Western Boundary Time Series in the Atlantic Ocean

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1. PROJECT SUMMARY

The Western Boundary Time Series project represents NOAA's longest term observing system for the Atlantic Meridional Overturning Circulation (MOC). Over the past 20+ years the program has worked to measure both the warm upper and cold lower limbs of the MOC near the western boundary of the Atlantic Ocean at 27°N. The Western Boundary Time Series project consists of two main elements, each of which is broken into several sub-elements:

Element 1 – Observe and quantify the Florida Current transport and water property variability

- Florida Current transport time-series variability is monitored using an out-of-service phone cable instrumented with a voltage recording system. Recording system failures (either computer or wiring) occur approximately once per year. Additional funding is required to provide spares and to repair failed equipment. Tests of possible future replacement systems for the cable have commenced (using AOML Base funds and old instruments) to prepare for the day in which the cable fails in a terminal manner. Additional funds to support these instruments (e.g. batteries, anchors) has been added to the budget in addition to funds for repairing the cable voltage systems.
- Florida Current transport snapshot variability and the calibration and continuity of the cable system are monitored using dropsonde/XBT cruises up to 10 times per year (this data is also used by the SOOP program for analysis of the data from the AX7 line). Dropsonde floats have been lost or damaged about once per year. Additional funds are needed to repair/modernize/improve the dropsonde floats. This expense has been included in an Equipment Support add-task.
- Florida Current transport and water mass snapshot variability are also monitored by CTD/LADCP sections each year (this data is also used for SOOP – AX7 analysis). Charter funding for these cruises has been inadequate in recent years.

Element 2 – Observe and quantify the Antilles and Deep Western Boundary Current transport and property variability

- Antilles and Deep Western Boundary Current transport and water mass snapshot variability are monitored by annual CTD/LADCP cruises. The capability and reliability of the NOAA fleet to support these cruises in recent years has been insufficient.
- Antilles and Deep Western Boundary Current transport time-series variability is monitored using a line of five PIES/CPIES moorings. These moorings were bought using a mix of OCO (four instruments) and AOML Base funds. The latter covered one instrument in the original array and also covered the purchase of one replacement PIES after an instrument was lost. If this program component is to continue, more

robust funding from OCO is required. Additional equipment funds for replacement instrument, sensors, and deck units have been included in the Equipment Support add-task.

2. PROJECT BACKGROUND

In the subtropical North Atlantic, the meridional overturning circulation consists primarily of two western boundary components: the northward flowing Gulf Stream and the southward flowing Deep Western Boundary Current. The Gulf Stream is the strong surface intensified flow along the east coast of the United States that brings warms waters of tropical origin northward along the eastern seaboard of the United States. The Gulf Stream also brings with it carbon, nutrients and tropical fish. It supplies warm waters along the coast that impact a multitude of important climate phenomena including hurricane intensification, winter storm formation and moderate European weather. The Gulf Stream includes the bulk of what we call the 'upper limb' of the meridional overturning circulation in the subtropical Atlantic, in addition to a strong wind-driven flow. As the Gulf Stream flows northward it loses heat to the atmosphere until eventually, in the subpolar North Atlantic, some of the waters carried in the current become cold enough to sink to the bottom of the ocean. This cold deep water then flows southward along the continental slope of the eastern United States as the Deep Western Boundary Current, which represents the 'lower limb' of the meridional overturning circulation.

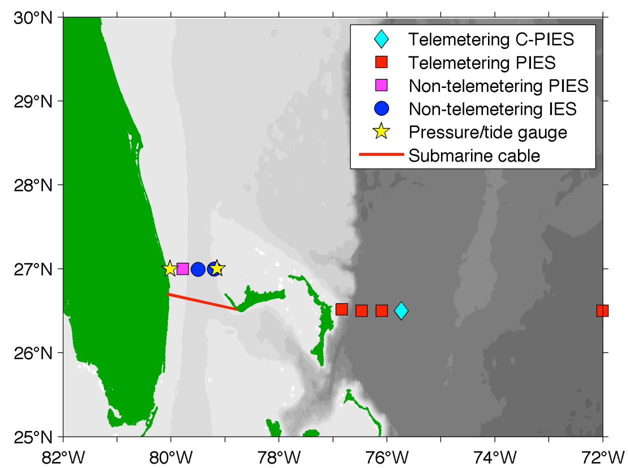

Figure 1. Moored components of the Western Boundary Time Series program**.**

Along the east coast of Florida, the Gulf Stream is often referred to as the Florida Current and it is fortuitously confined within the limited bathymetric channel between Florida and the Bahamas Islands, thus making a long-term observing system both practical and cost effective. Similarly, the Deep Western Boundary Current is located within several hundred miles to the east of Abaco Island, Grand Bahamas. The convenient geometry of the Bahamas Island chain thus allows an effective choke point for establishing a long term monitoring program of both the upper and lower limbs of the overturning circulation.

