Cruise Report

PIRATA Northeast Extension 2018

NOAA Ship *Ronald H. Brown*

RB-18-02

March 7 – April 14, 2018

Ft. Lauderdale, FL – Durban, S. Africa

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PIRATA Northeast Extension 2018 Scientific Party

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Moorings: Steve Kunze (NOAA/PMEL), Daryn White (NOAA/PMEL).

Note: This report provides detailed information about the hydrographic measurements and mooring operations carried out during the cruise. This work is in support of the PIRATA Northeast Extension project and is part of a collaborative agreement between AOML and PMEL and is funded by NOAA's Climate Program Office. All results reported in this document are subject to revision after post-cruise calibrations and other quality-control procedures have been completed.

OVERVIEW

The March-April 2018 PIRATA (Prediction and Research Moored Array in the Tropical Atlantic) Northeast Extension (PNE) cruise RB-18-02 was designed to (1) Collect oceanographic and meteorological observations in the northeastern tropical Atlantic, (2) Recover and redeploy the PIRATA Northeast Extensions' four TFlex moorings. The oceanographic component of (1) includes measurements of conductivity, temperature, pressure, oxygen concentration, and horizontal velocity from CTD casts, and horizontal velocity measurements from the hull-mounted ADCP. The majority of the measurements were acquired along the 23°W meridian, which samples the southeastern corner of the subtropical North Atlantic, a region of subduction that is important for the subtropical cell circulation; the Guinea Dome and oxygen minimum zone, where the subtropical and tropical gyres meet; and the tropical current system and equatorial waveguide. The meteorological component of (1) focused on measurements of air temperature, relative humidity, wind velocity, shortwave radiation, longwave radiation, and rainfall from the ship's meteorological sensors. Many of the scientific goals of RB-18-02 were achieved. However, we were unable to perform approximately 20 of the planned CTD casts because of the loss of two science days to unexpected ship maintenance and repairs in Ft. Lauderdale. We were also unable to recover and re-deploy the PIRATA mooring at 20.5ºN, 23ºW due to rough seas and strong winds.

We thank the crew and officers of the *Ronald H. Brown* for their work during the cruise and their help before, during, and after the cruise. Three surface moorings were successfully recovered and redeployed by Chief Bosun Michael Lastinger and the deck crew using an efficient method that eliminated the need for small boat operations. Thanks to the survey technicians, Josh and Patricia, and the Electronic Technician, Jeff Hill, for their assistance during CTD casts. Thanks also to the rest of the crew, including the winch operators, engineers, galley crew, who kept operations running smoothly. Finally, we appreciate the efforts of the Field Operations Officer and Commanding Officer to ensure efficient operations.

Unfortunately, the AEROSE group could not participate in the 2018 PNE cruise due to a scheduling conflict. It is hoped that they will be back for the next cruise in 2019.

Introduction

1. PIRATA Northeast Extension

The Prediction and Research Moored Array in the Tropical Atlantic (PIRATA) is a three-party project involving Brazil, France and the United States that seeks to monitor the upper ocean and near-surface atmosphere of the tropical Atlantic via the deployment and maintenance of an array of moored buoys with subsurface sensors and automatic meteorological stations. The array consists of a total of 18 moorings, 10 of which were deployed in 1997-1998, running along the equator and extending southward along 10ºW to 10ºS and northward along 38ºW to 15ºN. Following the success of this initial array, additional moorings were deployed in the southwestern tropical Atlantic in 2005, in the northeastern tropical Atlantic in 2006-2007 (the PIRATA Northeast Extension), and at 6ºS, 8ºE in 2013 (Fig. 1). All of these moorings continue to be maintained as part of the sustained ocean observing system.

The Northeast Extension samples a region of strong climate variations on intraseasonal to decadal scales, with impacts on rainfall rates and storm strikes for the surrounding regions of Africa and the Americas. The northeastern tropical Atlantic includes the southern edge of the North Atlantic subtropical gyre, defined by the westward North Equatorial Current (NEC), and the northern edge of the clockwise tropical/equatorial gyre defined by the North Equatorial Countercurrent (NECC). This area is the location of the North Atlantic's oxygen minimum zone, found between depths of 400 m and 600m. The size and intensity of this zone is a potential integrator of long-term North Atlantic circulation changes, and the extremely low oxygen values have significant impacts on the biota of the region. The cyclonic Guinea Dome is centered near 10ºN, 24ºW, between the NECC and NEC in the eastern Tropical Atlantic. It is driven by trade wind-induced upwelling and may play an active role in modulating air-sea fluxes in this region.

