CRUISE REPORT

***R/V Endeavor* Cruise EN-570**

RAPID/MOCHA Program
October 3-19, 2015
Port Everglades, FL to Port Everglades, FL

1. Introduction and Objectives

The RAPID/MOCHA/WBTS program is a joint research effort between the National Oceanography Centre (Southampton, U.K.), the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS), and NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML). The objective of this program is to continuously observe the strength and structure of the Atlantic meridional overturning circulation at 26.5º N using a trans-basin observing system. The U.K. program is referred to as "RAPID-WATCH" and is a part of the U.K. Rapid Climate Change Program (RAPID) funded by the National Environmental Research Council (NERC). The U.S. program is referred to as "MOCHA" (Meridional Overturning Circulation and Heat-flux Array) and is funded by the National Science Foundation (NSF). NOAA contributes significantly to the effort through its Western Boundary Time Series (WBTS) Program.

The goals of cruise EN-570 were to:

1. Service (recover and redeploy) 4 deep-sea moorings located off the eastern Bahamas along latitude 26.5°N.
2. Deploy 2 pressure-inverted echo sounders (PIES) and recover data from 6 PIES by underwater acoustic telemetry.
3. Conduct CTD (Conductivity-Temperature-Depth) and Lowered ADCP (Acoustic Doppler Current Profiler) sections across the Florida Current at 27ºN, Northwest Providence Channel, and along the 26.5ºN RAPID-MOCHA western boundary line east of Abaco, Bahamas, and
4. Perform several additional deep water CTD casts to calibrate moored instrumentation.

2. Cruise Synopsis

The cruise departed from Port Everglades (Ft. Lauderdale), FL on October 3 at 0830 local time. The ship arrived off Bimini at 1330 local to try to launch a small boat to go in and complete our Bahamian check in, but it was found to be too rough to accomplish this safely, and so the ship steamed on to Port Lucaya. This resulted in a considerable delay as we had to wait until morning (0900 Sunday AM) to go in, and ultimately we completed the clear-in (including a visit by the Bahamian immigration officer to the ship) by 1500 Sunday Oct. 4. After steaming the length of NW Providence channel and through Hole-in-the-wall, we stopped in deep water to do a test CTD/LADCP cast to 1000 m, followed

by a calibration CTD ("cal-dip") cast to the full ocean depth (Station 001). This cal-dip cast, and another one later in the cruise (Station 30), were done to obtain in-situ calibration data for all the Seabird microcat instruments to be deployed on, and recovered from, the moorings. As usual for these casts, the outer ring of Niskin bottles was removed and small airplane straps were put on the frame so that the microcats could be clamped on. The first cal-dip cast suffered from a very large wire-angle, due to a strong southward surface current (1-1.5 kts) and winds from the SW at >20 kts, forcing ship to steam almost with the surface current to maintain heading. As a result, the bottle stops - which are where the important calibration data are acquired - had significant vertical pressure changes, which hamper the calibration procedure. However, after examining the cast data it was determined that enough good data had been acquired so that the cal-dip cast did not need to be repeated.

Following this, the Abaco 26.5ºN CTDO_2/LADCP section was commenced on October 5th, and completed on October 11th (stations 2 to 29). The NOAA/AOML CTD/LADCP system was used, with a hybrid 150/300 kHz LADCP system using a NOAA 300 kHz Workhorse ADCP looking upward from the CTD frame and a U. Miami 150 kHz ADCP looking downward. The CTD and LADCP systems both functioned well for the entire section and no instruments or sensors had to be replaced, except for swap-out of the star-cable in the middle part of the section due to ADCP communication problems. The wire angle problem we had during the cal-dip cast also persisted for the early casts on the Abaco line, and resulted as well in large horizontal ship movement during the stations. We had to start CTD 003 about 1 nmi south of its normal position, to make sure we would not drift into either mooring WB0 or WB1 during the cast. These wire-angle problems gradually subsided along the section as both the winds and currents decreased. On one cast (CTD022), the LADCPs lost power due to insufficient battery charging after the previous casts (it was determined that the charger had not been properly connected after the star-cable swap). Some of the LADCP casts showed high-error profiles in deep water on the eastern half of the line, which is (unfortunately) rather typical due to the very weak scattering environment there.