This project consists of two components to monitor the western boundary currents in the subtropical Atlantic: *Element 1:* Real-time Florida Current transport measurements using a submarine telephone cable and calibration cruises, *Element 2:* Deep Western Boundary

Current water property measurements using dedicated research ship time and quasi-real-time transport monitoring using moored instruments.

Element 1: Continuous Transport measurements of the Florida Current

The project maintains NOAA's well-established and climatically significant Florida Current volume transport time series. Over 25 years of daily mean voltage-derived transports have been obtained for the Florida Current using out-of-service and in-use cables spanning the Straits of Florida. The cable voltages can be converted to physically meaningful transport estimates i.e., intensity of the flow, using electromagnetic induction theory. These transport measurements contain interannual and decadal changes on the order of 10% of the long-term mean transport, and during some periods the decadal changes track the North Atlantic Oscillation Index. The strong correlation of Florida Current transport variability with the North Atlantic Oscillation during some time periods, and by extension with the large-scale sea-surface temperature patterns associated with the North Atlantic Oscillation, suggests connections to tropical Atlantic variability on climatically significant time scales. These strong correlations also link the Florida Current transport with the numerous significant weather and climate phenomena that are related through large-scale ocean-atmosphere patterns in the Atlantic, including decadal and inter-decadal variations in fisheries, rainfall, and hurricane activity.

Funding provides for continuous collection of cable voltages (each minute) and automated removal of geomagnetic noise. In addition to the cable measurements, regular calibration cruises are required for this project's success. These measurements are funded through a complementary project that measures the upper ocean thermal structure in the Atlantic through high-density VOS XBT observations. Funding from the high-density XBT program provides for four two-day small charter boat calibration cruises on the R/V F. G. WALTON SMITH each year and eight-ten one-day charters onboard small fishing vessels, provided sufficient ship-time is available.

Future continuance of the Florida Current transport time series is dependent at present upon the continuing stability of the telephone cable itself (which is beyond NOAA control as the cable belongs to AT&T). As will be discussed shortly, investigations of new monitoring systems are being made to plan for any future cable failure.

Element 2: Deep Western Boundary Current Time Series

Over the past 20+ years a variety of snapshot sections and time series mooring arrays have been placed along the continental slope east of Abaco Island, Grand Bahamas, in order to monitor variability of the transport carried by the Deep Western Boundary Current. The Abaco time series began in August 1984 when the NOAA Subtropical Atlantic Climate Studies Program extended its Straits of Florida program to include measurements of western boundary current transports and water mass properties east of Abaco Island, Grand Bahamas. Since 1984, more than 20 hydrographic sections have been completed east of Abaco, most including direct velocity observations, and salinity and oxygen bottle samples. Many sections have also included measurements of carbon, chlorofluorocarbon, and other water mass tracers.

The repeated hydrographic and tracer sampling at Abaco has established a high-resolution, high quality record of water mass properties in the Deep Western Boundary Current at 26.5ºN. Events such as the intense convection period in the Labrador Sea and the renewal of classical Labrador Sea Water in the 1980's are clearly reflected in the cooling and freshening of the Deep Western Boundary Current waters off Abaco with the arrival of a strong chlorofluorocarbon pulse approximately 10 years later. This data set is unique in that it is not a single time series site but in instead a time series of transport sections, including high quality water property measurements, of which very few are available in the ocean that approach even one decade in length. This element includes annual cruises across the DWBC to measure the water mass properties and transports. With the cooperation of University of Miami researchers (Drs. Johns and Beal) and funding from the National Science Foundation for the Meridional Overturning Circulation and Heat transport Array (MOCHA), and sharing of personnel and ship-time resources, these cruises have been conducted twice each year since 2004. This level of sampling will continue through 2014.

Also starting in 2004, a new component was added to the project consisting of a low-cost monitoring system that provides a daily time-series of the magnitude of the Deep Western Boundary Current mass transport in quasi-real-time (downloaded to research ships twice each year). This new monitoring system includes a moored array of Inverted Echo Sounders (IESs), and each instrument is additionally equipped with a bottom pressure gauge (PIES) and in one case a bottom current meter (CPIES). The line of PIES/CPIES moorings stretches across the shallow northward flowing Antilles Current as well as the southward flowing Deep Western Boundary Current. The IES monitoring system will also be compared to a series of measurement systems that have been deployed as part of an interagency and international partnership that is testing a variety of low cost methods for observing the complete meridional overturning circulation cell at 26.5ºN in the Atlantic (e.g. MOCHA and the United Kingdom’s Rapid Climate Change Program).

Continued time series observations at Abaco are seen as serving three main purposes for climate variability studies:

- Monitoring of the DWBC for water mass and transport signatures related to changes in the strengths and formation regions of high latitude water masses in the North Atlantic for the ultimate purpose of assessing rapid climate change.
- Serving as a western boundary endpoint of a subtropical meridional overturning circulation (MOC)/heat flux monitoring system designed to measure the interior dynamic height difference across the entire Atlantic basin and its associated baroclinic heat transport.
- Monitoring the intensity of the Antilles Current as an index (together with the Florida Current) of interannual variability in the strength of the subtropical gyre.