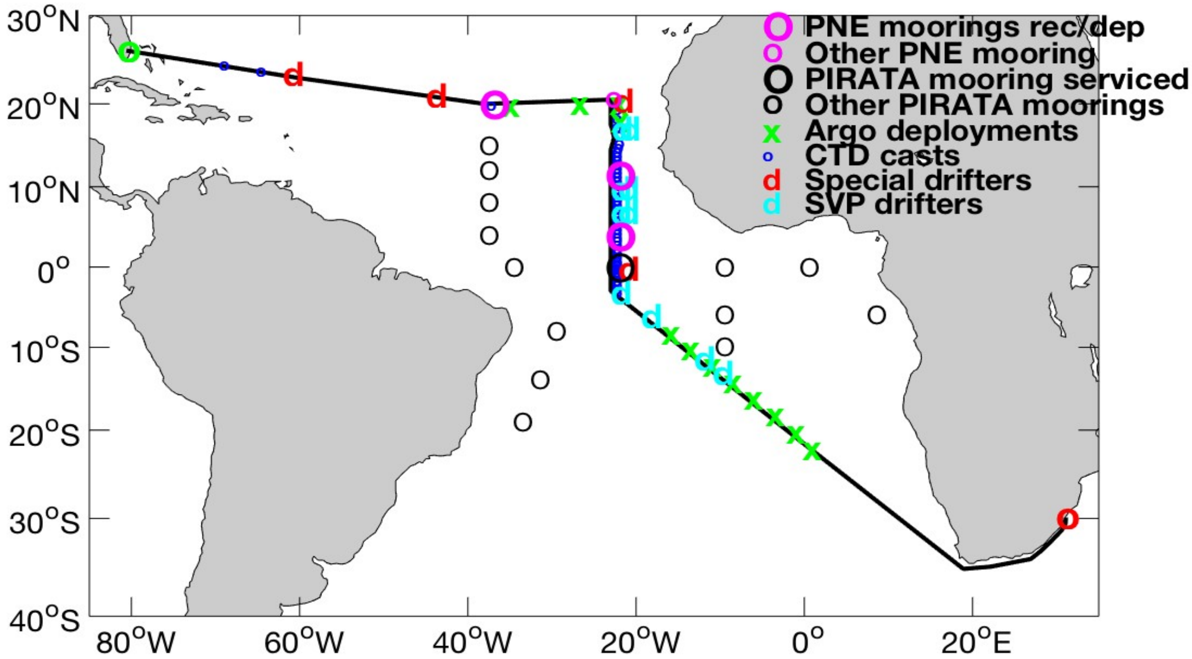

Figure 1 Cruise track (black line) with locations of the PNE moorings (large pink circles show those recovered and deployed during the cruise, small pink circle indicates the mooring was not) and other PIRATA moorings (large black circle indicates mooring was serviced, small black circles show moorings that were not). Green and red circles indicate the beginning and end ports of Ft. Lauderdale and Durban, respectively. Blue circles show the locations of 50 CTD casts performed during the cruise. Green crosses indicate locations of Argo deployments, red 'd's' show where batches of experimental drifters were deployed, and cyan 'd's' show the locations of regular surface velocity program (SVP) drifter deployments.

The tropical North Atlantic includes the Main Development Region (MDR) of tropical cyclones. Many major hurricanes that ultimately threaten the eastern United States begin as atmospheric easterly waves propagating westward from the African continent. Once over the MDR in the 10ºN -20ºN band, these waves are exposed to convective instability driven by the upper ocean's high heat content. The resulting infusion of energy can result in closed cyclonic circulation and development from tropical depression to tropical storm and hurricane. These hurricanes are known as Cape Verde-type hurricanes, to distinguish them from storms forming further west, and they are often the most powerful storms to strike the US east coast. There is profound uncertainty regarding the specific atmospheric/oceanic conditions that determine which of the atmospheric waves will develop into tropical cyclones and then hurricanes. Specifically, the quantitative effects of the Saharan Aerosol Layer (SAL), anomalous sea surface temperatures (SST), upper-layer oceanic heat content, and atmospheric wind shear on the formation of tropical cyclones are poorly known.

Seasonal tropical storm and hurricane forecasts are generated annually and are based primarily on statistical analyses of historical data and the formulation of empirical predictors (e.g., ENSO index, Atlantic SST, Sahel rainfall, etc.). Recent empirical studies have demonstrated that tropical storm and hurricane activity in the Atlantic Ocean varies on decadal and multi-decadal time-scales and that this variability is correlated with SST anomalies in the MDR. There is hope that a better understanding of decadal-multidecadal SST variability in the tropical North Atlantic will lead to improved predictions of Atlantic hurricane activity and rainfall fluctuations over South America and Africa. There is currently great uncertainty regarding the roles of wind-induced evaporative cooling, cloudiness- and dust-induced changes in surface radiation, anthropogenic aerosol-induced surface cooling, and ocean mixed layer dynamics, in driving interannual-multidecadal SST variability in the tropical North Atlantic. Measurements from the moorings of the PIRATA Northeast Extension are valuable for conducting empirical heat budget analyses, which diagnose the causes of SST variability and are also useful for numerical model validation.

Order of Operations

The R/V *Ronald H. Brown* (RHB) departed Ft. Lauderdale, Florida on March 7 at 18:00 UTC and proceeded eastward toward the first mooring site. The RHB's underway oceanic and atmospheric measurement system was turned off during the transit through the Bahamas' EEZ since research clearance had not been requested from the State Department.

At 19:00 UTC on March 9, on the way to the first mooring, a fully instrumented CTD test cast to a depth of 1500 m was performed at 24°39'N, 69°42'W using the forward winch, and 12 bottles were fired. Instruments included in the test cast and all subsequent casts include dual temperature, conductivity, and oxygen, as well as upward- and downward-looking 300 kHz ADCPs. The winch and all CTD equipment performed well. The following day (March 10) the CTD package was hooked up to the aft winch, and at 17:30 UTC a second test cast to 1500 m was carried out. No major problems were found. We therefore kept the CTD package on the aft winch for the upcoming casts. A summary of all CTD casts performed during the cruise is available in Table 1 in section 2.1. On the way to the first mooring site, two batches of experimental surface drifting buoys were deployed as part of an AOML/PhOD experiment (led by Gustavo Goni, Rick Lumpkin, and Ulises Rivero) to determine the trajectories of Sargassum and marine debris in the tropical Atlantic. The first deployment occurred at 12:00 UTC on March 11 at 23°31'N, 61°44'W and consisted of 13 experimental drifters and 2 regular Surface Drifter Program (SVP) drifters, one with a drogue and one without. The specific date, times, and locations of deployments, as well as the types of experimental drifters, are summarized in Table 2 in section 2.3. The second batch of drifters, also consisting of 13 experimental and 2 SVP, was deployed at 10:00 UTC on March 14 at 21°08'N, 45°27'W.

The RHB arrived at the first mooring site (20°01’N, 37°52’W) at 12:30 UTC on March 16. The recovery and deployment were successful, and a CTD/ADCP cast was conducted between 00:00 and 01:30 UTC on March 17, after the mooring deployment. On the way to the next mooring site, two Argo floats were deployed, supplied by Pelle Robbins and Larry George of Woods Hole Oceanographic Institution. The locations and times of all Argo float deployments during the cruise are shown in Table 3 in section 2.3. Weather conditions worsened as we transited to the 20.5°N, 23°W mooring, with strong northeasterly trade winds of 20-30 kt and seas increasing to 10-12 ft. Upon arrival at the mooring site on the morning of March 20, it was determined that the conditions were too rough to recover the mooring that day. The main considerations were the sea state, which consisted of 10-12 ft short-period swells from multiple directions, and sustained winds of 25-30 kt, which were close to the limit for safe operation of the ship's crane. Because conditions were not forecast to improve in the following two days, and since we were already about three days behind schedule due to time lost to unexpected ship repairs (2 days) and weather (1 day), we decided to leave the mooring in the water. A CTD cast to 1500 m was performed at the mooring site (20°27’N, 23°09’W) between 12:00 and 13:30 UTC. An Argo float was deployed shortly after leaving the mooring location (see Table 3 for exact time and location), as was the third batch of experimental surface drifters (Table 2).