During the Abaco CTD section, acoustic telemetry was attempted at several of the PIES sites (PIES sites B, C, D, and E) while doing CTD stations nearby them, and this worked very well in all cases. (This was the first MOCHA cruise where we have tried this, rather than doing the PIES data telemetry as a separate operation.) At one of the sites (PIES C) the data telemetry was also done again - during a nighttime break in the mooring operations after the CTD section was completed - in order to collect more data than could be collected during the time of the CTD cast.

After the Abaco CTD line was completed, mooring operations began, luckily under very cooperative weather. All planned mooring operations (Tables 1 and 2) were successfully completed between Oct. 13 – 16, beginning at mooring WBC and finishing at mooring WB0. The mooring operations all went relatively smoothly except that there were numerous tangles in the moorings when they came up, particularly on mooring WB3 (M420) where the segments between 3000 m and the bottom came up in reverse order, with several wire segments having to be stopped off and tended simultaneously. We also

experienced several problems with the new XEOS radios and strobes used on these moorings: on moorings WB0 and WBC the radios were never heard, and mooring WB3 the strobe did not work when shielded from sunlight. In each of these cases the batteries were found to be drained after being opened (meaning most likely that they never turned off once deployed, i.e. that the conductivity bridge switch did not turn them off once underwater.) The radio antenna on mooring WB0 was also bent and the metal inside was exposed with signs of corrosion, but it still worked (in air) after replacing the drained batteries, so this was apparently not the main problem (although how and why it broke is not known.) Finally, the radio on WB3 did not work after it surfaced, or during its recovery, until after the top float was brought on deck, when it suddenly came on strongly. In contrast, both of the Argos beacons (used on WB3 and WBC) functioned normally, with several messages being received after surfacing.

The instruments on all of the moorings came up in good shape, with no signs of damage. Initial download of the data showed that all of the instruments collected full records which appeared to be of good quality.

During breaks in the mooring work, additional PIES operations were conducted (Table 3), including deployment of two PIES (at sites A2 and C, the latter being a new "data-pod" PIES), and an attempted recovery of PIES-A2 (which was unsuccessful; this PIES had been malfunctioning for some time and had already had one failed recovery attempt on a previous cruise). Acoustic data telemetry was also performed at PIES site A. At the completion of all mooring and PIES operations, a final CTD cast (CTD 030) was done to provide post-recovery cal-dip data for the microcats recovered from mooring WB3.

On the evening of Oct. 16th the ship returned back through Hole-in-the-wall, heading for a planned morning (0900 local) clear-out of the Bahamas at Port Lucaya on Oct. 17th. Clear-out successfully completed at 1130. The CTD/LADCP section across Northwest Providence Channel (stations 31-35) was completed at 2130 on October 17th, and the final CTD/LADCP section across the Straits of Florida at 27°N (stations 36-44) was completed at 1530 on Oct 18th. Spikes were noted in the primary temperature sensor and salinity data on cast 39, and after this recurred again on cast 40 the primary temperature sensor was swapped. The pump on the primary side was also replaced after cast 41, and the pump cable was swapped after cast 42, which resulted in improved performance.

The scientific work of the cruise was finished with one day to spare, which was fortunate as a strong cold front descended over the Straits of Florida on the night of October 18th that would have made work in the Straits very difficult on the 19th. The ship arrived at the Port Everglades sea buoy at approximately 0400 local Oct 19th. Berthed by 0915. The cruise was very successful and all planned operations were accomplished.

