *Langseth* crew with Teresa Kennedy (URI/UT Tyler) leading the at-sea component of this outreach effort.

At sea, float MCOMS and SUNA sensors were cleaned prior to deployment by dabbing with a lens wipe followed by a DI water rinse and blot dry or a double DI water rinse and blot. For the first deployment, float 1489 was lowered from the streamer deck without incident. However, due to the potential for a float to bump the ship's hull once seas picked up, all future deployments occurred from the port main deck stern. On deployment of 1483, due to ship the float tilted and made contact with the rail, though it appeared that the only point of contact was the blue deployment disk. Ship speed during deployments was 2.6-4 knots and occurred after the ship had steamed 1 nm away from the CTD station.

All floats will complete standard Argo missions. The floats will drift at 1,000 m then dive to 2,000 m before collecting data on the way back up to the surface every 10 days. Data is publicly available via the Argo program data system (https://argo.ucsd.edu/data/) as well as the GO-BGC data page (https://www.go-bgc.org/data.

	Serial #	Latitude	Longitude	Date and Time (GMT)	Depth	Station	Comments
1	1489	1.319	-3.002	02/10/2024 19:15	5128	2	deployed from streamer deck
2	1562	-3.517	-3.000	02/15/2024 06:22	4842	16	
3	1561	-7.514	-1.138	02/17/2024 14:12	4449	24	
4	1560	-11.517	0.847	02/20/2024 02:59	5605	32	
5	1559	-15.517	1.033	02/22/2024 12:55	5780	40	
6	1558	-19.523	1.253	02/24/2024 21:44	5524	48	
7	1542	-23.519	1.470	02/27/2024 05:52	5070	56	
8	1358	-27.638	1.703	02/29/2024 11:40	4653	64	
9	1530	-31.505	1.419	03/02/2024 14:53	4457	72	
10	1557	-47.508	0.650	03/14/2024 05:39	3951	104	
11	1483	-51.985	0.219	03/16/2024 21:50	3082	113	bumped railing due to ship tilt, impact on deployment disk

Additionally, at each of the above deployment locations, water was collected and filtered for POC and HPLC samples to be analyzed back on land. The sampling scheme was:

Level	POC**	HPLC
Underway	-	2 (duplicate)
Surface	2 (duplicate)*	-
Chlorophyll max	1	1

*If there is insufficient water at the surface please collect using the underway system.
**POC samples take priority over HPLC samples.

Since the instrument package did not have a transmissometer or fluorometer, the chlorophyl maximum depth was estimated as the mixed layer depth (MLD) + 15m. Later in the cruise this was adjusted to MLD+25 and MLD+40 based on the first profiles from floats previously deployed on A13.5.

HPLC and POC samples were collected at each corresponding CTD stations. At each station one underway sample, one underway duplicate, one chlorophyll max depth (c-max) sample, one wet blank (from duplicate) and one dry blank were collected for each measurement (HPLC and POC separately). One to two liters were collected for each sample, based on water availability. Nitrile gloves were worn for sample collection and processing. Following filtration protocols, each container was rinsed with filtered sea water. Kristian Furnes led the sampling and filtration for these stations.

Filtering took place immediately following Niskin and underway sampling. Water samples were filtered through pre-combusted, 25 mm GF/F filters secured on a filtration manifold attached to a vacuum pump. Filters were folded in half sample-side inwards, labeled following protocol, and stored at -80°C for later analysis. In total, 10 underway samples, 10 underway duplicate samples, 10 c-max samples, 10 wet blanks (from duplicate) and 10 dry blanks were collected. Due to miscommunication during float station 4, surface samples for HPLC were collected

instead of underway, and the 35 m depth was collected for HPLC instead of c-max. Similarly, on this station 35 m depth was collected for POC instead of surface, and another c-max sample was collected for POC instead of surface duplicate.

