Western Boundary Time Series in the Atlantic Ocean

Molly Baringer, Silvia Garzoli and Christopher Meinen
NOAA Atlantic Oceanographic and Meteorological Laboratory, Miami FL

1. Project Summary

Goal/Rationale: This project seeks to continuously monitor two important components of the thermohaline circulation in the Subtropical North Atlantic with the ultimate goal of determining the state of the overturning circulation and providing a monitoring system for rapid climate change. The components include the northward flowing Florida Current and the southward flowing Deep Western Boundary Current. The Florida Current is the warm surface intensified flow that represents the bulk of what we call the upper limb of the thermohaline circulation in the subtropical Atlantic.

The Western Boundary Time Series project represents NOAA's longest term observing system for the Atlantic Meridional Overturning Circulation (MOC). Over the past 25+ 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.

Components of the observing system include continuous real-time cable measurements of Gulf Stream transport, cable calibration cruises including eight to ten small boat dropsonde cruises, quarterly Walton Smith CTD/LADCP cruises, annual full depth hydrographic CTD/LADCP cruises across the Deep Western Boundary Current and beginning in 2004 continuous moored measurements of the deep transports using inverted echosounders (PIES).

General Overview:
The project maintains NOAA's well-established and climatically significant Florida Current volume transport time series. 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 since 1982. 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.

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 1980s 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.

The Western Boundary Time Series project consists of two main elements, each of which is broken into several sub-elements:

<u>Continuous Measurements:</u> –

- Antilles and Deep Western Boundary Current transport time-series variability is monitored using a line of five PIES/CPIES moorings.
- Florida Current transport time series using pressure tide gauges placed into service in July 2008.
- Florida Current transport time-series variability is monitored using an out-of-service phone cable instrumented with a voltage recording system. In addition a backup system for the current cable is being tested: this system includes two pressure gauges spanning the Florida Straits at 27°N.

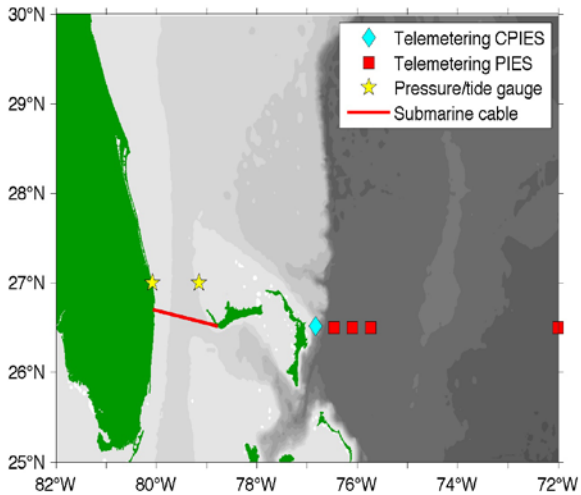

Figure 1: *Summary locations of continuous time series components of the Western Boundary Time Series program.*

<u>Discrete Property Measurements</u> –

- Antilles and Deep Western Boundary Current transport and water mass snapshot variability are monitored by annual CTD/LADCP cruises for velocity, temperature, salinity and oxygen. These measurements are used to describe long term watermass changes in the circulation in addition to calibration of the continuous time series measurements.
- 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) along the 27N latitude in the Florida Straits.

- CTD/LADCP sections conducted on small boats four times per year along the 27N latitude in the Florida Straits each year, providing additional samples for cable calibration as well detailed vertical structure of the Florida Current velocity coincident with temperature, salinity and oxygen measurements and hence can provide estimates of property fluxes beyond just volume transport.

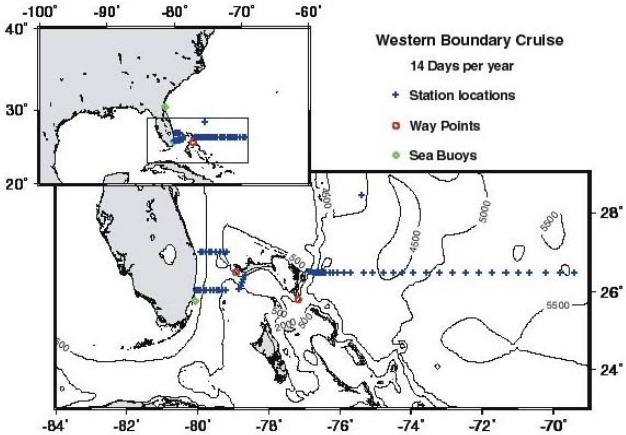

Figure 2: *Summary locations of discrete CTD/LADCP and dropsonde locations from the Western Boundary Time series program.*

The observations carried out at NOAA/AOML as part of the Western Boundary Time Series project also couple constructively with the US/NSF & UK/NERC funded moored time series observations east of Abaco Island, Grand Bahamas to serve three primary purposes for climate variability studies:

1. Monitoring of the DWBC for water-mass and transport signatures related to changes in the strengths and regions of high latitude water mass formation in the North Atlantic.
2. Providing the western boundary endpoint of a subtropical Meridional Overturning Circulation and heat transport monitoring array designed to measure the thermohaline overturning circulation at 26.5 N and the time varying meridional heat transport.
3. Monitoring the intensity of the Florida Current and the Antilles current as an index 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.

Primary users of the data collected in this program are largely the international scientific community, of which some small indicator of its impact includes the more than 25 research scientists from more than 16 different institutions and 6 countries that have subscribed to the real-time email update distribution list. This is only a small subset of the research community

that uses this data that has been endorsed by many national and international science panels including US CLIVAR, International CLIVAR, OceanSites, OceanObs09 etc. While direct assimilation of transport information into operational models is not routinely possible, modeling and analysis products regularly make use of these data as benchmarks for model fidelity. Due to the longstanding nature of this program, a large international program was started in 2004 in collaboration with the U.S. National Science Foundation, the U.K. Rapid Watch Program and Germany to measure the remaining components of the MOC circulation not included in NOAA's long-standing program.