Because of the time lost to ship repairs in Ft. Lauderdale and to the weather going from the first mooring to the second mooring, the CTD stations planned for the “whole number” latitudes going southward between 20°N and 16°N were abandoned, leaving only 19°30'N, 18°30'N, 17°30'N, 16°30'N, and 15°30'N. All casts were performed to 1500 m. The 12-hour CTD watches consisted of Greg Foltz and Diego Ugaz (12 pm – 12 am) and Charles Featherstone and Luis Pomales (12 am – 12 pm). Featherstone conducted all oxygen titration of CTD water samples. Ugaz and Pomales performed all salinity calibration readings using autosal “Joisey” in the temperature-controlled autosal room. An Argo float was deployed inside the Cape Verde EEZ (18°12'N, 23°00'W) and two SVP drifters were deployed at 17°12'N, 23°W. As the RHB progressed southward along 23°W, conditions improved and the originally-planned 0.5° spacing of CTD casts along 23°W was restored starting at 15°30'N and proceeding southward toward the next mooring at 11.5°N. At the 12.5°N CTD station, several oxygen sensors were attached to the CTD frame prior to the cast in order to provide calibration data for oxygen sensors mounted to the 11.5°N PNE mooring. These sensors were part of a German (GEOMAR) project to monitor dissolved oxygen in the upper 300 m from three PNE moorings along 23°W. A GEOMAR technician (Boris Kisjeloff) was aboard to oversee the oxygen sensor deployments and calibrations. During the CTD cast, the package was stopped for three minutes at 7 different depths during the upcast so that the oxygen sensors could acquire robust readings.

During several CTD casts prior to arrival at the 11.5°N mooring, large “spikes” in the readings from multiple sensors were noticed. There was also an increase in the number of modulo errors reported. Therefore, prior to the CTD cast at the 11.5°N mooring location, the CTD package was disconnected from the aft winch wire and connected to the forward winch. The forward winch worked perfectly for all remaining casts (no data spikes, no modulo errors). For several casts north of 11.5°N, highly anomalous oxygen titration values were noticed (values were much lower than the CTD sensor values and previous titration values). The night shift (Foltz, Ugaz) adjusted their sampling technique to include slower injection of chemicals and to limit the time between injection and shaking. These improvements eliminated the large discrepancies that had been present for previous casts. The titration values from casts 007, 008, 012, 013, and 014 were excluded from the analysis used to correct the CTD oxygen profiles.

The RHB arrived at the third PNE mooring (11°29’N, 23°00’W) at 9:00 UTC on March 23. After a successful mooring recovery and deployment, at CTD cast was performed to 1500 m, beginning 18:00 UTC and ending 19:30 UTC. The RHB continued southward along 23°W, performing CTD casts every 0.5° of latitude until the next mooring at 4°N. Two SVP drifters were deployed at 10°00'N, 23°00'W and two were deployed at 7°00'N, 23°00'W (see Table 2).

The 4°N, 23°W PNE mooring was reached at 8:00 UTC on March 26. The mooring recovery was successful, including 11 Nortek current meters, 10 of which were part of an AOML/PhOD project (Tropical Atlantic Current Observations Study, TACOS) to measure the upper-ocean horizontal velocity and its vertical shear. The mooring that was deployed included 5 Nortek current meters as a follow-on to the successful TACOS experiment. A CTD cast to 1500 m was conducted following the mooring operations (17:30-19:00 UTC). Several GEOMAR oxygen sensors were attached to the CTD frame for calibration readings, and the CTD package was stopped at 6 locations on the upcast to acquire readings.

After the mooring operations at 4°N, RHB continued southward along 23°W while performing CTD casts every 0.5° of latitude until 1°N. From 1°N to the equator, the spacing between casts was reduced to 0.25° of latitude. The pre-cruise plan included high-resolution casts within 2° of the equator. However, days lost to RHB ship repairs in Ft. Lauderdale prevented us from achieving this. During the CTD cast at 0°30'N, salinity and oxygen readings from the secondary sensor were significantly biased in the upper 20-30 m during the downcast. The problem persisted for four additional casts until it was realized that the secondary pump “y-valve” tube was not allowing air to escape efficiently. After the tube was replaced, all sensors worked normally again. The problems with the secondary sensor readings during those casts did not affect the processed CTD profiles because the primary sensor values were used.

The 0°, 23°W PIRATA mooring, maintained by the French, was reached in the morning of March 28. Small boat operations were used to replace the radiation and rain sensors on the buoy, which could not be replaced during a French servicing cruise several weeks earlier. A deep CTD cast to 3750 m was carried out prior to the mooring work, and the fourth and final experiment drifting buoy batch was deployed following the buoy servicing. Between the equator and 1°S, CTD casts were performed every 0.25° of latitude, then at 0.5° spacing to 3°S. Several surface drifters and

Argo floats were deployed during the transit from the last CTD station at 3°S to Durban, South Africa (see Tables 2 and 3 for detailed information).