3. Scientific Personnel

Name	Position	Organization
Bill Johns	Ch. Scientist	RSMAS/ U. Miami
Adam Houk	Scientist	RSMAS/ U. Miami
Mark Graham	Technician	RSMAS/ U. Miami
Cobi Christiansen	Technician	RSMAS/ U. Miami
Johna Ruszin	Student	RSMAS/ U. Miami
Florent Aguesse	Student	NOCS/RSMAS/U. Miami
Christopher Meinen	Co-ch. Sci.	NOAA/ AOML
Ulises Rivero	Technician	NOAA/ AOML
Grant Rawson	Technician	CIMAS/U. Miami
Pedro Pena	Technician	NOAA/ AOML
Tom Sevilla	Technician	CIMAS/U. Miami
James Hooper	Technician	CIMAS/U. Miami

3. Cruise Operations

3.1 Mooring Operations

Mooring Recoveries

Four subsurface moorings were successfully recovered from the locations listed in Table 1 and shown in Figure 1. These moorings contained a mixture of current meters, Acoustic Doppler Current Profilers (ADCPs), and temperature/salinity/pressure recorders. Site WBL3 is a short "bottom lander" mooring containing only a high precision bottom pressure sensor and releases.

Table 1. Mooring Recoveries

Mooring Site	Mooring Number	Latitude (ºN)	Longitude (ºW)	Depth (m)	Date of Recovery
WB0	M419	26° 30.54'	76° 50.51'	1005	10/16/2015
WB3	M420	26° 29.93'	76° 29.79'	4840	10/14/2015
WBC	M422	26° 30.84'	76° 06.24'	4809	10/13/2015
WBL3	M421	26° 29.36'	76° 29.18'	4845	10/13/2015

Mooring Deployments

Four moorings (3 taut-wire moorings and 1 bottom lander) were deployed at the locations listed in Table 3 and shown in Figure 1. Acoustic surveying of the on-bottom position of all moorings was successfully completed after each mooring deployment.

Table 2. Mooring Deployments

Mooring Site	Mooring Number	Latitude (ºN)	Longitude (ºW)	Depth (m)	Date of Deployment
WB0	M439	26° 30.52'	76° 50.47'	1006	10/16/2015
WB3	M440	26° 29.61'	76° 29.74'	4842	10/15/2015
WBC	M442	26° 30.76'	76° 06.35'	4819	10/14/2015
WBL3	M441	26° 28.89'	76° 28.86'	4845	10/16/2015

3.2 PIES Operations

NOAA/AOML maintains a line of pressure-equipped inverted echo sounders (PIES) along 26° 30' N as part of its Western Boundary Time Series program. Regular maintenance the PIES array was also performed on the cruise. This maintenance consisted primarily of acoustic download of the last ~8 months of daily-averaged data collected by the PIES. One PIES (Site C) was acoustically downloaded twice to allow for a longer download (i.e. lengthier file retrieved) on the second download. Unsuccessful efforts were also made to recover a malfunctioning PIES at Site A2; deployment of a replacement PIES at that site was successful. A new prototype 'data-pod' satellite data transmission device for a bottom moored PIES, called the Adaptable Bottom Instrument Information Shuttle System ("ABIISS"), was deployed for testing beside the existing PIES at Site C. The operations involving PIES during the cruise are summarized in Table 3.

Table 3. PIES Operations

Site Name	Latitude	Longitude	Date	Planned operation	Operation results
A	26° 30.938' N	76° 50.036' W	Oct. 15, 2015	Telemetry	Success
A2	26° 30.062' N	76° 44.775' W	Oct. 15, 2015	Recovery	Fail
A2	26° 30.075' N	76° 44.782' W	Oct. 15, 2015	Deployment	Success
B	26° 29.470' N	76° 28.180' W	Oct. 6, 2015	Telemetry	Success
C	26° 30.020' N	76° 05.550' W	Oct. 6 & 12, 2015	Telemetry	Success
C - ABIISS	26° 30.040' N	76° 05.550' W	Oct. 12, 2015	Deployment	Success
D	26° 30.130' N	75° 42.330' W	Oct. 7, 2015	Telemetry	Success
E	26° 30.000' N	71° 59.998' W	Oct. 9, 2015	Telemetry	Success