The Western Boundary Time Series project is one component of the NOAA “Ocean Reference Station” system in the Atlantic Ocean, and it specifically addresses the NOAA climate goals by providing long term integrated measures of the global thermohaline (overturning) circulation. This project is designed to deliver yearly estimates of the state of the thermohaline circulation, i.e. its intensity, properties, and heat transport. Heat and carbon generally are released to the atmosphere in regions of the ocean far distant from where they enter. Monitoring the transport within the ocean is a central element of documenting the overturning circulation of fresh water, heat and carbon uptake and release. Long-term monitoring of key choke points, such as the boundary currents along the continents including the Gulf Stream and the Deep Western Boundary Current, will provide a measurement of the primary routes of ocean heat, carbon, and fresh water transport and hence include the bulk of the Meridional Overturning Circulation.

Project web sites:

http://www.aoml.noaa.gov/phod/floridacurrent/
http://www.aoml.noaa.gov/phod/wbts/

3. FY 2008 PROGRESS

Element 1: Continuous transport of the Florida Current

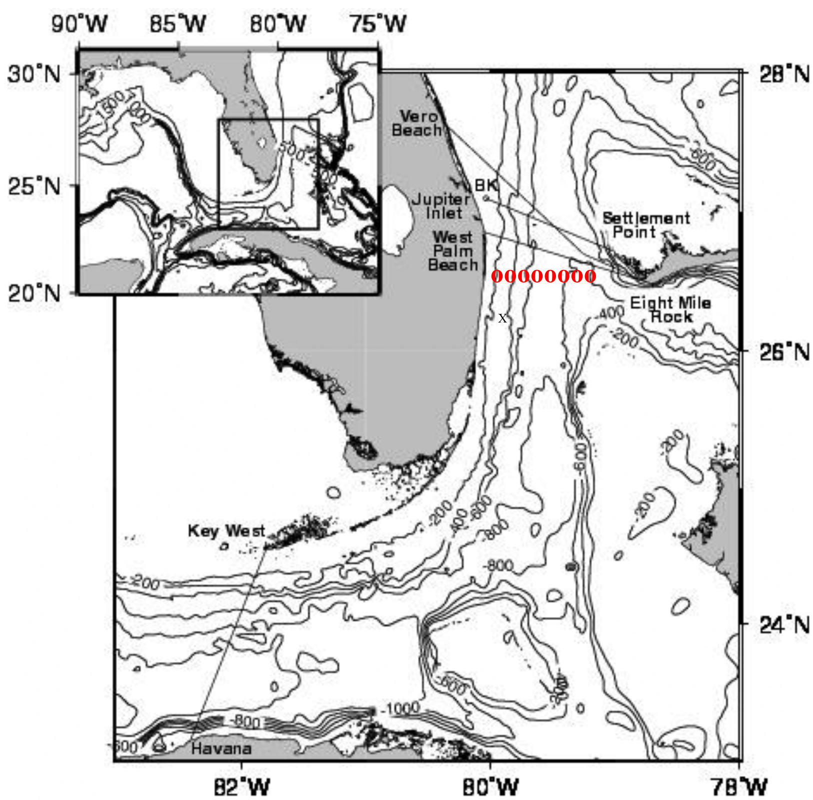

Figure 2. Location of submarine telephone cables (solid black) and nine stations (red) occupied during calibration cruises.

Recording instruments are located at Eight Mile Rock, Grand Bahamas Island. At Eight Mile Rock and in West Palm Beach, Florida, electrode equipment is in place, securing a stable reference voltage (i.e. grounds) at either end of the submerged telephone cable owned by AT&T. The monitored cable can be seen in Figure 2, stretching across the Florida Straits. Data acquisition has continued using the cable during FY08 however there were several short periods of up to three-weeks that data collection was not possible due to electronics failures with the recording system. The largest loss was of 20 days in December 2007 when there was a failure in a conductor in the wire to the anode. A failure in the voltage recording computer in March 2008 resulted in a loss of 8 days of data, and a recording system upgrade made in June 2008 resulted in the loss of a few hours of data. Last year during the period from January 2007 through October 2007 there was a slight low-bias in the cable transports relative to the dropsonde cruise data. This offset was traced to a failure in one of the anodes (Earth ground), which was replaced in October 2008. The data during the low offset period was completely recovered and a new version was available via the web site in October 2008. This FY has seen the continued success of the stable system of processing and quality control for both the calibration section data and the cable transport data implemented in FY05. Cable voltages are recorded every minute, and are post processed to form daily transport estimate. The Table 1 below shows the number of hourly averaged voltage measurements. Note that OCO funding in recent years has been insufficient to maintain the necessary recording system repairs and replacements, and at times AOML Base funds have been used for the purchase of replacement systems and parts. A small amount of additional funds has been added to the budget for this year to address this shortfall.