Summary of oceanographic and atmospheric work performed and data collected during the cruise:

1. Recovery and redeployment of three TFlex moorings at 20°N, 38°W; 11.5°N, 23°W; and 4°N, 23°W.
2. Replacement of surface radiation sensors and rain gauge on 0°, 23°W mooring.
3. CTD/O_2/ADCP profiles to 1500 dbar at 50 locations, including each TFlex mooring site.
4. CTD/O_2/ADCP profile to 3750 dbar on the equator.
5. Salinity of the CTD bottle samples collected with Niskin bottles.
6. Dissolved oxygen concentration of the CTD bottle samples collected with Niskin bottles.
7. Dissolved inorganic carbon concentration from near-surface CTD bottles (one per cast).
8. Deployment of 65 satellite-tracked surface drifting buoys (10 standard SVP, 55 experimental).
9. Deployment of 12 Argo floats.
10. Continuous recording of shipboard ADCP data.
11. Continuous recording of Thermosalinograph (TSG) data.
12. Heading data from the Meridian Attitude and Heading Reference System (MAHRS) and the Position and Orientation Systems for Marine Vessels (POS MV).
13. Weatherpak meteorological sensors (Univ. Miami).
14. Microwave radiometer (Univ. Miami).
15. Marine Atmospheric Emitted Radiance Interferometer (M-AERI) (an infrared Fourier transform spectrometer (FTS)) to measure uplooking and downlooking spectral radiances, marine boundary layer profiles of temperature and water vapor, and skin SST (Univ. Miami).
16. Mole fraction of carbon dioxide in air (NOAA/AOML).
17. Automated surface pCO_2 (NOAA/PMEL).

Oceanic Data

1. TFlex moorings (from Steve Kunze, NOAA/PMEL)

Summary of Mooring Operations		
Site	**Mooring ID #**	**Operation**
20N, 38W	PT013/PT021	Rec / Depl
20.5N, 23W	PT012/PT	Sched. Rec / Depl cancelled
11.5N, 23W	PT011/PT022	Rec / Depl
4N, 23W	PT009/PT023	Rec / Depl
0, 23W	PT018	Repair

Lost or Damaged Instruments and Equipment ***(from rec moorings)***
None

On-deck instrument or hardware failure ***(pre-deployment)***		
Sensor type	**Serial No**	**Comments**
Tflex tube	0009	Indicated "computer to modem comms are bad." See comments below.
Tflex tube	0052	Iridium call data incomplete. See comments below.
Rain gauge	728	No data
Rain gauge	1952	Unstable data
Rain gauge	1947	No data

Acoustic releases
All acoustic releases performed well.

Fishing and Vandalism		
Site	**Mooring ID**	**Comments**
20N, 38W	PT013	Ball of longline wrapped around 200 m OTN sensor
11.5N, 23W	PT011	Small amount of fishing line entangled on bridle above SSTC. No damage noted.
4N, 23W	PT009	Longline fouling @ 40 m, 56.6 m, 60 m, below 100 m sensor. 200 m OTN pushed up wire to 180 m sensor. Nilspin cut to core at 200 m.

Shipping notes:

Two step bed trucks were loaded for transport to Ft. Lauderdale and were sent off prior to receiving word that there was a delay with the ship schedule. One driver was able to accommodate the delay while the other had to unload our equipment to storage in Ft. Lauderdale and move on. Arrangements were made and the goods were re-loaded and delivered to the RHB in a timely manner. Loading our equipment onto the ship, on schedule, was completed trouble free.

Upon the completion of the cruise an air freight shipment consisting of all of the recovered and unused instruments, with the exceptions of the recovered Aquadopps and long wave radiation sensors, was arranged through Global Logistics Shipping via Mae Chu and picked up pier side shortly after arrival.

Noteworthy Operational Details:

20N, 38W
PT013 Recovery: The 60m TC had been flagged as being constant and the SSC was noted as shifted. Also note that the rain gauge, #1843, was a reused sensor that was swapped out from a prior repair on the last PNE cruise.
Longline fouling was present at the 200m OTN sensor on recovery.
Upon acquiring data the 60m TC was found not to be logging. Its sample count was ~6100 less than that of the other sensors. The clock error was similar and the battery voltages looked ok.
Unmarked nylon Z172 was recovered with some damage near the bottom thimble. This was noted on the prior deployment log and was held back for this subsequent deployment. It was later re-terminated to keep it in circulation. Two meters were removed from it and the new length of 656m was reported to the lab to update the master record.

20.5N, 23W
Operations Cancelled. Due to heavy seas and high winds operations had to be abandoned. The conditions exceeded the safe operating parameters of the ship cranes with sustained 25kt+ winds.

11.5N, 23W
PT011 Recovery: There were a lot of resets documented during this deployment and TP500 was flagged as =1E35. There was a minor, non-damaging amount of fishing line on the bridle above the SSTC sensor. The case screws at the base of the shield were missing from the SSTC but the sensor was uncompromised.
Upon data recovery both of the TP sensors had dead batteries. New batteries were used to attempt to recover any data. 9774 samples were recovered from TP300, far less than the data recovered from other operational sensors. TP500 had no recoverable data.

4N, 23W
PT009 Recovery: This site was flagged for bad rain data, and failure of Aquadopps at 6.6m, 36.6m, and 86.2m due to low battery power. C60 was reported high and it had reset once. There was a fair amount of longline discovered from 40 to 60 meters with the 40m, 56.6m, and 60m sensors fouled by it. Some longline was also found just below the 100m sensor and that was as far as it went. The OTN sensor had been pushed up the nilspin to the bottom of the 180m sensor and there was a gash in the nilspin exposing the core at the original 200m location of the sensor. Many of the Aquadopp serial numbers could not be determined on deck during recovery. However, when the net shedding cones were removed the numbers were found to be painted onto the cases next to the connectors. Upon data recovery the flagged Aquadopps all had partial data records. The 6.6m unit had lasted longer than the other two. Its clock error wasn't extreme but the date was significantly off by over a month. The dates on the other two appeared to be lost completely and the clocks errors were greater.

0, 23W
PT018B Repair: This mooring site which is routinely serviced by our French partners had been recently deployed by them using recovered short and long wave radiation sensors and no rain gauge due to lack of available inventory. A "repair" operation was performed to update the mooring with fresh sensors. Due to problems that were experienced on this cruise with our rain

gauges there were none that were ideal candidates. An attempt to use a one that tested noisy on deck failed. It didn't provide any output when swapped in. Therefore the rain gauge that we had just recovered five days earlier at 11.5N23W was used. This was problematic as well but eventually the TFLEX system recognized it and the operation was completed successfully.
This was my first personal experience conducting a repair on a TFLEX buoy. Serious consideration must be given regarding the sea state when conducting these types of operations. It requires direct PC communications with the TFLEX tube thus exposing the connection for brief periods of time which may subject it to water splashing over the buoy hull.

