CRUISE REPORT

R/V Knorr Cruise KN-200-4

RAPID/MOCHA Program
April 13 – May 3, 2011
Port Everglades, FL to Port Everglades, FL

1. Introduction and Objectives

The RAPID/MOCHA 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 establish an operational measurement system to continuously observe the strength and structure of the Atlantic meridional overturning circulation across the basin at 26.5º N. 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 Program.

The goals of cruise KN-200-4 were to:

1. Service 14 deep-sea moorings located off the eastern Bahamas along latitude 26.5°N, including 9 taut wire subsurface current meter/CTD moorings, and 5 "bottom-lander" moorings containing high-precision bottom pressure gauges.

2. Deploy 3 Pressure-Inverted Echo Sounders (PIES) and recover data from 3 PIES sites 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.

4. Perform several additional deep water CTD casts to calibrate moored instrumentation, and

5. Deploy 8 satellite tracked surface drifters and 3 profiling APEX floats at chosen locations along the cruise track.

2. Cruise Synopsis

The cruise departed from Port Everglades (Ft. Lauderdale), FL on April 13 at 0830 local time. The ship arrived in Freeport at 1410 local and anchored offshore to complete Bahamian clearance and immigration, which was finished by 1540 local. The CTD/LADCP section across Northwest Providence Channel (Stations 1 to 5). was accomplished without any problems, with both CTD and LADCP systems functioning well The NOAA/AOML CTD/LADCP system was used, with NOAA's CTD frame interfaced to the Knorr's Seabird deck unit. A "chinese finger" wire clasp system with a safety strap was attached to the CTD cable just above the termination for added deployment security of the system. The LADCP system is a hybrid 150/300 kHz system, with a 300 kHz Workhorse ADCP looking upward from the CTD frame and a 150 kHz ADCP looking downward. On this cruise we tested two new 150 kHz ADCPs, on loan from Woods Hole, that are designed specifically for deep water LADCP operations and were recently repaired by R.D. Instruments.

Once in deep water east of Abaco, 4 deep "cal-dip" CTD stations (Stations 6 to 9) were done to obtain in-situ calibration data for all the Seabird microcat instruments to be deployed on the moorings, and to test acoustic releases at depth prior to use. The first two cal-dip casts included only Seabird microcats and on these casts we also ran the LADCP system, which provided the first deep water tests of the new 150 kHz LADCP. The profiles from the LADCP system looked very good, similar in quality to what had been obtained in the past with the AOML hybrid system in this region. On the 3rd of these caldip casts, with 4 UK releases included on the CTD and the LADCP system disabled, a minor delay was caused by neglecting to remove the 12 kHz pinger from the CTD frame. This required the CTD to be retrieved after ~900m wire out and the cast restarted after removing it, in order to perform the release tests at depth.

Following this, the Abaco 26.5º N CTDO_2/LADCP section was commenced on April 15th, and completed on April 20th (Stations 10 to 35). Nine surface drifters were launched along the section, at station 18 (2 drifters), station 25 (3 drifters), and station 29 (2 drifters). APEX floats were launched at stations 23, 32, and 35.

During the section, CTD 19 had to be hurried to completion by skipping all bottles above about 1000m on the upcast, because of a vessel in distress nearby that we had to go assist. This turned out to be a 250ft+ Bolivian-flagged vessel that ran out if fuel and began firing flares. We stood off ready to assist until the U.S. Coast Guard arrived. During this break we replaced the primary temperature sensor on the CTD package, after noticing that there was a larger than normal temperature difference between the two sensors (off by about 0.002 at depth). The primary sensor was measuring higher than the secondary. We chose to replace the primary sensor because it also showed a high bias relative to all the freshly-calibrated microcats during the caldip casts, whereas the comparison with the secondary was closer.

The problem with the CTD temperature sensor difference remained on subsequent casts; the new primary T sensor actually showed a slightly higher offset relative to the secondary (up to 0.003 at depth). A relatively large (up to 0.05 deg C) temperature bias, and conductivity bias, between the sensors also continued to occur on the upcast, with the values converging to their downcast offset during bottle stops. On station 23 we tried swapping out the pump for the primary sensors – no change. On station 24 we swapped out the secondary pump; still no affect. At this point it was decided not to swap out the secondary sensor since it compared well with the microcats, and it is likely more accurate than either of the primaries used. This also keeps one sensor pair in place for the whole section. (It was later discovered, after completing the section, that this temperature offset in the thermocline was due to flow deflection off of the ADCP heads, as it did not occur during a cal-dip cast performed with the downward-looking ADCP removed. Unlike the old dual LADCP system, the downward looking 150 kHz unit could not be mounted in the center of the frame, and had to be mounted off center and closer to the CTD sensors. Evidently this proximity caused the upcast temperature and conductivity bias.)