Table 1. Data return from continuous cable voltages (% Return based on the maximum number of days possible in one year: e.g. 365 for non-leap years and 366 for leap years like 2004).

FY 2008	FY 2007	FY 2006	FY 2005	FY 2004
93% Return	100% Return	98% Return	88% Return	87% Return[2]

Utilizing both AOML Base funds and OCO funds, in July 2008 a set of moored instruments was deployed to test combinations of different of equipment that could be used to monitor the transport of the Florida Current continuously in case of a future failure of the real-time cable system. Some funds for this were provided by OCO in 2006 as a one-time add-task to add voltage recorders to a second cable across the Florida Straits. Subsequent to the delivery of those OCO funds the Bahamian telephone cable company Batelco declined to allow the instrumentation of their active fiber optic cable, so alternative methods are being tested. Three inverted echo sounders (one including a bottom pressure sensor, a PIES) from old experiments in the 1980s and 1990s and two new pressure gauges were deployed at five sites spanning the straits (Figure 3). Together these instruments will be tested to find which combination of instruments will give us the best delayed-mode estimate of the transport. These instruments will necessitate one additional day of ship time each year to service the instruments. Data will be available annually, approximately

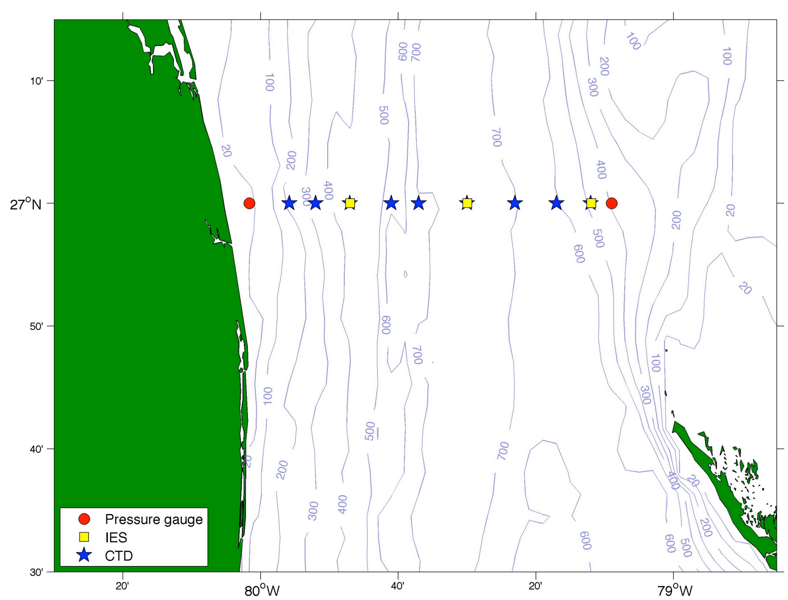

Figure 3. Locations of new moored instruments being tested as possible replacement systems for measuring Florida Current transport. Also shown are the locations of the standard CTD/LADCP and dropsonde/XBT sites used in the Florida Straits.

3 months after servicing the array. Additional funds will be required to maintain these moored equipment, and a small increase has been included in the budget to account for fixed equipment costs. If the moored equipment proves to reproduce the measurements of the cable, at a future date OCO funds will be required for the purchase of modern, more reliable inverted echo sounders as well as of spare pressure gauges.

Table 2. Cruise dates for 1-day small boat calibration cruises using dropsonde instrument.

Planned Cruise	FY 2008	FY 2007	FY 2006	FY 2005	FY 2004
1	4-Oct-2007[1]	13-Dec-2006	11-Nov-2005	19-Nov-2004 dropsonde lost	9-Dec-2003
2	6-Nov-2007	15-Dec-2006	17-Nov-2005	29-Nov-2004	16-Dec-2003
3	28-Nov-2007	29-Mar-2007	2-Feb-2006	17-Feb-2005	9-Jan-2004
4	7-Dec-2007	19-Jun-2007	14-Mar-2006	24-Feb-2005 section incomplete due to weather	13-Jan-2004 – GPS failure on two stations
5	23-Jan-2008	10-Jul-2007	27-Mar-2006	18-May-2005	7-May-2004
6	29-Jan-2008	5-Sep-2007, dropsonde electronics problems	22-Jun-2006	21-Jun-2005 dropsonde lost	24-May-2004
7	22-Apr-2008	27-Sep-2007	30-Jun-2006	31-Aug-2005	Jun 7, 2004
8	7-May-2008	Postponed to early FY08 due to weather	20-Jul-2006		Jun 11, 2004
9	10-Jul-2008[2]		15-Sep-2006		Aug 24, 2004
10	14-Jul-2008				1-Sep-2004 - GPS antenna failure
	90% successful	87.5% successful	100% successful	50% successful[3]	100% successful[4]

Small charter boat calibration trips:

A total of ten 1-day surveys were conducted using a dropsonde profiler (the first cruise had been postponed from the last FY due to weather; on one cruise the dropsonde was lost). Measurements are taken at nine stations along 27ºN (same locations as the CTD sites shown in Figure 3) and include vertically averaged horizontal velocity, surface

[1] Carry-over cruise from FY07 that had been postponed due to weather/scheduling isues.