Instrumentation and Hardware Notes:

TFLEX Tube 0009: Upon setting up this system with the intent of deploying it at 4N23W it indicated that "computer to modem comms are bad" when the XMIT test was attempted. The tube was opened up and four circuit board standoffs were found to be broken which, in effect, left the cpu, met, and serial boards dangling. The faceplate circuit board exhibited evidence of moisture exposure as well. This system had been programmed with version 2.01 firmware which was necessary for the mooring design for which it was intended. Our spare system, 0003, had version 1.16. In the hopes that the 2.01 programmed CPU board in 0009 still functioned properly it was used to replace the CPU in system 0003. This turned out to be successful. Modified configuration settings to the CPU were made to change it from 0009 to 0003 and the system was deployed as 0003.
Unused TFLEX tube 0009 now has the CPU from 0003 in it for shipment back to PMEL. Some parts provided by the RHB ET helped to piece the circuit boards back into place. It is less than ideal and will need to be addressed back at PMEL.

TFLEX Tube 0052: This system had tested well up until about March 15 th when it was observed that the iridium dial-ins were supplying only a few hours of data versus the six hours that were expected. The firmware in this system is 1.16 which is susceptible to problems if there are issues with any Aquadopps that are testing on it. A loose inductive connection was found on the Aquadopp that was connected to the system. This was fixed but the problem persisted. It was intended to be deployed at 20.5N23W but operations were cancelled due to rough sea and weather conditions. It was packed for return to PMEL.

Rain Gauges: Unsurprisingly, the unpredictability of our rain gauges plagued us from the outset of this cruise. Both of our spares had to be rotated in within one day of testing and a recovered gauge had to be used for a repair.

GEOMAR Oxygen Sensors: There were no problems encountered when testing the sensors on deck for real-time data. Two sites were chosen for these deployments however operations at the first site, 20.5N23W, were cancelled. At the second location, 11.5N23W, the oxygen sensors did not perform as expected once deployed. Due to the Aquadopp glitch inherent in firmware 1.16, the Aquadopp was commented out of the system calibration file until after the inductive loop was complete on the deployment. At that time the calibration file was resent to include the Aquadopp. The O2 data from address 7 never came in, address 13 came in for only a few transmissions, and address 15 seemed alright throughout the operation. Buried in the incoming data stream there seemed to be some indication identifying the two sensors in question but we could not interpret this. After consulting with Dan Dougherty on this behavior he endeavored and prevailed in getting the problem worked out at the lab.

Software Notes: None

Ship Notes or issues:

The ORE 8011M deck units that we are now using are not compatible with the RHB hull mounted transducer which is wired for the older 8011/8011A deck units. There had previously been a pigtail onboard to adapt our units to the shipboard system. It has since gone missing. Word was passed on to the lab and pigtail cables were purchased for use on upcoming RHB cruises. Recovered releases were interrogated by lowering our own transducer over the side.

Ancillary Projects:

A German GEOMAR representative also participated on this cruise in collaboration with PMEL to install oxygen loggers on the subsurface string of the three 23W locations. The TFLEX systems at 20.5N and 11.5N were configured for real-time oxygen data while standalone oxygen measurements are being taken at 4N. The 20.5N site operations were cancelled though as previously mentioned.

2. Conductivity-Temperature-Depth (CTD) and Acoustic Doppler Current Profiler (ADCP) casts

2.1 CTD casts

AOML's CTD package was initially configured with 24 Niskin bottles. For the PNE cruise, 8 bottles were removed in order to make more room around the sensors and ADCPs, leaving 12 bottles to be fired at various depths during the casts (to collect water samples for salinity and dissolved oxygen calibration) and four spare bottles. The sensors on the CTD frame consisted of primary and secondary temperature, conductivity, and oxygen (six total) and upward- and downward-looking 300 kHz ADCPs.

A total of 50 CTD/ADCP casts, including two instrumented test casts, was conducted by Greg Foltz, Diego Ugaz, Charles Featherstone, and Luis Pomales, with assistance from the Survey Technicians (Table 3). CTD processing was performed using Seabird software. After acclimating in the autosal room for at least two days, salinity samples were calibrated using the autosal "Joisey." Oxygen titration was performed by Charles Featherstone in order to calibrate dissolved oxygen concentration obtained from the CTD sensors.

Table 3 Date (UTC), start time (UTC), end time (UTC), latitude, and longitude of CTD casts.

CTD #	Date	Start	End	Latitude	Longitude	Description
0	Mar 9	19:20	20:45	24°39.4'N	69°42.4'W	test cast (1500 m)
1	Mar 10	17:30	18:55	24°01.6'N	65°17.3'W	test cast (1500 m)
2	Mar 17	00:00	01:15	20°01.3’N	37°50.4’W	at mooring (1500 m)
3	Mar 20	12:00	13:15	20°26.7’N	23°08.6’W	at mooring (1500 m)
4	Mar 20	19:05	20:30	19°30.0’N	23°00.0’W	(1500 m)
5	Mar 21	01:55	03:10	18°30.0’N	23°00.0’W	(1500 m)
6	Mar 21	08:30	09:45	17°29.9’N	23°00.1’W	(1500 m)
7	Mar 21	15:15	16:30	16°29.9’N	22°44.0’W	(1500 m)
8	Mar 22	22:30	23:50	15°29.9’N	22°44.0’W	(1500 m)
9	Mar 22	02:30	03:45	15°00.0’N	22°52.0’W	(1500 m)
10	Mar 22	06:30	07:50	14°29.9’N	22°59.9’W	(1500 m)
11	Mar 22	10:35	11:50	14°00.1’N	23°00.0’W	(1500 m)
12	Mar 22	14:45	16:00	13°29.9’N	23°00.0’W	(1500 m)
13	Mar 22	18:40	19:00	13°00.0’N	23°00.0’W	(1500 m)
14	Mar 23	22:40	00:15	12°30.1’N	23°00.0’W	(1500 m)
15	Mar 23	03:00	04:10	12°00.0’N	23°00.0’W	(1500 m)
16	Mar 23	17:55	19:25	11°28.9’N	22°59.7’W	at mooring (1500 m)
17	Mar 23	23:05	00:20	11°00.0’N	23°00.1’W	(1500 m)
18	Mar 24	03:05	04:20	10°30.0’N	23°00.0’W	(1500 m)
19	Mar 24	07:00	08:15	10°00.0’N	23°00.1’W	(1500 m)
20	Mar 24	11:00	12:10	09°30.1’N	23°00.0’W	(1500 m)
21	Mar 24	14:55	16:05	09°00.0’N	23°00.0’W	(1500 m)
22	Mar 24	18:50	20:05	08°30.0’N	23°00.0’W	(1500 m)
23	Mar 24	22:45	00:00	08°00.1’N	23°00.0’W	(1500 m)