6.3 Deep Argo float

Principal Investigators: Susan Wijffels (WHOI), Steven Jayne (WHOI), and Pelle Robbins (WHOI)
Shipboard personnel: Jesse Anderson (ESR)

1 MRV DeepSOLO Argo float was deployed following CTD station 42. Deep Argo floats are expanding the observational capability of the Argo network to full ocean depth (https://argo.ucsd.edu/expansion/deep-argo-mission/). DeepSOLO floats are equipped with an SBE 61 Deep Argo CTD and are rated to a depth of 6000 m. The Deep Argo float was readied in Norfolk, VA by Deb West-Mack (WHOI) and Aidan Thayer (WHOI). Prior to deployment, the plastic protective wrap was removed, the water release reinforcement line removed, and a line attached to the backup release. The float was placed atop 2 pallets to keep the water release dry until time for deployment. Once the ship had steamed 1 nm away from the CTD station, we attempted to lift the float using the ship's boom; however, the boom had mechanical issues at the last minute. The deployment bridal was instead attached to a line and lowered by hand into the water from the port main deck stern. Once in the water the backup release was pulled before the water release had a chance to activate. The float moved away from the vessel without incident and quickly released from its deployment box. Ship speed during deployment was 3.2 kts.

	Serial #	Latitude	Longitude	Date and Time (GMT)	Depth	Station	Comments
1	12070	-16.522	1.082	2/23/24 03:37	5443	42	Ship boom malfunctioned, deployed by hand, pulled quick release before water release activated

6.4 EM-Apex floats

Principal Investigators: James Girton (UW/APL), Zoli Szuts (UW/APL), and Ren-chieh Lien (UW/APL)
Shipboard personnel: Jesse Anderson (ESR) and Zachary Erickson (PMEL)

A total of 7 floats were deployed for Sampling QUantitative Internal-wave Distributions (SQUID), a part of the National Oceanographic Partnership Program's Global Internal Waves Experiment (https://nopp-giw.ucsd.edu/). The SQUID team is developing a global observing network for internal wave generated shear, energy flux, and mixing through the deployment of profiling floats which can measure velocity, and shear, as well as temperature, salinity, and pressure. All floats deployed were Teledyne Webb Electro-Magnetic Autonomous Profiling EXplorers (EM-

APEX). These floats infer water motion by measuring induced electromagnetic currents while spinning. Additionally, they are equipped with a microstructure sensor and the standard float SBE-41CP CTD to measure temperature, salinity, and pressure. Data from these floats are available at http://faculty.washington.edu/girton/squid/.

All floats were readied for deployment in Seattle, WA and Norfolk, VA by instrument team members Charlie Parker (UW/APL) and Jacob Dossett (UW/APL). At sea, protective covers for the CTD and microstructure probe were carefully removed just before deployment, and the electrode caps were replaced with shade caps. All deployments took place on the port stern of the *Langseth* while the ship was steaming ~3 knots. A Sea Catch quick release device was attached to a line on the ships boom, then latched around the deployment filament on each float. A line was then tied to the release mechanism on the Sea Catch. The float was lifted up and out from the ship using the ship's boom, then lowered until the bottom of the float touched the water. The quick release line was then pulled, freeing the float into the water. During the deployment of float #10316 the quick release line caught under one of the electrode caps, and two pulls - one to reorient the line and a second to pull the quick release - were required. No other issues were noted during deployments.

	Serial #	Latitude	Longitude	Date and Time (GMT)	Depth	Station	Comments
1	10318	-0.016	-3.000	02/11/2024 20:06	5136	6	
2	10319	-5.020	-2.995	02/16/2024 02:15	4823	19	
3	10313	-14.522	0.980	02/21/2024 22:16	5670	38	
4	10316	-34.018	1.264	03/04/2024 10:09	4754	77	quick release line caught on electrode cap
5	10315	-45.526	0.852	03/12/2024 09:33	4630	100	
6	10312	-49.959	0.409	03/15/2024 16:39	3709	109	
7	10242	-38.199	15.201	03/21/2024 12:00	4286	N/A	

6.5 Surface Velocity Program (SVP) Drifters

Principal Investigator: Shaun Dolk (AOML), Rick Lumpkin (AOML), and Luca Centurioni (UCSD/SIO)

Shipboard personnel: Jesse Anderson (ESR), Zachary Erickson (PMEL), and numerous members of the science party