[2] Dropsonde was lost.

[3] Final cruise postponed to next fiscal year due to weather/scheduling issues. Two dropsonde instruments were lost due to equipment malfunctions. One cruise was only partially completed due to weather.

[4] Two additional cruises were planned for FY04 due to dropsonde failures in FY03.

velocity and expendable temperature probes (XBTs). The cruise dates are shown in Table 2. Over the course of the year our engineering staff has been designing a new generation of dropsonde and we are testing the final components during the most recent cruises. This new generation of dropsonde will include a portable CTD capable of measuring pressure, salinity and temperature. Development of this new generation of dropsonde, and replacements that have been made for losses of older style dropsondes, have been covered using largely AOML Base funds.

Full Water Column calibration cruises:
Two-day cruises on RV Walton Smith are generally scheduled four times per year. Sufficient ship-time funds for only one of the cruises were provided by the charter ship fund in FY08, however days for an additional three-day cruise were provided by a related U. Miami program that could not use all of their days. All cruises include nine stations with full water column CTD, lowered ADCP, and continuous shipboard ADCP. The station locations are shown in Figures 2 and 3. Table 3 below includes the cruise dates and number of water samples taken for oxygen concentration (O2) and salinity (S).

Table 3. Cruise dates for 2-day calibration cruises on the R/V Walton Smith. Note FY2005: The last cruise planned for in FY 2005 was postponed for early FY 2006. Note FY 2007: Only three cruises were completed due to lack of ship-time charter funds. Note: FY2008 Only one two-day cruise was planned in FY2008 due to lack of ship-time charter funds; a second three-day cruise was done using sea-days donated by a related program at U. Miami.

FY2008		FY2007		FY2006		FY 2005		FY 2004	
Date	Samples	Date	Samples	Date	Samples	Date	Samples	Date	Samples
Dec 2007	19-20, 60 O2, 48 S	Dec 2006	13-14, 60 O2, 48 S	Dec 2005	14-16, 60 O2, 48 S	Dec 3-4, 2004	58 O2, 44 S	Jan 2003	8-9, 55 O2, 46 S
Jul 2007	7-9, 60 O2, 48 S	Jun 2007	28-29, 60 O2, 48 S	Jan 2006	29-31, 60 O2, 48 S	Jun 2005	3-4, 58 O2, 45 S	May 2004	6-7, 47 O2,
		Oct 2007	4-5, 60 O2, 48 S	Jun 2006	25-27, 60 O2, 48 S	Jul 2005	11-12, 58 O2, 45 S	Jul 4-5, 2004	56 O2,
				Sep 2006	18-19, 68 O2, 48 S	Nov 2005	20-23, 60 O2, 48 S	Aug 2004	27-28, 55 O2, 42 S
50% of planned cruises		75% of planned cruises		100% of planned cruises		100% of planned cruises		100% of planned cruises	

<u>*Element 2: Deep Western Boundary Current time series*</u>
Two cruises involving full-water-column CTD, lowered ADCP, and shipboard ADCP were planned during FY08 within the Florida Straits and east of Abaco Island, Bahamas. At each station, a package consisting of a Seabird Electronics Model 9/11+ CTD O_2 system, an RDI 150 kHz Workhorse Lowered Acoustic Doppler Current Profiler, a RDI 300 kHz Workhorse Lowered Acoustic Doppler Current Profiler, and 23 10-liter Niskin bottles, was to be lowered to the bottom. This provides profiles of velocity, pressure, salinity (conductivity), temperature, and dissolved oxygen concentration. Water samples were collected at various depths and analyzed for salinity and oxygen concentration to aid with CTD calibration.

The first hydrographic cruise this year took place on the R/V Seward Johnson during Apr. 4-30. The second cruise was originally planned to go on the NOAA Ship Ronald H.

Brown, however maintenance issues with that vessel required both rescheduling and downsizing (due to a funding shortfall) the cruise which then took place on the R/V Cape Hatteras during Sept 26-Oct. 3. (This downsizing of the cruise due to insufficient funds from the NOAA fleet resulted in the loss of about 70% of the planned CTD stations including nearly all of the deep stations, which was the primary scientific goal of the hydrographic survey). The stations were occupied at the locations shown in Figure 4. Table 4 lists the cruise dates and bottle samples taken compared to previous years.