24	Mar 25	02:40	03:50	07°30.0’N	23°00.0’W	(1500 m)
25	Mar 25	06:35	07:50	07°00.0’N	23°00.0’W	(1500 m)
26	Mar 25	10:35	11:45	06°30.0’N	23°00.0’W	(1500 m)
27	Mar 25	14:35	15:45	05°59.9’N	23°00.0’W	(1500 m)
28	Mar 25	18:30	19:45	05°30.0’N	23°00.3’W	(1500 m)
29	Mar 25	22:25	23:40	05°00.7’N	23°00.0’W	(1500 m)
30	Mar 26	02:20	03:30	04°30.0’N	23°00.0’W	(1500 m)
31	Mar 26	17:30	19:00	04°02.9’N	23°00.1’W	at mooring (1500 m)
32	Mar 26	22:30	23:45	03°30.0’N	23°00.0’W	(1500 m)
33	Mar 27	02:30	03:40	03°00.0’N	23°00.0’W	(1500 m)
34	Mar 27	06:25	07:50	02°30.0’N	23°00.0’W	(1500 m)
35	Mar 27	10:30	11:50	02°00.0’N	23°00.1’W	(1500 m)
36	Mar 27	14:40	15:45	01°29.9’N	23°00.2’W	(1500 m)
37	Mar 27	18:30	19:45	01°00.1’N	23°00.1’W	(1500 m)
38	Mar 27	21:10	22:30	00°45.1’N	23°00.0’W	(1500 m)
39	Mar 28	00:00	01:15	00°30.1’N	23°00.1’W	(1500 m)
40	Mar 28	02:30	03:45	00°15.0’N	22°59.6’W	(1500 m)
41	Mar 28	05:20	07:50	00°01.0’N	22°57.2’W	at mooring (3750 m)
42	Mar 28	14:10	15:20	00°15.1’S	22°59.7’W	(1500 m)
43	Mar 28	16:55	18:10	00°30.1’S	23°00.0’W	(1500 m)
44	Mar 28	19:45	21:00	00°45.0’S	23°00.0’W	(1500 m)
45	Mar 28	22:35	23:45	01°00.0’S	23°00.0’W	(1500 m)
46	Mar 29	02:20	03:30	01°30.0’S	23°00.0’W	(1500 m)
47	Mar 29	06:10	07:25	02°00.0’S	23°00.0’W	(1500 m)
48	Mar 29	10:05	11:15	02°30.0’S	23°00.1’W	(1500 m)
49	Mar 29	14:00	15:15	02°59.9’S	23°00.2’W	(1500 m)

The latitude-depth section of temperature from the CTD casts shows the warmest sea surface temperatures (SSTs) concentrated in the 0°-7°N latitude band of the intertropical convergence zone (ITCZ) (Fig. 2). SSTs in the ITCZ region exceed 27°C and drop to 24°C-26°C to the north and south. A sharp seasonal thermocline is present at the base of the mixed layer at all locations, with the temperature decreasing approximately 10°C over a distance of 10-20 m. The meridional slopes of the isotherms are consistent with the dominant zonal currents in the eastern tropical Atlantic: the westward North Equatorial Current (NEC) between 10°N-20°N, the eastward North Equatorial Countercurrent (NECC) between 3°N-10°N, and the westward South Equatorial Current between 1°S-3°S.