During casts 21 and 22, download problems began to occur with the WH150 LADCP (master), where the download would stop abruptly and freeze up. Otherwise, serial communications were still good. Hooking directly into the WH150 LADCP instead of through the star-cable solved the download problem, so it appeared to be a star cable problem. Unfortunately communications could not be re-established with the WH300 after reconnecting the star-cable back to the WH150, and so we had to swap in the spare AOML WH300 for station 23. We suspected a blown fuse on the WH300, but after opening it up and inspecting it, no problem was found, and the system began working again. We planned on replacing the star cable after cast 23, but the download began working reliably again on that and subsequent casts, and so the star cable was not replaced.

The last two planned CTD stations on the Abaco line were skipped, due to an advancing low pressure system from the east, and mooring work was commenced on April 20th, at site WB6. All planned mooring operations (Tables 1-4) were successfully completed between April 20 – May 1, working from east to west across the array. For most of the tall moorings (WB2, WBH2, WB3, WB4, and WB5), the approach was to recover the old mooring on one day, normally in the afternoon, and deploy the replacement mooring the next morning, with bottom lander recoveries and deployments fit in between. For the shorter moorings (WB-ADCP, WB0, WB1, and WB6), multiple mooring operations were usually conducted on each day. Few problems occurred. Among them was the failure of all of the new Novatech combination radio-strobe beacons used on the U.S. moorings, as well as the ARGOS locator beacons on moorings WB3 and WB5. The batteries were drained on the radio/strobe units, indicating that they never powered off when submerged, the reason for this is TBD. The problem with the ARGOS locators was identified as a failure of the pressure switches to activate when they reached the surface. Also, Mooring WB3 came up very tangled and some segments had to be stopped off and recovered in reverse order. The mooring appeared to be laid out quite nicely downwind when it hit the surface, and we turned back upwind after latching onto it after a short turn to the right. This turn was perhaps too tight and it is possible we dragged the mooring across itself and some of the loops got caught. One microcat on this mooring (at 250m) had clearly been the victim of a shark bite, with teeth scrapes evident and the sensor cover ripped off. Nevertheless it returned a full record.

During the evening breaks in the mooring work, operations consisted of PIES deployments and acoustic data telemetry (Table 5), and several additional CTD casts that either provided post-deployment CTD data for the PIEs sites and/or post-recovery cal-dip data for the microcats retrieved from all of the moorings (stations 36 to 43).

Because of the shortening of the Abaco CTD/LADCP section and the lack of any subsequent weather delay during the cruise or other operational problems, the cruise was nearly 2 days ahead of schedule at the end of the mooring work. The extra time was split between an extended shipboard ADCP survey of the region north of the Little Bahama Bank prior to beginning the Florida Straits CTD section, and moving up the ship's arrival schedule in port by one day (May 3rd instead of May 4th).

The final CTD/LADCP section across the Straits of Florida at 27°N was completed at 1920 local on May 2nd. The ship arrived at the Port Everglades sea buoy at approximately 0200 local May 3rd. Berthed by 0715. The cruise was nearly 100% successful: all planned activities except for the last two CTD stations on the Abaco CTD line were successfully accomplished.

3. Scientific Personnel

Name	Position	Organization
Bill Johns	Ch. Sci.	RSMAS/ U. Miami
Adam Houk	Scientist	RSMAS/ U. Miami
Mark Graham	Technician	RSMAS/ U. Miami
Robert Jones	Technician	RSMAS/ U. Miami
Erik van Sebille	Post-doc	RSMAS/ U. Miami
Greta Leber	Student	RSMAS/ U. Miami
Chris Meinen	Scientist	NOAA/ AOML
Andrew Stefanick	Technician	NOAA/ AOML
Pedro Pena	Technician	NOAA/ AOML
Kyle Seaton	Technician	NOAA/ AOML
Rigoberto Garcia	Scientist	CIMAS/ U. Miami
Eleanor Frajka-Williams	Scientist	NOC Southampton
Darren Rayner	Scientist	NOC Southampton
Rob McLachlan	Technician	NOC Southampton
Christian Crowe	Technician	NOC Southampton
Dave Childs	Technician	NOC Southampton
Stephen Whittle	Technician	NOC Southampton
Thomas Roberts	Technician	NOC Southampton
Chris Hughes	Student	NOC Southampton

Kyle McDermott	Intern	MATE

3. Cruise Operations

3.1 Mooring Operations

Mooring Recoveries

Thirteen subsurface moorings were successfully recovered from the locations listed in Tables 1 and 2 and shown in Figure 1. These moorings contained a mixture of current meters, Acoustic Doppler Current Profilers (ADCPs), and temperature/salinity recorders. Sites with an “L” in their name represent bottom lander moorings which contained only precision bottom pressure sensors.