4. $CTDO_2$/LADCP Stations

A total of 44 $CTDO_2$ stations were conducted during the cruise (Table 4, Figure 2). At each station, profiles of temperature, salinity (conductivity), and dissolved oxygen concentration were collected from the surface to within approximately 20 m of the

bottom, using a dual Sea-Bird SBE-911plus CTD system. Some additional stations were performed to provide calibration data for SBE microcat instruments to be deployed on (or recovered from) the moorings. During these casts, the outer rack of Niskin bottles was removed from the Rosette to accommodate the mooring instruments and the CTD package was lowered to its target depth, with 5 minute bottle stops during the package retrieval. These casts were not part of the regular $CTDO_2$/LADCP hydrographic sampling performed on the cruise and are indicated by an asterisk (*) in Table 4.

Several new altimeters were tested during the CTD sections, including two Valeport and two Konsberg-Simrad altimeters. After adjustment all seemed to perform well; however one Valeport altimeter failed at station 30 for as-yet unknown reasons. A high-precision, fast-response thermistor (SBE-35RT, sampling at the bottle stops) was also used on the CTD package for all the stations on this cruise to enable more accurate calibration of the CTD temperature sensors.

Water samples for calibration of the salinity and dissolved oxygen profiles were collected using a 24-bottle Rosette system containing 10 liter Niskin bottles. Salinity samples were analyzed on a Guildline Auto-Sal salinometer, while dissolved oxygen samples were titrated using a modified Winkler technique with automated electrical endpoint determination.

Current profiles were also measured at the stations using a paired downward-looking 150 kHz and upward-looking 300 kHz Workhorse Acoustic Doppler Current Profiling 'hybrid" system (LADCP).

Table 4. $CTDO_2$ /LADCP Station Locations

Station	Date	Time (UTC)	Latitude (^oN)	Longitude (^oW)	Depth (m)
1*	10/05/2015	0755	25° 58.20	76° 53.86	4513
2	10/05/2015	1622	26° 30.78	76° 53.04	741
3	10/05/2015	1802	26° 29.46	76° 49.95	1272
4	10/05/2015	2013	26° 29.58	76° 44.88	3870
5	10/06/2015	0021	26° 29.64	76° 39.43	4682
6	10/06/2015	0450	26° 29.76	76° 34.20	4897
7	10/06/2015	0937	26° 29.58	76° 28.05	4902
8	10/06/2015	1419	26° 29.34	76° 20.95	4898
9	10/06/2015	1904	26° 28.86	76° 13.11	4876
10	10/06/2015	2338	26° 29.28	76° 05.11	4866
11	10/07/2015	0416	26° 29.10	75° 53.90	4801
12	10/07/2015	0857	26° 29.34	75° 43.11	4751
13	10/07/2015	1347	26° 29.40	75° 30.75	4748
14	10/07/2015	1904	26° 29.52	75° 18.46	4705
15	10/07/2015	2354	26° 29.58	75° 05.20	4674
16	10/08/2015	0446	26° 29.22	74° 48.24	4598
17	10/08/2015	0942	26° 29.52	74° 31.08	4552

18	10/08/2015	1427	26° 29.58	74° 13.71	4607
19	10/08/2015	1932	26° 30.24	73° 52.10	4799
20	10/09/2015	0057	26° 29.94	73° 29.41	5024
21	10/09/2015	0616	26° 30.00	73° 08.02	5123
22	10/09/2015	1156	26° 29.70	72° 46.37	5203
23	10/09/2015	1741	26° 30.06	72° 22.96	5263
24	10/09/2015	2352	26° 30.06	71° 59.38	5372
25	10/10/2015	0820	26° 30.18	71° 29.73	5501
26	10/10/2015	1436	26° 30.36	70° 59.25	5576
27	10/10/2015	2057	26° 29.52	70° 28.72	5580
28	10/11/2015	315	26° 29.58	69° 59.27	5577
29	10/11/2015	949	26° 30.18	69° 29.64	5430
30*	10/16/2015	2234	25° 57.30	76° 53.73	4444
31	10/17/2015	1600	26° 25.98	78° 39.96	748
32	10/17/2015	1731	26° 20.04	78° 42.92	667
33	10/17/2015	1849	26° 15.18	78° 45.85	508
34	10/17/2015	2004	26° 10.08	78° 47.96	439
35	10/17/2015	2123	26° 04.03	78° 50.91	293
36	10/18/2015	411	27° 00.12	79° 12.13	466
37	10/18/2015	535	27° 00.10	79° 17.12	600
38	10/18/2015	647	27° 00.09	79° 23.10	650
39	10/18/2015	808	27° 00.27	79° 30.10	745
40	10/18/2015	942	27° 00.27	79° 37.08	620
41	10/18/2015	1104	27° 00.58	79° 41.04	515
42	10/18/2015	1250	27° 00.30	79° 47.15	370
43	10/18/2015	1409	27° 00.96	79° 52.14	235
44	10/18/2015	1515	27° 00.35	79° 56.14	120