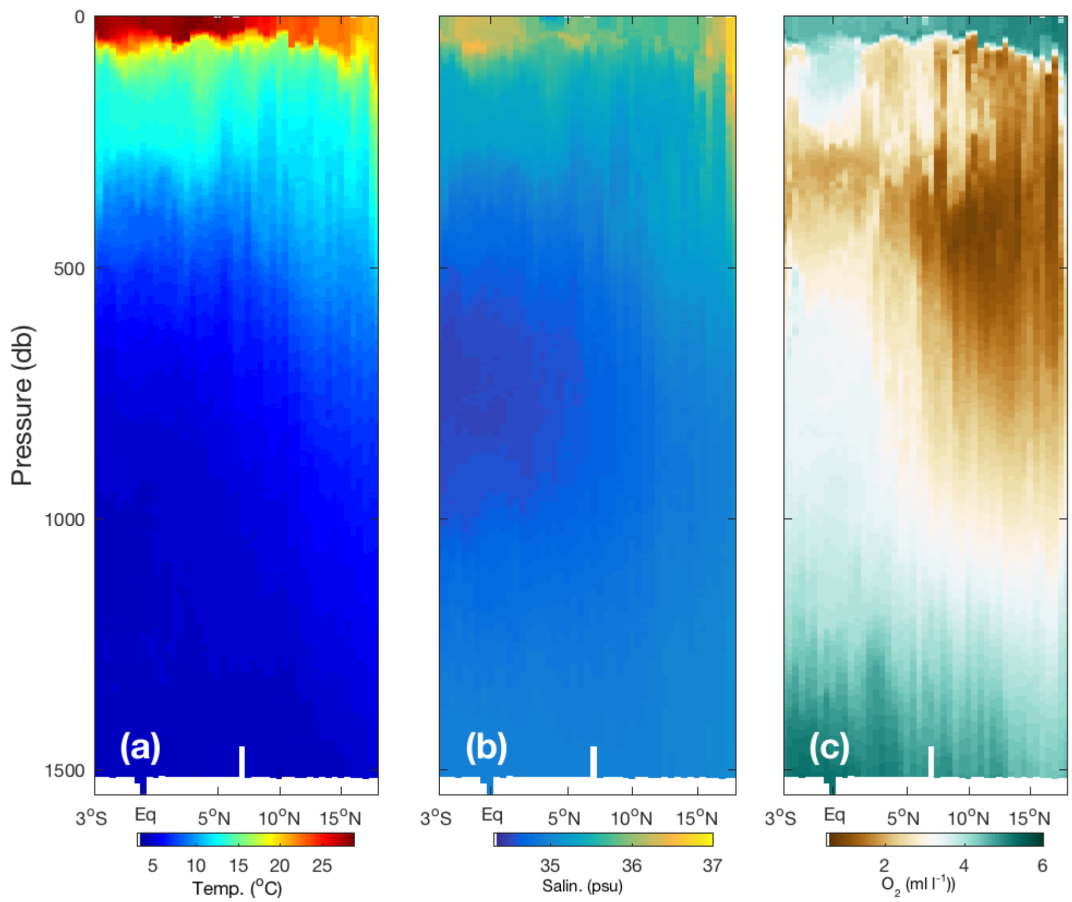

Figure 2 Latitude-depth sections of (a) temperature, (b) salinity, and (c) oxygen acquired along 23°W during the cruise.

The salinity section shows the low-salinity core of the Antarctic Intermediate Water between 400 and 1200 dbar, freshest at 3°S and becoming saltier to the north (Fig. 2). High-salinity subtropical water (>36.5 PSS) is apparent at depths of 0-100 m between 15°N and 20°N and to a lesser extent between 40-70 m just south of the equator. The 15-20°N high-salinity water mass can be traced in part to the subtropical North Atlantic, where an excess of surface evaporation over precipitation leads to the highest surface salinity in the global ocean. The subtropical salinity maximum water subducts and travels poleward in the eastern tropical North Atlantic. In the subtropical South Atlantic, high-salinity water subducts and travels northward to the equator, where it is carried eastward in the Equatorial Undercurrent. The high-salinity features visible at 20°N and on the equator in the latitude-depth section are consequences of the subduction of subtropical salinity maximum water in the North and South Atlantic, respectively. Much lower values of salinity (34.5-35.5) in the upper 40 m between 3°N-5°N result from an excess of precipitation over evaporation in the ITCZ.

The dissolved oxygen section along 23°W shows high concentrations (> 4 ml l^{-1}) in the surface mixed layer and below 1200 dbar (Fig. 2). There is a pronounced oxygen minimum zone centered at a depth of about 300-500 m between 5°N-20°N. This water is in the stagnant shadow zone of the North Atlantic, which is not part of the circulation associated with the ventilated thermocline of the subtropical gyre.

Salinity calibration values from the CTD bottle samples are available for each cast. The autosal performed well and the room temperature remained fairly stable, within about one degree of 24°C. The offset between each CTD bottle value and the associated autosal calibration value is shown in Fig. 3. The autosal run for casts 4-7 shows very little scatter in the difference between the sensor and calibration values and a noticeable upward trend. It is unclear what caused this. The error for the calibrated salinity is 0.0045 psu, which is higher than the WOCE standard of 0.002 psu. Before correcting the CTD sensor values based on the calibration readings, the calibration readings were corrected for any spurious trends identified during each autosal run, using the Matlab code provided by Jay Hooper.

Oxygen calibration values from the CTD bottle samples are available for each cast. The oxygen titration for each sample was performed during the cruise by Charles Featherstone. As noted previously in the report, larger than expected offsets between the calibration values and sensor values were noticed during several casts and were likely caused by suboptimal sampling procedures. These titration values were removed before correcting the CTD sensor values. The offset between the sensor and calibration readings show the expected dependence on depth, with larger offsets (sensor value too low) at greater depths (Fig. 3). The error for the calibrated oxygen is 0.033 ml/l, which is roughly 1% of the measured oxygen concentrations and within the range recommended by WOCE.

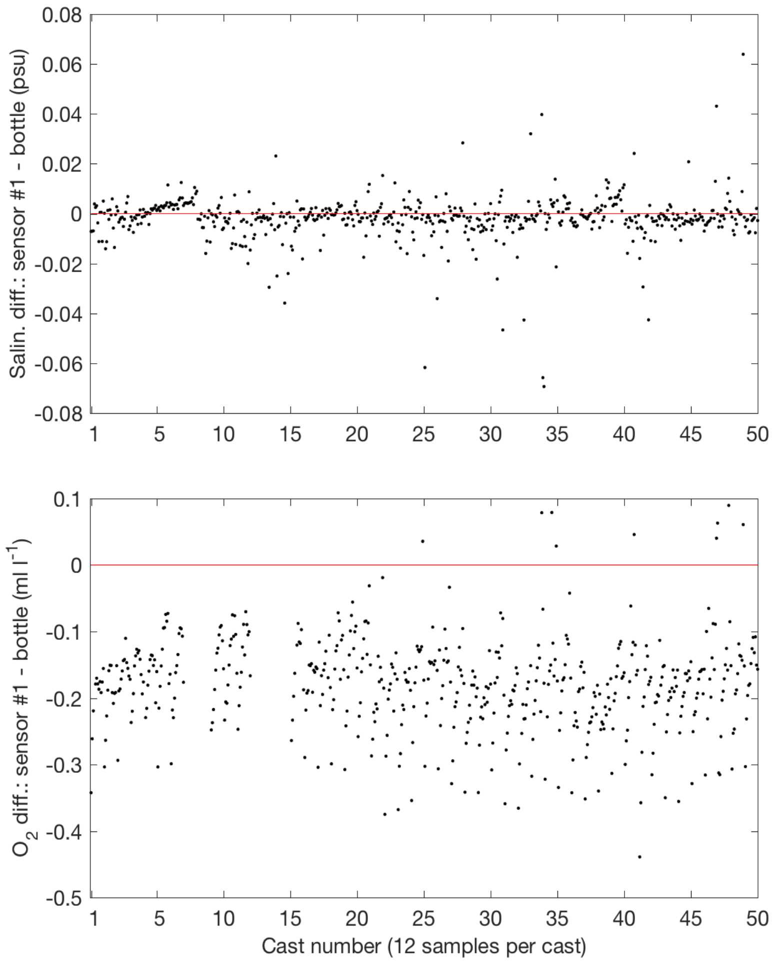

Figure 3 (top) Difference between salinity value from CTD primary sensor and bottle sample. Negative values indicate that bottle sample was higher than sensor value. Red line shows a difference of zero. (bottom) Same as (top) except for oxygen concentration.