Table 1. U.S. Mooring Recoveries

Mooring Site	Mooring Number	Latitude (ºN)	Longitude (ºW)	Depth (m)	Date of Recovery
WB0	M390	26° 30.41'	76° 50.45'	1004	04/29/2011
WB3	M391	26° 29.37'	76° 30.02'	4840	04/25/2011
WB5	M392	26° 30.16'	71° 58.70'	5294	04/21/2011
WBL3	M394	26° 29.42'	76° 29.64'	4843	04/25/2011
WBL5	M395	26° 30.05'	71° 59.20'	5240	04/21/2011

Table 2. U.K. Mooring Recoveries

Mooring Site	Mooring Number	Latitude (ºN)	Longitude (ºW)	Depth (m)	Date of Recovery
WBADCP	n/a	26° 31.50'	76° 52.08'	609	04/30/2011
WB1	n/a	26° 29.97'	76° 49.12'	1394	04/29/2011
WB2	n/a	26° 30.87'	76° 44.79'	3796	04/27/2011
WBH2	n/a	26° 28.86'	76° 34.74'	4824	04/26/2011
WB4	n/a	26° 21.18'	75° 43.32’	4713	04/23/2011
WB6	n/a	26° 29.65'	70° 31.40’	5491	04/20/2011
WB2L5	n/a	26° 30.38'	76° 44.63’	3882	04/28/2011
WB4L5	n/a	26° 21.26'	75° 42.95’	4713	04/24/2011

Mooring Deployments

A total of 14 moorings (9 taut-wire moorings and 5 bottom landers) were deployed at the locations listed in Table 3 and 4 and shown in Figure 1. Acoustic surveying of the on-bottom position of all moorings (except for some of the bottom landers) was successfully completed after each mooring deployment.

Table 3. U.S. Mooring Deployments

Mooring Site	Mooring Number	Latitude (ºN)	Longitude (ºW)	Depth (m)	Date of Deployment
WB0	M402	26° 30.39'	76° 50.47'	1005	04/30/2011
WB3	M403	26° 29.40'	76° 29.87'	4840	04/26/2011
WB5	M405	26° 29.48'	71° 59.07'	5298	04/22/2011
WBL3	M404	26° 29.09'	76° 29.72'	4843	04/25/2011
WBL5*	M406	26° 30.06'	71° 59.18'	5295	04/22/2011

* mooring location on bottom not surveyed after deployment.

Table 4. U.K. Mooring Deployments

Mooring Site	Mooring Number	Latitude (ºN)	Longitude (ºW)	Depth (m)	Date of Deployment
WBADCP*	n/a	26° 31.50'	76° 52.08'	617	04/30/2011
WB1	n/a	26° 30.19'	76° 48.91'	1375	04/29/2011
WB2	n/a	26° 30.92'	76° 44.57'	3796	04/28/2011
WBH2	n/a	26° 28.61'	76° 37.32'	4763	04/27/2011
WB4	n/a	26° 29.21'	75° 48.56’	4745	04/24/2011
WB6*	n/a	26° 29.58'	70° 31.53’	5500	04/21/2011
WBAL2*	n/a	26° 31.57'	76° 52.55’	501	04/30/2011
WB2L7	n/a	26° 30.43'	76° 44.55’	3882	04/28/2011
WB4L7	n/a	26° 29.04'	75° 48.62’	4713	04/23/2011

* mooring location on bottom not surveyed after deployment.

3.2 Inverted Echo Sounders

NOAA maintains a line of pressure inverted echo sounders (PIES) along 26° 30’ N as part of its Western Boundary Time Series program. Some of the instruments are configured with an additional acoustic current meter, referred to as CPIES. The operations involving PIES/CPIES during the cruise are summarized in Table 5.

Table 5. PIES Operations

IES Site name	Latitude (°N)	Longitude (°W)	Date (UTC)	Depth (m)	Operation performed
PIES A	26 30.95	76 50.02	04/30/2011	1137	Telemetry
CPIES A2	26 30.02	76 44.61	04/28/2011	3832	Telemetry
PIES B	26 29.48	76 28.16	04/27/2011	4805	Deployment
PIES C	26 30.10	76 05.27	04/26/2011	4766	Deployment
PIES D	26 30.16	75 42.33	04/25/2011	4690	Deployment
PIES E	26 30.00	71 59.95	04/22/2011	5233	Telemetry

4. $CTDO_2$/LADCP Stations

A total of 52 $CTDO_2$ stations were conducted during the cruise (Table 6, 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 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, which were lowered to specific depths not necessarily near to the bottom. During these casts, the outer rack of Niskin bottles was removed from the Rosette to accommodate the moored 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 6.

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 optical endpoint determination.