* Instrument calibration casts

5. Underway Measurements

Thermosalinograph

Values of surface temperature and salinity were continuously monitored using a Sea-Bird temperature-conductivity recorder installed in the ship's seawater intake line, and logged by the vessels's underway recording system.

Shipboard Acoustic Doppler Current Profiler

Upper ocean currents were continuously measured with a 300 kHz vessel-mounted Acoustic Doppler Current Profiler (ADCP). The second VM ADCP system (a 75 kHz Ocean Surveyor system) was unfortunately not available for the cruise due a transducer malfunction that was discovered before the cruise but could not be repaired in time. The depth range of good velocity data from the 300 kHz system typically extended to 80 m

below the vessel. Data were processed onboard in real time using the UHDAS acquisition system. Gyrocompass data were continuously corrected by an ASHTEK multi-receiver GPS system.

6. Preliminary Results

The Abaco section showed a flow pattern that is fairly typical of the region - a strong southward Deep Western Boundary Current below 1000 m within about 100 km of the Bahamas escarpment, overlain by a northward, thermocline-intensified Antilles current centered at about 300-500 m depth along the Abaco shelf (Fig. 4). Surface currents just above the core of the Antilles current were southward and very strong, in excess of 0.5 m/s. Offshore of the Deep Western Boundary Current were two bands of northward recirculation, and farther offshore the currents were variable and mostly weaker except for some stronger bands of deep flow (which may not be real due to errors associated with the very weak backscattering strength in the deep offshore region).

The Florida Current was found to be relatively weak at the time of the CTD/LADCP section across it, on Oct. 18, judging by surface currents that were ≤1.5 m/s when values of ≥2.0 m/s are more typical.

7. Release of Project Data

In accordance with the provisions specified in the cruise prospectus and application for Bahamian clearance, the full data results from this experiment will be provided to the Commonwealth of the Bahamas according to the following schedule:

Shipboard Measurements

All shipboard measurements, including underway data records and $CTDO_2$/LADCP station data, will be provided within 1 year of the termination of the cruise (October, 2016).

Moored Instrumentation

Time series data records from the moored instruments will be provided within 2 years of recovery of the instruments (nominally October, 2017).

7. Acknowledgements

The support and able assistance provided by the Captain and crew of the *R/V Endeavor* is gratefully acknowledged. Support for the scientific research was provided by the U.S. National Science Foundation and the NOAA Climate Program Office. The Commonwealth of the Bahamas graciously granted privileges to conduct scientific research in their territorial waters.