10 Surface Velocity Program (SVP) and 8 Surface Velocity Program Barometer (SVPB) drifters along the track of the A13.5 hydrographic line. These drifters from the Global Drifter Center at AOML are NOAA's contribution to the Global Drifter Program (https://www.aoml.noaa.gov/global-drifter-program/). SVP and SVPB drifters are both drougued to 15 m depth and measure ocean velocities through changes to the drifters' locations tracked with GPS. Additionally, SVP drifters measure sea surface temperature and SVPB drifters measure both temperature and barometric pressure. Data is sent back to shore via Iridium telemetry. Shaun Dolk handled drifter logistics and advised deployment locations. All drifters were deployed from the port main deck stern. Prior to deployment protective plastic was removed, then 2 people threw the drifters into the ocean by hand. Ship speed during deployment was ~10

knots. Real-time data are freely available at https://erddap.aoml.noaa.gov/gdp/erddap/tabledap/OSMC_RealTime.html and delayed mode/quality-controlled data at *https://erddap.aoml.noaa.gov/gdp/erddap/tabledap/drifter_6hour_qc.html*.

	Serial #	Latitude	Longitude	Date and Time (GMT)	Depth	Station	Comments
SVP 1	64309500	-1.017	-3.001	02/12/2024 15:18	5134	9	
SVP 2	64309830	-4.019	-3.001	02/15/2024 12:54	4472	17	
SVP 3	64309870	-6.010	-2.395	02/16/2024 16:44	4792	21	
SVP 4	64309900	-8.015	-0.708	02/17/2024 22:05	5032	25	
SVP 5	64309890	-10.018	0.781	02/19/2024 05:34	5695	29	
SVP 6	64309430	-13.013	0.922	02/21/2024 00:24	5513	35	
SVP 7	64309490	-15.032	1.007	02/22/2024 05:29	5414	39	
SVP 8	64309480	-19.015	1.220	02/24/2024 14:36	5529	47	
SVPB 1	300534064196350	-44.015	1.003	03/11/2024 12:47	4262	97	
SVPB 2	300534064197700	-44.017	1.002	03/11/2024 12:48	4266	97	
SVPB 3	300534064196340	-46.009	0.799	03/13/2024 08:33	4003	101	
SVPB 4	300534064195340	-46.011	0.799	03/13/2024 08:34	4043	101	
SVPB 5	300534064197370	-49.032	0.502	03/15/2024 03:09	3954	107	
SVPB 6	300534064194350	-49.034	0.502	03/15/2024 03:10	3952	107	
SVPB 7	300534064195710	-50.969	0.326	03/16/2024 07:06	2055	111	
SVPB 8	300534064195380	-50.970	0.327	03/16/2024 07:07	2055	111	
SVPB 9	300534064193360	-51.981	0.225	03/16/2024 21:55	3066	113	
SVPB 10	300534064196380	-51.980	0.227	03/16/2024 21:56	3070	113	