Current profiles were also measured at the stations using a paired downward-looking 150 kHz Broadband and upward-looking 300 kHz Workhorse Acoustic Doppler Current Profiling 'hybrid" system (LADCP). Two new 150 kHz ADCPs built by R.D. Instruments for Woods Hole for LADCP operations were tested on the cruise. The first unit (SN) worked reliably and was used for all three of the sections across the Florida Current, Northwest Providence Channel, and the Abaco section. The 2^{nd} unit (SN) was tested during several "cal-dip" casts and was found to have a malfunction related to a faulty compass or inaccurate internal compass calibration. The quality of the velocity profiles from the dual LADCP system will be further evaluated after the cruise, but the indications were that the profiles using the first 150 kHz system were of good quality, on a part with earlier systems used by NOAA/AOML, and that the new 150 kHz units produced by RDI may serve as a good replacement for the now defunct 150 broadband ADCPs previously used for this purpose.

Table 6. $CTDO_2$ Station Locations

Station	Date	Time (UTC)	Latitude (^{o}N)	Longitude (^{o}W)	Depth (m)
1	4/13/2011	2107	26^o 25.96’	78^o 40.52’	753
2	4/13/2011	2325	26^o 19.99’	78^o 43.03’	682
3	4/14/2011	0057	26^o 15.00’	78^o 46.01’	513
4	4/14/2011	0217	26^o 09.98’	78^o 48.00’	450
5	4/14/2011	0345	26^o 04.02’	78^o 50.98’	299
6*	4/14/2011	1405	25^o 57.22’	76^o 53.67’	4400
7*	4/14/2011	1820	25^o 57.31’	76^o 53.62’	4436
8*	4/14/2011	2332	25^o 57.26’	76^o 53.73	4422
9*	4/15/2011	0344	25^o 57.24’	76^o 53.70’	4419
10	4/15/2011	1029	26^o 31.49’	76^o 53.00’	470
11	4/15/2011	1139	26^o 31.01’	76^o 49.91’	1125
12	4/15/2011	1323	26^o 29.94’	76^o 44.55’	3920
13	4/15/2011	1752	26^o 30.05’	76^o 39.27’	4645
14	4/15/2011	2216	26^o 29.99’	76^o 33.88’	4920
15	4/16/2011	0320	26^o 30.04’	76^o 28.51’	4925
16	4/16/2011	0805	26^o 30.02’	76^o 20.69’	4920
17	4/16/2011	1234	26^o 30.23’	76^o 12.91’	4895
18	4/16/2011	1700	26^o 29.97’	76^o 05.14	4881
19	4/16/2011	2132	26^o 29.95’	75^o 54.01’	4824
20	4/17/2011	0335	26^o 30.05’	75^o 42.25’	4772
21	4/17/2011	0750	26^o 30.02’	75^o 30.02’	4766
22	4/17/2011	1210	26^o 30.00’	75^o 17.97’	4716
23	4/17/2011	1810	26^o 30.02’	75^o 04.86	4699
24	4/17/2011	2242	26^o 30.01	74^o 47.95’	4615
25	4/18/2011	0320	26^o 29.98’	74^o 30.98’	4574
26	4/18/2011	0824	26^o 29.86’	73^o 14.04’	4650
27	4/18/2011	1336	26^o 29.90’	73^o 51.42’	4820
28	4/18/2011	1858	26^o 30.09’	73^o 29.84’	5031
29	4/19/2011	0006	26^o 29.99’	73^o 08.00’	5129
30	4/19/2011	0532	26^o 30.08’	72^o 46.02	5210
31	4/19/2011	1102	26^o 29.95’	72^o 23.01’	5265
32	4/19/2011	1656	26^o 30.12’	71^o 59.71’	5363
33	4/19/2011	2314	26^o 30.06’	71^o 30.05’	5500
34	4/20/2011	0544	26^o 30.03’	71^o 00.05’	5561
35	4/20/2011	1242	26^o 30.12’	70^o 29.91’	5564
36*	4/20/2011	1928	26^o 31.51’	70^o 31.40	5565
37*	4/21/2011	0224	26^o 30.03’	70^o 30.07’	5437

38*	4/24/2011	0033	26° 29.18’	75° 48.44’	4710
39*	4/25/2011	0400	26° 30.17’	75° 42.37’	4663
40	4/26/2011	0335	26° 30.12’	76° 05.25’	4773
41*	4/27/2011	0136	26° 29.46’	76° 28.16’	4804
42*	4/28/2011	2248	26° 29.91’	76° 39.22’	4568
43*	4/30/2011	2009	26° 47.42’	76° 32.64’	4557

* 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 dual vessel-mounted Acoustic Doppler Current Profiler (ADCP) system consisting of a 300 kHz and 75 kHz Ocean Surveyor system. The depth range of good velocity data from the 300 kHz system typically extended to 80 m below the vessel, and to approximately 800 m for the 75 kHz system, depending on sea state conditions. Data were processed onboard in real time using the UHDAS acquisition system. Gyrocompass data were continuously corrected by a POS-MV inertial navigation system.