2.2. ADCP casts

A total of 50 lowered ADCP casts were obtained using upward- and downwar-looking 300 kHz ADCPs. The resultant meridional sections of zonal and meridional velocity are shown in Fig. 4. The equatorial undercurrent is clearly visible within about 1.5° of latitude from the equator, with eastward velocities reaching 1 m/s. Strong westward flow of the South Equatorial Current is noticeable north and south of the undercurrent core.

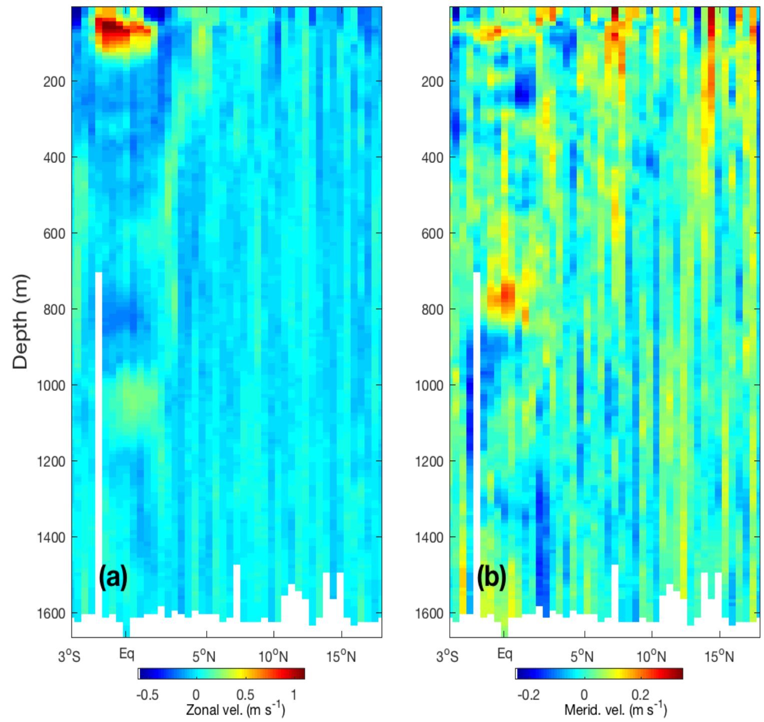

Figure 4 Zonal (a) and meridional (b) velocity sections along the 23°W cruise track from the lowered ADCP casts.

2.3. Surface drifter and Argo deployments

A total of 55 experimental debris and sargassum surface drifters was deployed during the cruise. Fig. 5 shows pictures of some of the deployments. In addition, 10 regular SVP drifters were deployed. See Fig. 1 and Table 2 for the drifter deployment locations and times.

Figure 5 Deployments of (left) debris drifters and (right) sargassum drifters at 0°, 23°W.

Table 2 Date (UTC), time (UTC), latitude, and longitude of drifter deployments.

Date	Time	Latitude	Longitude	Description
Mar 11	12:00	23°31'N	61°44'W	*Experimental batch #1:* 4 medium spheres 1 large spheres 3 cubes 2 squares 3 sargassum 1 drogued SVP, 1 undrogued SVP
Mar 14	20:00	21°8'N	45°27'W	*Experimental batch #2:* 4 medium spheres 1 large spheres 3 cubes 2 squares 3 sargassum 1 drogued SVP, 1 undrogued SVP
Mar 20	14:20	20°19'N	23°07'W	*Experimental batch #3:* 4 medium spheres 2 cubes 2 squares 3 sargassum 1 drogued SVP, 1 undrogued SVP
Mar 28	12:30	00°00'N	22°59'W	*Experimental batch #4:* 3 medium spheres 2 cubes 2 squares 3 sargassum 1 drogued SVP, 1 undrogued SVP
Mar 21	11:35	17°12'N	22°53'W	2 SVP
Mar 24	08:15	10°00'N	23°00'W	2 SVP
Mar 25	07:50	07°00'N	23°00'W	2 SVP
Mar 29	15:30	03°01'S	22°59'W	1 SVP
Mar 30	17:00	06°00'S	19°24'W	1 SVP
Apr 01	10:35	11°10'S	13°07'W	1 SVP
Apr 02	01:15	13°00'S	10°52'W	1 SVP

A total of 10 Argo floats were deployed (see Fig. 1 and Table 3 for details). They were housed in individual cardboard boxes with straps around them that were held together by a water-activated release. A long rope was provided for lowering the box over the railing off the back of the ship. Within a few seconds of hitting the water, the release activated, setting free the float in the box and allowing us to pull up the straps and release. The straps and releases were saved and placed in the AOML storage container for later shipment to WHOI.

Table 3 Date (UTC), time (UTC), latitude, and longitude of Argo deployments.

Date	Time	Latitude	Longitude
Mar 17	11:50	20°05'N	36°01'W
Mar 19	07:00	20°18'N	27°15'W
Mar 20	14:10	20°20'N	23°08'W
Mar 21	04:50	18°12'N	23°00'W
Mar 31	08:55	08°00'S	16°59'W
Apr 01	00:50	09°57'S	14°35'W
Apr 01	17:15	12°00'S	12°05'W
Apr 02	09:10	14°00'S	09°37'W
Apr 03	01:00	15°58'S	07°10'W
Apr 03	17:20	18°01'S	04°36'W
Apr 04	09:15	20°00'S	02°04'W
Apr 04	23:00	22°00'S	00°18'W