7. Stations

Station	Cast	LADCP #	Latitude	Longitude	Depth	Start time	End time	Wire time
			°N	°E	m	GMT	GMT	HH:MM
Test 1	1					2024-02-06 15:08	2024-02-06 15:49	00:41
Test 2	1					2024-02-05 15:39	2024-02-05 16:15	00:36
Test 3	1					2024-02-04 14:30	2024-02-04 15:21	00:51
2	1		1.33	-3.00	5247	2024-02-10 15:25	2024-02-10 18:56	03:31
3	1		1.00	-3.00	5243	2024-02-10 21:43	2024-02-11 01:18	03:34
4	1		0.67	-3.00	5249	2024-02-11 04:00	2024-02-11 07:30	03:29
5	1		0.33	-3.00	5255	2024-02-11 10:03	2024-02-11 13:34	03:30
6	1		0.00	-3.00	5239	2024-02-11 16:07	2024-02-11 19:42	03:34
7	1		-0.33	-3.00	5271	2024-02-11 22:30	2024-02-12 02:02	03:31
8	1		-0.67	-3.00	5252	2024-02-12 04:31	2024-02-12 08:00	03:28
9	2		-1.00	-3.00	5235	2024-02-12 11:26	2024-02-12 15:02	03:35
10	1		-1.33	-3.00	5140	2024-02-12 17:46	2024-02-12 21:23	03:36
11	4		-1.67	-3.00	5205	2024-02-13 19:14	2024-02-13 22:49	03:35
12	1		-2.00	-3.00	5156	2024-02-14 01:23	2024-02-14 04:49	03:25
13	1		-2.33	-3.00	5055	2024-02-14 07:58	2024-02-14 11:23	03:25
14	1		-2.67	-3.00	4869	2024-02-14 13:53	2024-02-14 17:11	03:17
15	1		-3.00	-3.00	5395	2024-02-14 19:46	2024-02-14 23:21	03:34
16	1		-3.50	-3.00	4946	2024-02-15 02:45	2024-02-15 06:03	03:17
17	1		-4.00	-3.00	4606	2024-02-15 09:32	2024-02-15 12:39	03:06
18	1		-4.50	-3.00	4963	2024-02-15 16:04	2024-02-15 19:27	03:23
19	1		-5.00	-3.00	4869	2024-02-15 22:39	2024-02-16 01:55	03:15
20	1		-5.50	-2.85	5168	2024-02-16 05:28	2024-02-16 08:51	03:22
21	1		-6.00	-2.41	4889	2024-02-16 13:14	2024-02-16 16:32	03:17
22	1		-6.50	-1.97	4253	2024-02-16 20:47	2024-02-16 23:47	02:59
23	1		-7.00	-1.56	4144	2024-02-17 03:53	2024-02-17 06:44	02:51
24	1		-7.50	-1.15	4516	2024-02-17 10:49	2024-02-17 13:53	03:04
25	1		-8.00	-0.72	5115	2024-02-17 18:18	2024-02-17 21:50	03:31
26	1		-8.50	-0.29	5197	2024-02-18 02:07	2024-02-18 05:34	03:27
27	1		-9.00	0.14	6065	2024-02-18 09:53	2024-02-18 13:50	03:57
28	1		-9.50	0.56	5123	2024-02-18 18:21	2024-02-18 21:53	03:31
29	1		-10.00	0.78	5866	2024-02-19 01:34	2024-02-19 05:20	03:45
30	1		-10.50	0.80	5886	2024-02-19 08:35	2024-02-19 12:21	03:46
31	1		-11.00	0.83	5810	2024-02-19 15:44	2024-02-19 19:36	03:52
32	1		-11.50	0.85	5740	2024-02-19 23:00	2024-02-20 02:42	03:41
33	1		-12.00	0.87	5758	2024-02-20 06:12	2024-02-20 09:54	03:42
34	1		-12.50	0.90	5643	2024-02-20 13:28	2024-02-20 17:12	03:44
35	1		-13.00	0.93	5614	2024-02-20 20:33	2024-02-21 00:13	03:39
36	1		-13.50	0.94	5676	2024-02-21 03:40	2024-02-21 07:21	03:40
37	1		-14.00	0.96	5684	2024-02-21 10:43	2024-02-21 14:34	03:50
38	1		-14.50	0.98	5788	2024-02-21 18:06	2024-02-21 21:56	03:50