6. Preliminary Results

The Abaco section showed a relatively strong Deep Western Boundary Current with speeds in excess of 0.3 m/s flowing close to the Bahamas escarpment (Fig. 3). In the upper water column there appeared to be a cyclonic eddy in the western part of the section that resulted in a strong (>0.6 m/s) southward flow just offshore of Abaco in the upper 1000 m. This cyclonic eddy is also evident in the temperature field by the associated doming of the isotherms (Fig. 4). Very near the coast there was a weak northward flow with a subsurface maximum near 200-300 m which is possibly a remnant of the subsurface Antilles Current that is normally found here. Farther offshore there were alternating bands of northward and southward flow in both the near surface and deep ocean, typical of wave or eddy features seen in previous sections. As the cruise progressed, and the ship returned to the escarpment region to perform mooring work about 10 days after the CTD section was completed, the cyclonic eddy was observed to move westward and its band of southward flow intensified to nearly 1.0 m/s at the surface and entirely displaced the northward flow found previously just offshore of Abaco.

Results from the ~36-hour shipboard ADCP survey conducted north of the Little Bahama Bank are shown in Figure 5. Previous modeling results have suggested that most of the Antilles Current, when present, flows northwestward from Abaco through this region to join the Gulf Stream system north of the Straits of Florida. During this cruise the characteristic Antilles Current off Abaco was not present, yet the survey still showed a considerable westward flow in this region (approx. 8 Sv in the upper 600 m) that appears to be joining into the Gulf Stream just north of the Banks. It is hoped that similar surveys can be done in the future, when the Antilles Current is present, to better understand its pathways downstream of the Bahamas.

Just prior to this survey, a brief Seabeam track was run along the Bahamas escarpment just north of the Abaco line to better define the upstream ridges that partially block the deep flow very close to the escarpment at 26.5°N. A CTD cal-dip cast (CTD043) was done just offshore of the most seaward protrusion of this upstream ridge, which was found at 26° 47'N. The LADCP profile from this cast, just 5 km off the edge of the escarpment (defined by location of the 1500m isobath), showed a very strong DWBC flow, of 0.4 m/s at 200om, indicating that the DWBC does (or can) flow very close to the edge of this ridge.

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 (May, 2012).

Moored Instrumentation

Time series data records from the moored instruments will be provided within 2 years of recovery of the instruments (nominally May, 2013).