Also listed in Table 4 are the operations completed at the inverted echo sounder mooring sites during the cruises. The easternmost inverted echo sounder with a pressure gauge (PIES) shown in Figure 4 was recovered in April 2008 due to an electronics failure in the instrument; data from the other four instruments was successfully downloaded via acoustic telemetry during the April 2008 cruise. The westernmost PIES washed ashore in the Bahamas in June 2008 due to an anchor failure; the instrument was recovered and redeployed 16 days after it surfaced. Two of the five inverted echo sounders (IES) sites shown in Figure 4 were recovered and redeployed during the September 2008 cruise due to concerns about their anchors and a replacement PIES was deployed at the easternmost site. Four additional temporary IES/PIES sites had been deployed during the September 2006 cruise (supplied by between the permanent sites for a planned two-year evaluation of the array resolution; two of the four were successfully recovered during the September 2008 cruise, the other two were lost, probably due to anchor failures. Note that OCO support to date for the PIES/CPIES moorings has been sufficient to repair and replace these mooring failures. To date CPO has provided funds for five instruments for the five permanent sites. One of these instruments was lost and replaced with AOML base funds. All other IES/PIES/CPIES described above are provided from AOML's aging stable of instruments (dating as far back as 1986, which partly explains the instrument failure). Additional OCO funds will be required in the future if the array of PIES/CPIES is to be maintained long-term especially with telemetry capable instruments. Funds for a spare CPIES (required for the turn-around cruise in spring 2010), for a replacement pressure sensor (to replace a failing sensor) and for a replacement deck unit (which has been damaged) have been included in an Equipment Support add-task.

Table 4. Cruise dates and water samples taken for Large Vessel full water column surveys of the Deep Western Boundary Current. September 2008 cruise was on the R/V Cape Hatteras. September 2006 and April 2008 cruises aboard the R/V Seward Johnson and the May 2005 cruise aboard the R/V Knorr were with ship time funded by NSF. April 2001 cruise on the R/V Oceanus. All other cruises were conducted on the NOAA Ship Ronald H. Brown. Additional nutrient and carbon measurements that were taken during the March 2006 cruise were collected using base funds. Funding for collection in future years is being requested as an Add Task.

FY	Date	Stations	Bottle Samples	Comments
2008	Sep, 2008	17	105 O2, 174 S	Telemetry data collected from one PIES and one CPIES, three PIES were deployed, three PIES and one IES were recovered, one PIES and one IES were lost
2008	Apr, 2008	45	400 O2, 634 S	Telemetry data collected from four PIES/CPIES, and one PIES was recovered
2007	Sep, 2007	48	737 O2, 706 S	Telemetry data collected from five PIES/CPIES
2007	Mar, 2007	74	1092 O2, 1135 S	Telemetry data collected from five PIES/CPIES
2006	Sep, 2006	42	465 O2, 568 S	2 IES recovered, 1 IES lost (but data retrieved via telemetry), 7 IES deployed, and data retrieved via telemetry from 2 IES
2006	Mar, 2006	72	921 O2, 943 S, 391 nut., 506 DOC/TOC, 80 DIC, 40 TALK	2 IES recovered, 2 IES deployed, data from 3 IES recovered via acoustic telemetry
2005	Sep, 2005	53	728 O2, 728 S	1 IES deployed, 2 IESs recovered, data from 3 IESs recovered via acoustic telemetry
2005	May, 2005	70	1084 O2, 1180 S	1 IES deployed, data recovered from 3 IESs via acoustic telemetry
2004	Sep, 2004	42	634 O2, 629 S	5 IES mooring deployments
2003	Feb, 2003	54	844 O2, 843 S	3 IES Mooring recoveries, Short Seabeam in Florida Straits
2002	June 2002	57	924 O2, 924 S	Extended Seabeam survey east of Abaco Island, SF6 samples.
2001	April 2001	33	607 O2, 659 S	4 IES mooring deployments