39	1		-15.00	1.00	5520	2024-02-22 01:31	2024-02-22 05:09	03:37
40	1		-15.50	1.03	5948	2024-02-22 08:40	2024-02-22 12:31	03:50
41	1		-16.00	1.06	5660	2024-02-22 16:23	2024-02-22 20:07	03:43
42	1		-16.50	1.08	5592	2024-02-22 23:38	2024-02-23 03:17	03:38
43	1		-17.00	1.11	5638	2024-02-23 06:52	2024-02-23 10:31	03:38
44	1		-17.50	1.14	5087	2024-02-23 14:04	2024-02-23 17:29	03:25
45	1		-18.00	1.17	5352	2024-02-23 20:55	2024-02-24 00:26	03:30
46	1		-18.50	1.19	5370	2024-02-24 03:52	2024-02-24 07:23	03:30
47	1		-19.00	1.22	5641	2024-02-24 10:39	2024-02-24 14:23	03:44
48	1		-19.50	1.25	5697	2024-02-24 17:43	2024-02-24 21:26	03:42
49	1		-20.00	1.28	5656	2024-02-25 01:34	2024-02-25 05:11	03:36
50	1		-20.50	1.31	5637	2024-02-25 08:32	2024-02-25 12:12	03:40
51	1		-21.00	1.33	5539	2024-02-25 15:33	2024-02-25 19:13	03:39
52	1		-21.50	1.36	5523	2024-02-25 22:28	2024-02-26 02:05	03:37
53	1		-22.00	1.39	5285	2024-02-26 05:34	2024-02-26 09:02	03:27
54	1		-22.50	1.42	5125	2024-02-26 12:38	2024-02-26 16:05	03:27
55	1		-23.00	1.44	4978	2024-02-26 19:24	2024-02-26 22:45	03:21
56	1		-23.50	1.47	5156	2024-02-27 02:13	2024-02-27 05:38	03:25
57	1		-24.00	1.50	5042	2024-02-27 09:05	2024-02-27 12:30	03:24
58	1		-24.50	1.53	5303	2024-02-27 15:53	2024-02-27 19:26	03:32
59	1		-25.00	1.56	4426	2024-02-27 22:49	2024-02-28 01:51	03:01
60	1		-25.50	1.58	5079	2024-02-28 05:07	2024-02-28 08:31	03:24
61	1		-26.00	1.61	4874	2024-02-28 11:52	2024-02-28 15:10	03:17
62	1		-26.50	1.64	5183	2024-02-28 18:27	2024-02-28 21:55	03:27
63	1		-27.00	1.67	4702	2024-02-29 01:13	2024-02-29 04:23	03:09
64	1		-27.50	1.69	4511	2024-02-29 07:39	2024-02-29 10:41	03:02
65	1		-28.00	1.72	4428	2024-02-29 14:00	2024-02-29 17:04	03:03
66	1		-28.50	1.75	4170	2024-02-29 20:28	2024-02-29 23:24	02:56
67	1		-29.00	1.78	3653	2024-03-01 02:48	2024-03-01 05:22	02:34
68	1		-29.50	1.81	3512	2024-03-01 08:44	2024-03-01 11:17	02:32
69	1		-30.00	1.83	3632	2024-03-01 15:07	2024-03-01 17:48	02:41
70	1		-30.50	1.70	4133	2024-03-01 21:32	2024-03-02 00:25	02:52
71	1		-31.00	1.56	4441	2024-03-02 04:04	2024-03-02 07:05	03:00
72	1		-31.50	1.42	4457	2024-03-02 10:53	2024-03-02 14:24	03:30
73	1		-32.00	1.27	4500	2024-03-02 19:01	2024-03-02 22:12	03:10
74	1		-32.50	1.13	4495	2024-03-03 02:02	2024-03-03 05:11	03:08
75	1		-33.00	0.98	4459	2024-03-03 08:41	2024-03-03 11:49	03:07
76	2		-33.50	1.10	4716	2024-03-03 23:33	2024-03-04 02:48	03:15
77	1		-34.00	1.22	4788	2024-03-04 06:31	2024-03-04 09:46	03:14
78	1		-34.50	1.16	4963	2024-03-04 13:28	2024-03-04 16:50	03:22
79	1		-35.00	1.09	4914	2024-03-06 10:45	2024-03-06 14:07	03:22
80	1		-35.50	1.05	4933	2024-03-06 18:08	2024-03-06 21:28	03:20
81	1		-36.00	1.01	5012	2024-03-07 00:57	2024-03-07 04:20	03:23
82	1		-36.50	1.00	5050	2024-03-07 07:49	2024-03-07 11:10	03:21
83	1		-37.00	1.00	5036	2024-03-07 14:52	2024-03-07 18:18	03:26
84	1		-37.50	1.00	5067	2024-03-07 21:41	2024-03-08 01:03	03:22