7. Acknowledgements

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

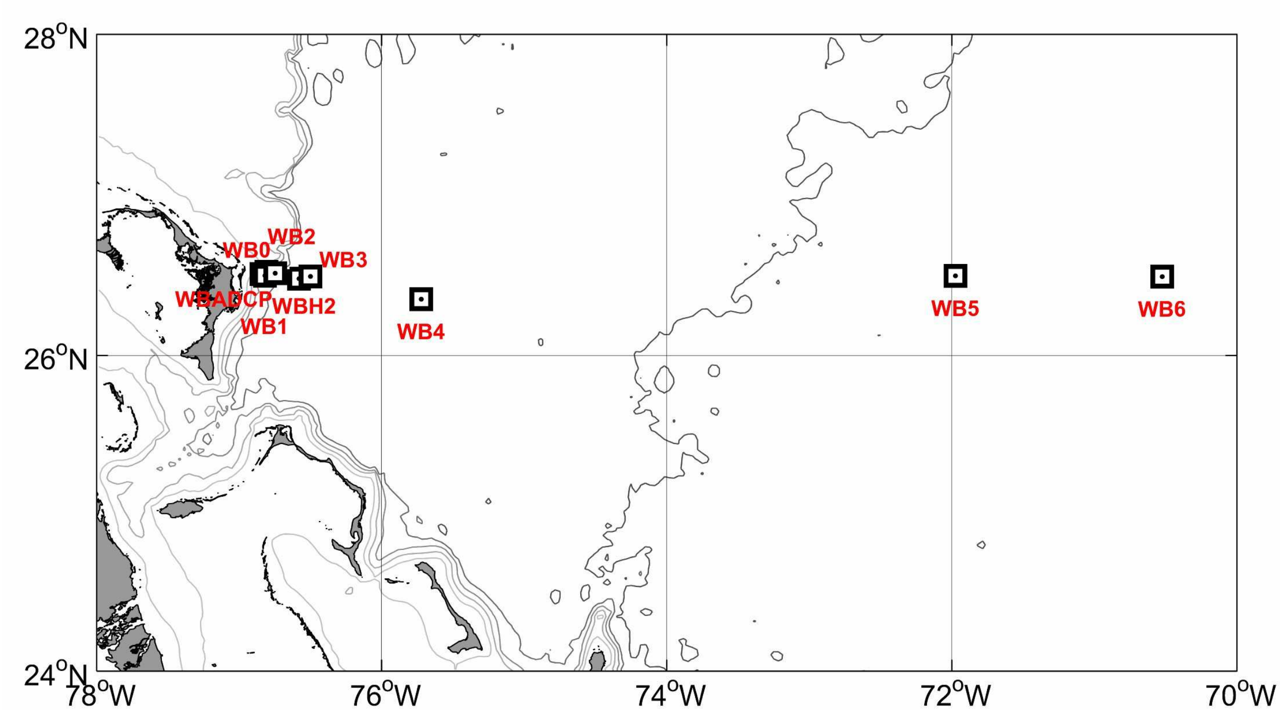

Figure 1. Current meter moorings recovered and deployed on KN-200-4. Additional "bottom lander" moorings (not shown on map) were deployed near mooring sites WBADCP, WB2, WB3, WB4, and WB5.

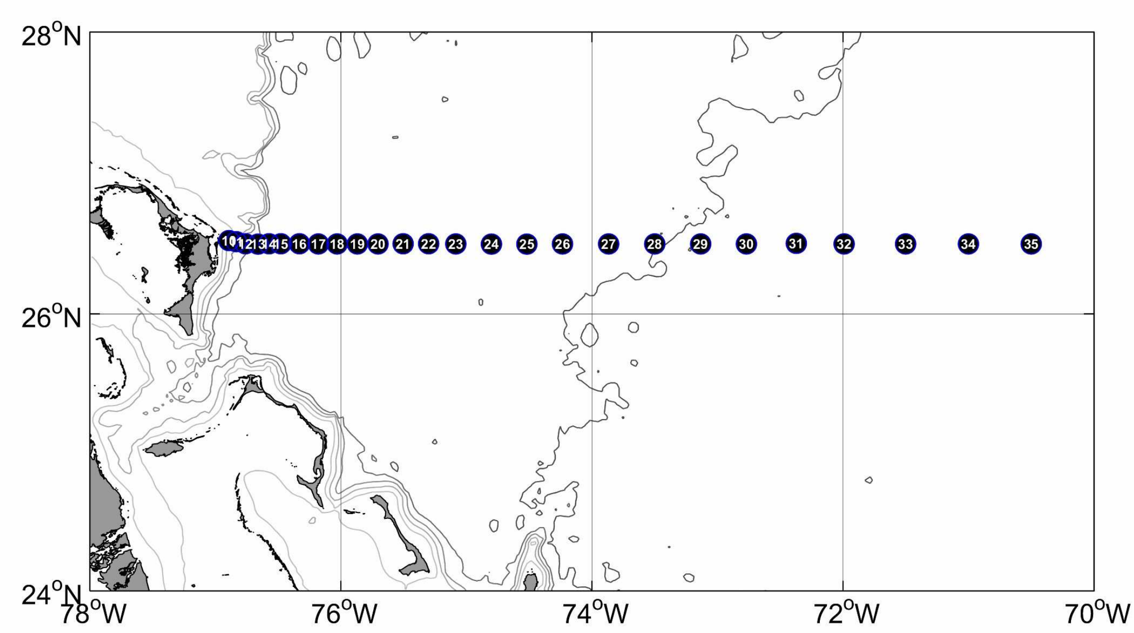

Figure 2a. CTDO$_2$/LADCP stations occupied along the 26.5° N Abaco line.