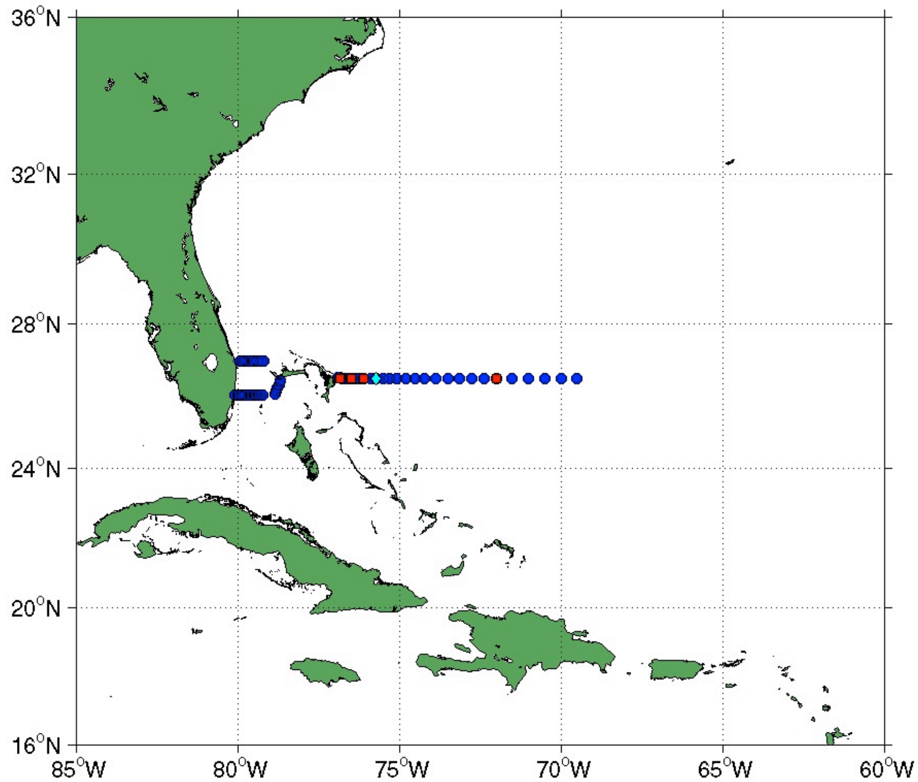

Figure 4. Approximate locations of full water column hydrographic stations sampled on the two cruises in FY 2005. Blue circles denote CTD sites. Red squares denote PIES moorings and the cyan diamond denotes a CPIES mooring. Note nearly all of the CTD stations east of Abaco Island were not occupied during the September 2008 cruise due to time constraints as discussed in the text.

4. RESEARCH HIGHLIGHTS

1. A recent publication illustrated how well the joint NOAA-NSF-NERC collaborative program is doing at capturing the total basin-wide-integrated transport through the combination of different types of measurement systems (Kanzow et al., 2008).

2. In a pair of papers (DiNezio et al., 2008, Meinen et al., 2008) the long-term variability of the Florida Current transport is documented back to the 1960s using modern and reanalyzed historical data and this variability is studied in the context of wind stress variability over the basin interior. The high percentage of variance in sub-annual periods is shown to conclusively necessitate continuous time-series observations in order to extract and study annual and interannual variations in the Florida Current transport.

3. Baringer and Meinen (2008) summarized in the State of the Climate Report (BAMS, 2008, 89(7), s49-s51) results from the first year of this new MOC monitoring array that appeared in Science in August (Kanzow *et al.,* 2007, Cunningham *et al.,* 2007). The results from the first year of this array indicate a

surprising amount of variability in the MOC strength. In fact within one year, all the MOC values estimated from Bryden *et al.,* (2005) can be found within the first year of the time series. These results cannot disprove the presence of a long-term trend in the strength of the MOC, but they do suggest that a careful error analysis be performed that includes the underlying variability of the MOC (the standard deviation of this first year was estimated as 3.1 Sv[5]). Fluctuations in the Florida Current show a clear negative correlation with NAO during the 1982-1998 time period (Baringer and Larsen, 2001); however while the NAO has been tending to decrease over the past twenty years, the Florida Current transport shows no corresponding long-term trend through 2007. The annual mean Florida Current transport observed in 2007 (31.8 Sv) falls only slightly below the long term mean of 32.1 Sv, and given the statistical standard error of the mean of 1 Sv for a year, 2007 cannot be termed as an unusual year in terms of the Florida Current transport. Compared to 2006 (annual mean of 31.3 Sv) the Florida Current appears to have increased only slightly. Note that 2007 shows similar variability to previous years and no anomalous events occurred during the year.

4. A paper analyzing the data from an array of 6 moorings deployed east of Abaco, Bahamas along 26.5ºN during March 2004 to May 2005 was published. These moorings formed the western boundary array of a trans-basin observing system designed to continuously monitor the meridional overturning circulation and meridional heat flux in the subtropical North Atlantic, under the framework of the joint U.K./U.S. RAPID-MOC (Rapid Climate Change – Meridional Overturning Circulation) program. Important features of the western boundary circulation include the southward-flowing Deep Western Boundary Current (DWBC) below 1000 m, and the northward-flowing “Antilles” Current in the upper 1000 m. Transports in the western boundary layer are estimated from direct current meter observations and from dynamic height moorings that measure the spatially-integrated geostrophic flow between moorings. The results of these methods are combined to estimate the time varying transports in the upper and deep ocean over the width of the western boundary layer to a distance of 500 km offshore of the Bahamas escarpment. The net southward transport of the DWBC across this region, inclusive of northward deep recirculation, is -26.5 Sv, which is divided nearly equally between Upper (-13.9 Sv) and Lower (-12.6 Sv) North Atlantic Deep Water (NADW). In the top 1000 m, 6.0 Sv flows northward in a thermocline-intensified jet near the western boundary. These transports are found to agree well with historical current meter data in the region collected between 1986 and 1997. Variability in both the shallow and deep components of the circulation is large, with transports above 1000 m varying between –15 to +25 Sv and deep transports varying between –60 to +3 Sv. Much of this transport variability occurs on relatively short time scales of several days to a few weeks associated with barotropic fluctuations. Upon removal of the barotropic fluctuations, slower baroclinic transport variations are revealed, including a temporary stoppage of the lower NADW transport in the DWBC during November 2004.