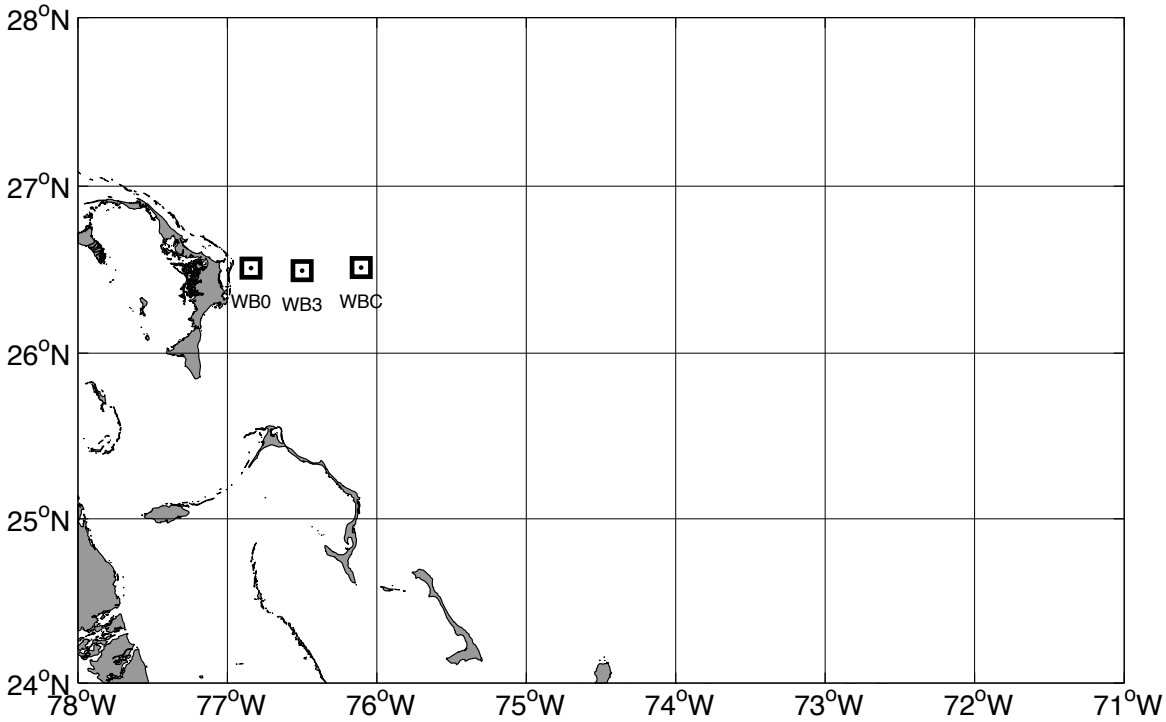

Figure 1. Current meter moorings recovered and deployed on EN-570. An additional "bottom lander" mooring (WBL3, not shown on map) was deployed near mooring WB3.

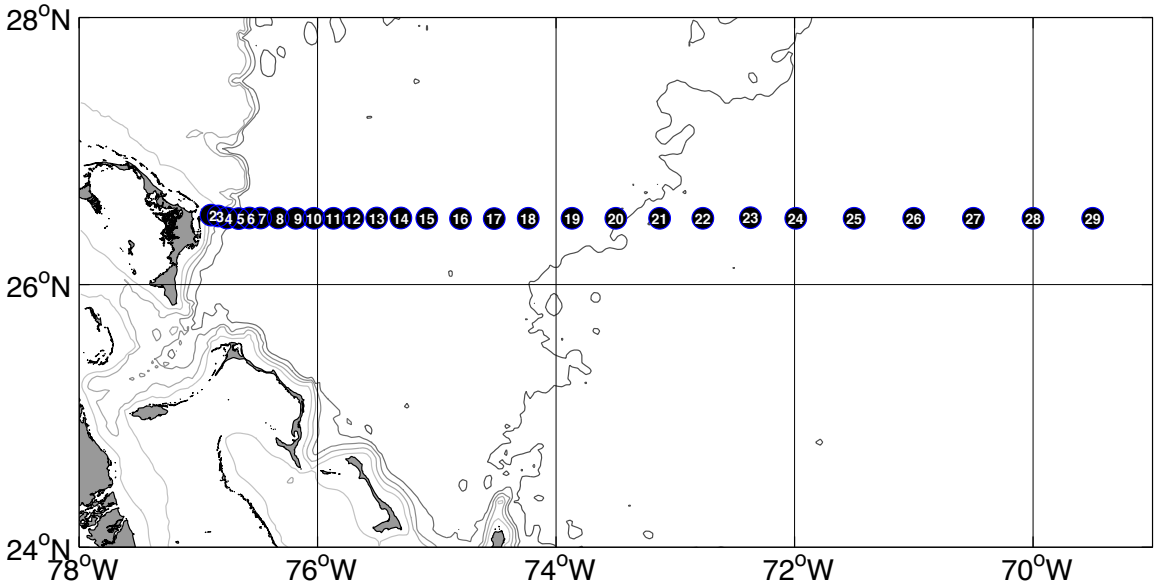

Figure 2a. CTDO$_2$/LADCP stations occupied along the 26.5° N Abaco line.