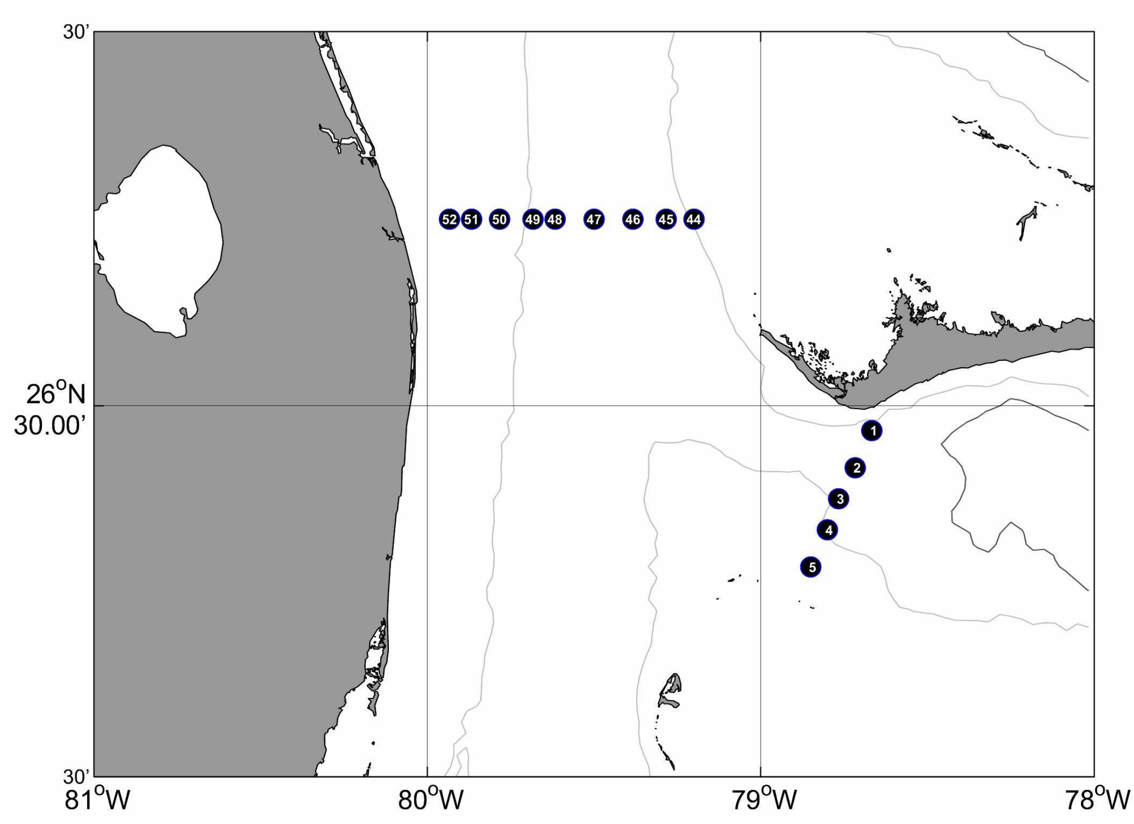

Figure 2b. CTDO$_2$/LADCP stations occupied along the 27° N Straits of Florida section and across the Northwest Providence Channel.

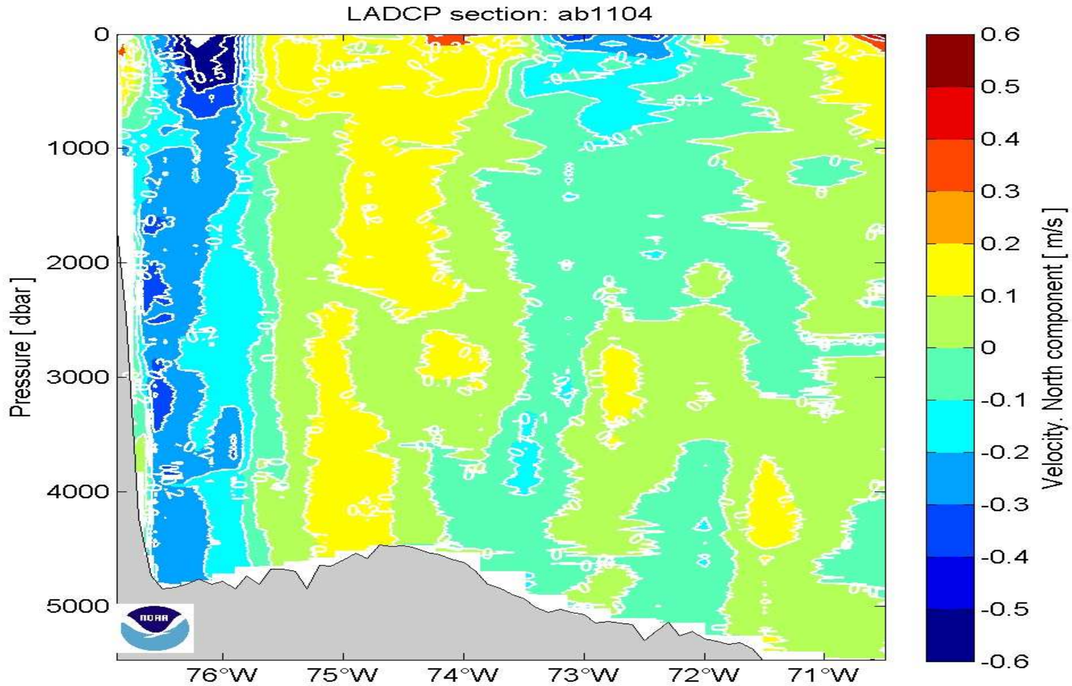

Figure 3. Absolute velocity section from LADCP off Abaco, along 26.5°N, Apr. 15-20.2011.