85	1		-38.00	1.00	4795	2024-03-08 04:19	2024-03-08 07:31	03:12
86	1		-38.50	1.00	5227	2024-03-08 10:42	2024-03-08 14:17	03:34
87	1		-39.00	1.00	5079	2024-03-08 17:34	2024-03-08 21:00	03:25
88	1		-39.50	1.00	5140	2024-03-09 00:24	2024-03-09 03:48	03:24
89	1		-40.00	1.00	4955	2024-03-09 07:10	2024-03-09 10:28	03:18
90	1		-40.50	0.92	4721	2024-03-09 14:06	2024-03-09 17:18	03:12
91	1		-41.00	0.83	4646	2024-03-09 20:34	2024-03-09 23:45	03:10
92	1		-41.50	0.75	4471	2024-03-10 03:09	2024-03-10 06:11	03:02
93	1		-42.00	0.88	2147	2024-03-10 09:29	2024-03-10 11:09	01:39
94	1		-42.50	1.00	3899	2024-03-10 14:29	2024-03-10 17:16	02:46
95	1		-43.00	1.00	3905	2024-03-10 20:42	2024-03-10 23:29	02:47
96	1		-43.50	1.00	4463	2024-03-11 03:05	2024-03-11 06:07	03:02
97	1		-44.00	1.00	4240	2024-03-11 09:27	2024-03-11 12:28	03:01
98	1		-44.50	0.95	4404	2024-03-11 16:13	2024-03-11 19:15	03:01
99	1		-45.00	0.90	4723	2024-03-11 22:50	2024-03-12 02:02	03:12
100	1		-45.50	0.85	4576	2024-03-12 06:01	2024-03-12 09:14	03:12
101	1		-46.00	0.80	3993	2024-03-13 05:35	2024-03-13 08:22	02:46
102	1		-46.50	0.75	4185	2024-03-13 12:14	2024-03-13 15:10	02:55
103	1		-47.00	0.70	4204	2024-03-13 18:58	2024-03-13 21:56	02:57
104	1		-47.50	0.65	3929	2024-03-14 02:25	2024-03-14 03:49	01:24
105	1		-48.00	0.60	4073	2024-03-14 09:21	2024-03-14 12:12	02:51
106	1		-48.50	0.55	4094	2024-03-14 16:11	2024-03-14 19:04	02:53
107	1		-49.00	0.50	3952	2024-03-15 00:08	2024-03-15 02:53	02:45
108	1		-49.50	0.45	3830	2024-03-15 07:37	2024-03-15 10:23	02:45
109	1		-50.00	0.40	3759	2024-03-15 13:33	2024-03-15 16:18	02:44
110	1		-50.50	0.35	3462	2024-03-15 20:29	2024-03-15 23:01	02:31
111	1		-51.00	0.30	1987	2024-03-16 05:12	2024-03-16 06:49	01:36
112	1		-51.50	0.25	2193	2024-03-16 12:52	2024-03-16 14:33	01:41
113	1		-52.00	0.20	3047	2024-03-16 19:05	2024-03-16 21:27	02:21

8. Bottle Issues

STNNBR	CASTNO	BTLPOS	SAMPNO	BTLNBR	FLAG	NOTES
1	1	4	10104	-999	4	Misfire.
10	1	23	100123	11117	3	May have slight leak on bottom.
12	1	23	120123	-999	3	May have slight leak on bottom.
13	1	23	130123	-999	9	Was reported empty, but was full.
21	1	19	210119	11121	3	Significant leak on bottom.
23	1	8	230108	11126	3	Pull disk/nozzle came off while sampling CFCs. Not sampled.
25	1	9	250109	11020	3	leaking from bottom end cap.
26	1	9	260109	11020	3	leaking from bottom end cap.
36	1	21	360121	11136	3	Pull disk on nozzle came off after CFCs sampled. Only CFC samples were collected.
37	1	5	370105	11058	3	Niskin nozzle was slowly dripping for much of the sampling, may have affected all except CFCs.
41	1	4	410104	-999	3	Major leak on bottom; lanyard from Niskin 3 had caught on bottom cap.
41	1	21	410121	11136	3	Slow leak on spigot during part of sampling.
61	1	9	610109	11020	3	Slow leak on spigot during sampling.
68	1	16	680116	11023	3	Pull disk on nozzle came off after CFC sample. No water came out. Put back on for all others to sample.
69	1	3	690103	11008	3	Small leak in bottom.
69	1	22	690122	11027	3	Spigot, pull ring was pushed in on recovery
69	1	24	690124	11004	3	Spigot, pull ring was pushed in on recovery
72	1	17	720117	11113	3	Slow leak on bottom.
87	1	9	11020	870109	3	Lanyard was caught on hook during recovery, bottle leaked. Only DOC, Nuts, and Salts sampled.
92	1	22	11027	920122	3	Rapid leak from bottom of bottle 22 - several drops per second.
94	1	24	11004	940124	3	Bottom leaking. Lanyard from bottle 23 stuck in bottle #24.
107	1	1	11082	1070101	4	Misfire - Bottle 1 empty
108	1	1	11082	1080101	4	Misfire - Bottle 1 empty.