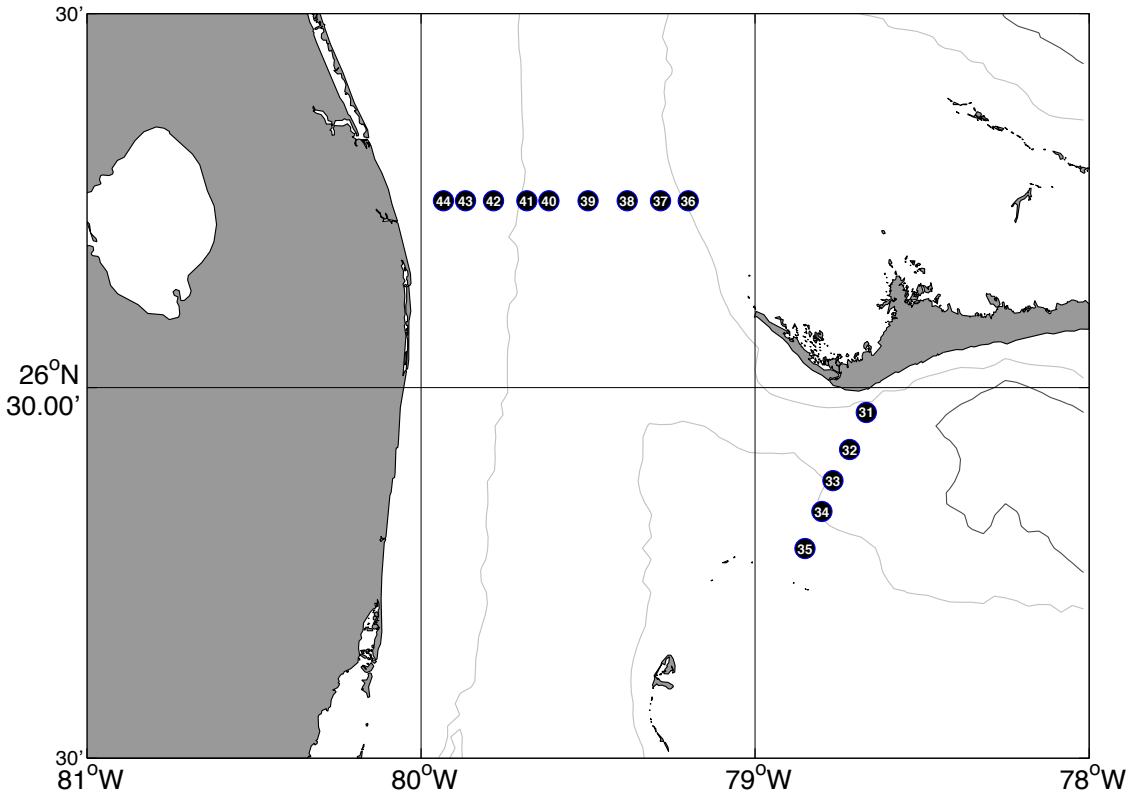

Figure 2b. CTDO$_2$/LADCP stations occupied along the 27° N Straits of Florida section and across the Northwest Providence Channel.