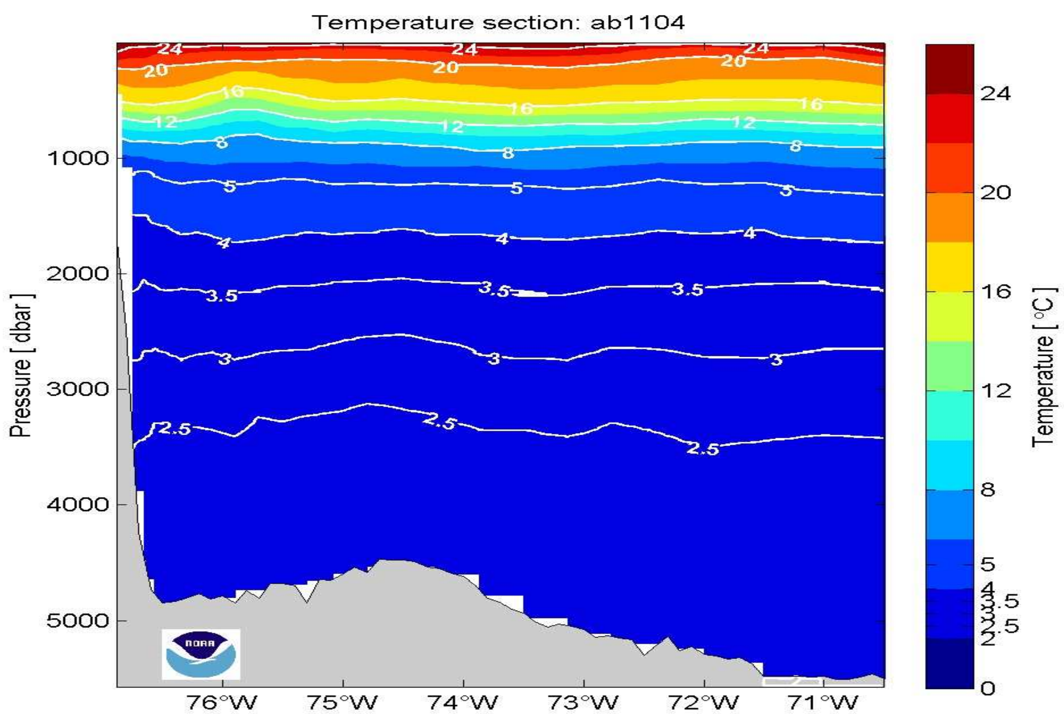

Figure 4. CTD emperature section off Abaco, along 26.5°N. Apr. 15-20, 2011.

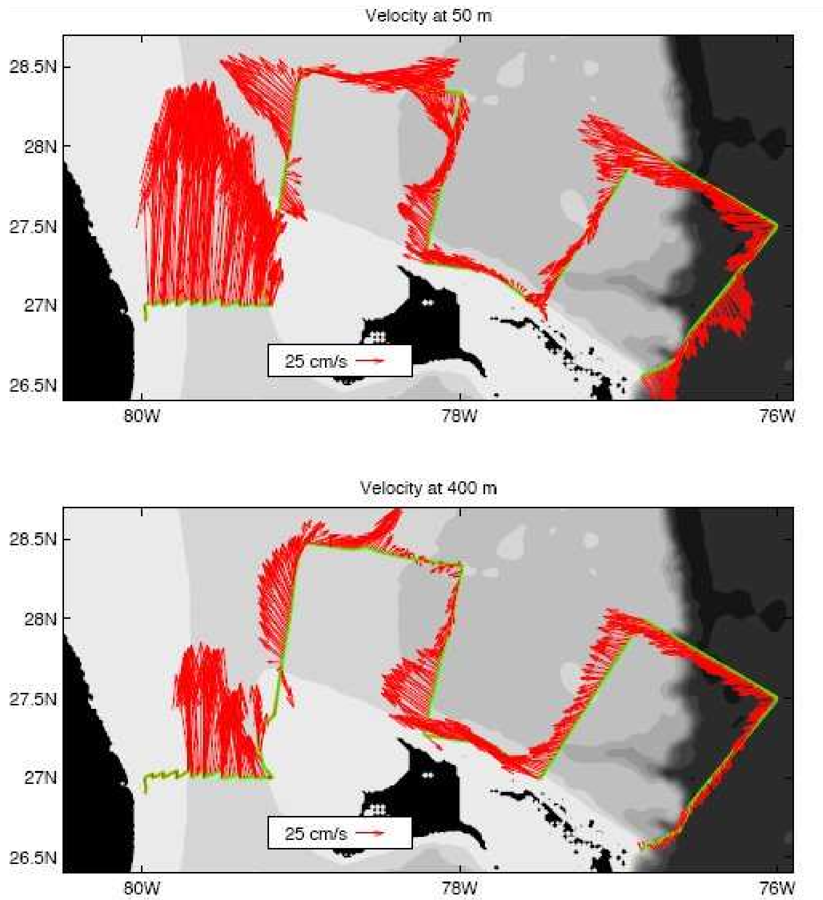

Figure 5. Currents patterns at 50 m (top) and 200 m (bottom) obtained during the shipboard ADCP survey north of Little Bahama Bank, and from the Florida Current section at 27°N.