[5] Sv is a Sverdrup or 10^6 m^3/s, a unit commonly used for ocean volume transports.

4. PEER REWIEDED PUBLICATIONS

Baringer, M. O., and C. S. Meinen, 2008:"The Meridional Overturning Circulation", in "State of the Climate in 2007", D. H. Levinson and J. H. Lawrimore (eds.), *Bull. Am. Met. Soc.*, 89(7), s49-s51, doi:10.1175/BAMS-89-7-StateoftheClimate.

DiNezio, P. N., L. J. Gramer, W. E. Johns, C. S. Meinen, and M. O. Baringer, 2008: "Observed Interannual Variability of the Florida Current: Wind Forcing and the North Atlantic Oscillation", *J. Phys. Oceanogr.*, in press.

Johns, W.E., L.M. Beal, M.O. Baringer, J.R. Molina, S.A. Cunningham, T. Kanzow, and D. Rayner., 2008: “Variability of shallow and deep western boundary currents off the Bahamas during 2004-2005: Results from the 26°N RAPID-MOC array”, *J. Phys. Oceanogr.*, 38(3), 605-623.

Kanzow, T., J. J-M. Hirschi, C. S. Meinen, D. Rayner, S. A. Cunningham, J. Marotzke, W. E. Johns, H. L. Bryden, L. M. Beal, M. O. Baringer, 2008: "A prototype system of observing the Atlantic Meridional Overturning Circulation - scientific basis, measurement and risk mitigation strategies, and first results", *J. Operational Oceanogr.*, 1, 19 - 28.

Meinen, C. S., M. O. Baringer, and R. F. Garcia, 2008: "Florida Current Transport Variabilty: An Analysis of Annual and Longer-Period Signals", *J. Geophys. Res.*, submitted.

5. ABSTRACTS/MEETING PROCEEDINGS

Meinen, C. S., M. O. Baringer, and R. F. Garcia, 2008: “Florida Current Transport Variability: An Analysis of Annual and Longer-Period Signals”. (RAPID Annual Meeting, June 30-July 2, Cambridge, United Kingdom.)

Baringer, M., W. Johns, C. Meinen, D. Shoosmith, and H. Bryden, 2008: “On the Structure of Florida Current Variability”. (RAPID Annual Meeting, June 30-July 2, Cambridge, United Kingdom.)

Johns, W., H. Bryden, M. Baringer, L. Beal, S. Cunningham, T. Kanzow, J. Hirschi, J. Marotzke, Z. Garraffo, C. Meinen, and R. Curry, 2008: “Observations of Meridional Heat Transport Variability from the 26.5°N RAPID-MOC Array”. (RAPID Annual Meeting, June 30-July 2, Cambridge, United Kingdom).

Kanzow, T., S. A. Cunningham, D. Rayner, M. O. Baringer, W. E. Johns, J. J.-M. Hirschi, L. M. Beal, C. Meinen, H. L. Bryden, 2008: “Observations of the temporal variability of the Atlantic meridional overturning circulation from the Rapid-MOC transatlantic array at 26.5ºN”. (RAPID Annual Meeting, June 30-July 2, Cambridge, United Kingdom).

Meinen, C. S., M. O. Baringer, and R. F. Garcia, 2008: “Variations of the Florida Current transport from 1964 to 2007 and the relationship to forcing”. (2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida).

Garcia, R. F., C. S. Meinen, M. O. Baringer, 2008: “Utilizing Voltage Measurements on a Submarine Cable to Estimate Florida Current Transport Operationally: A Real-Time Observing System. (2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida).

Fonseca, C. A., M. O. Baringer, C. S. Meinen, 2008: “Water Mass Changes in the Deep Western Boundary Current Along 26.5ºN”. (2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida).

Cunningham, S. A., T. Kanzow, D. Rayner, M. O. Baringer, W. E. Johns, J. Hirschi, L. M. Beal, C. S. Meinen, H. L. Bryden, J. Marotzke, 2008: “Observations of the Temporal Variability of the Atlantic Meridional Overturning Circulation”. (2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida).

Johns, W. E., H. L. Bryden, M. O. Baringer, L. M. Beal, S. A. Cunningham, T. Kanzow, J. Hirschi, J. Marotzke, Z. Garraffo, C. S. Meinen, 2008: “Observations of Atlantic Meridional Heat Transport Variability at 26.5°N from the RAPID-MOC Array. (2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida).

Peng, G, Z. Garraffo, G. Halliwell, O. Smedstad, C. S. Meinen, and V. Kourafalou, 2008: “Variability of the Florida Current Transport at 27ºN”. (2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida).

Bryden, H. L., S. A. Cunningham, T. Kanzow, D. Rayner, M. O. Baringer, W. E. Johns, J. Marotzke, J. Hirschi, L. M. Beal, C. S. Meinen, 2008: “An Operational Array for Monitoring the Atlantic Meridional Overturning Circulation at 26°N”. (2008 Ocean Sciences Meeting, March 2-7, Orlando, Florida).