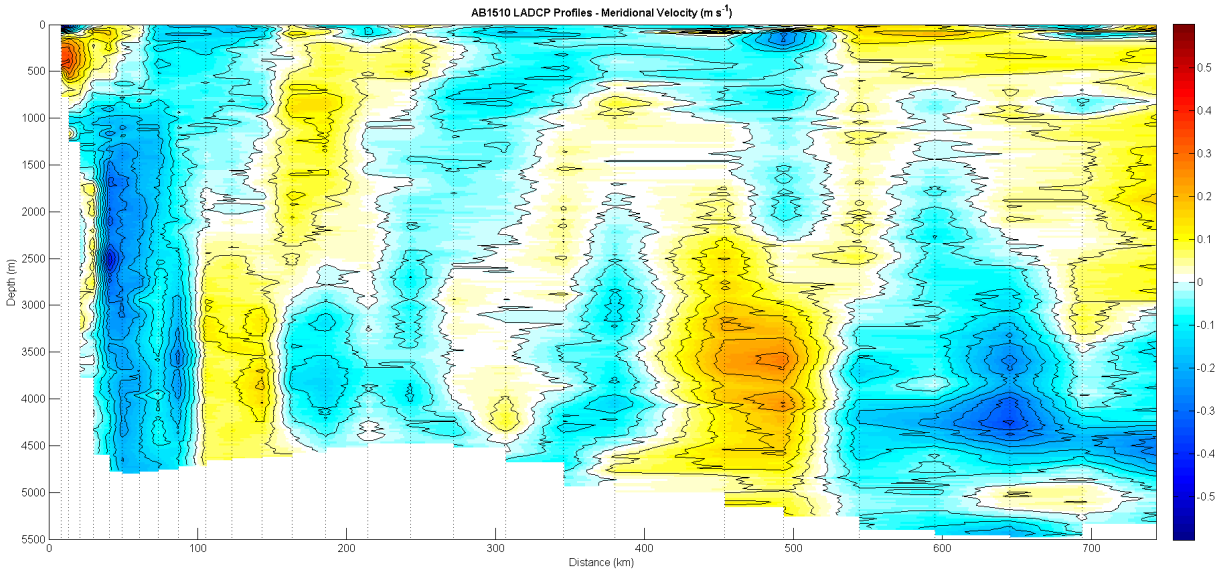

Figure 3. Meridional velocity section for the Abaco line, from Lowered-ADCP profiles collected at the CTD stations.

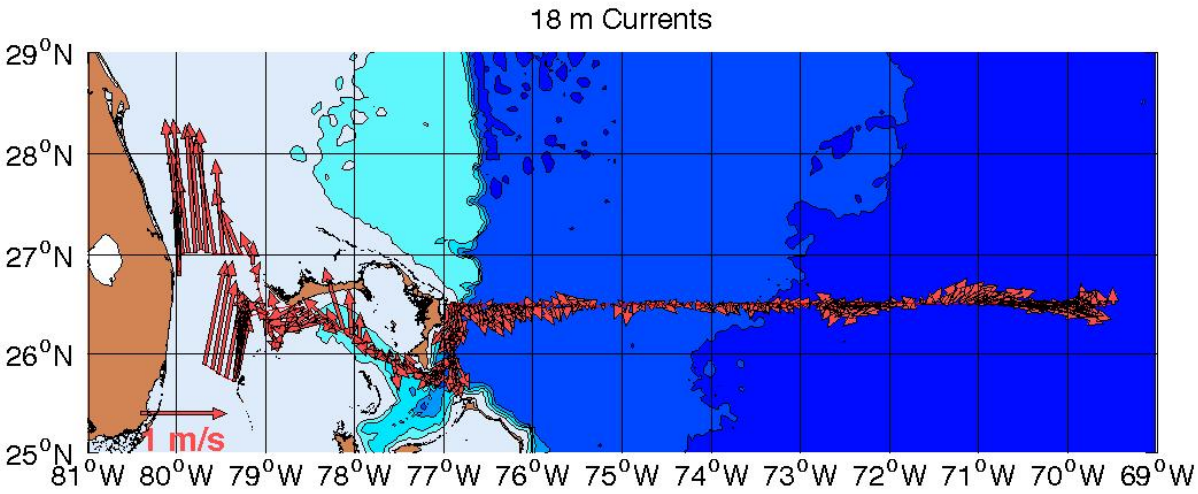

Figure 4. Near-surface currents along the cruise track, derived from the vessel-mounted ADCP.