Western Boundary Time Series in the Atlantic Ocean

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1. Project Summary

This project continuously monitors 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 and hence addresses the program deliverable on "ocean heat content and transport". 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 the upper limb of the thermohaline circulation (or meridional overturning circulation, MOC) in the subtropical Atlantic. Over the past 30+ 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 and is the longest time series of the flow that makes up the MOC available globally.

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. the intensity of the volume transport, using electromagnetic induction theory. The correlation of Florida Current transport variability with the climate relevant phenomena has been documented in numerous published scientific studies. These strong correlations link the Florida Current transport with significant weather changes, climate phenomena and large-scale ocean-atmosphere patterns in the Atlantic, including decadal and inter-decadal variations in fisheries, rainfall, and hurricane activity.

The repeated hydrographic sampling of the Deep Western Boundary Current (DWBC) collected by this project has established a high-resolution, high quality record of water mass properties east of Abaco Island Bahamas 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 is instead a 30 year 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 cruises across the DWBC to measure the water mass properties and transports. With the cooperation of University of Miami researchers (Dr. Johns) and funding from the National Science Foundation for the Meridional Overturning Circulation and Heat transport Array (MOCHA), as well as sharing of personnel and ship-time resources, these cruises have been conducted as much as twice each year since 2004.

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 and quarterly Walton Smith hydrographic and velocity cruises in the Florida Straits, annual full depth hydrographic cruises across the Deep Western Boundary Current and beginning in 2004 continuous moored measurements of the deep transports using inverted echo sounders. Figures 1 and 2 show the location of the various components of the observing system.

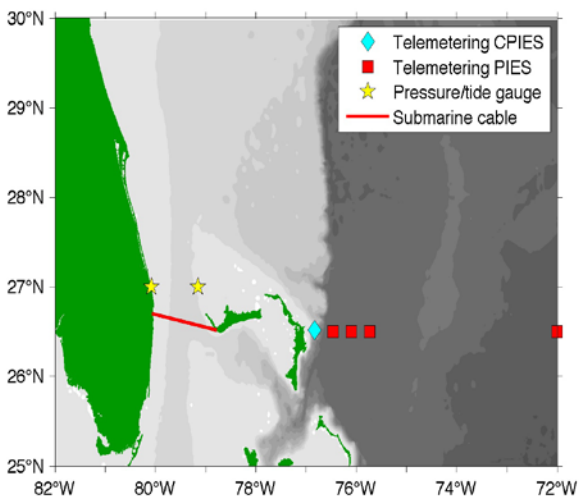

Figure 1: *Summary locations of continuous time series components of the Western Boundary Time Series program. Inverted echo sounder with pressure gauges (PIES), inverted echo sounders with pressure and current velocity (CPIES), pressure gauges and the submarine cable all provide daily estimates of the strength of the Western Boundary Currents components of the MOC.*

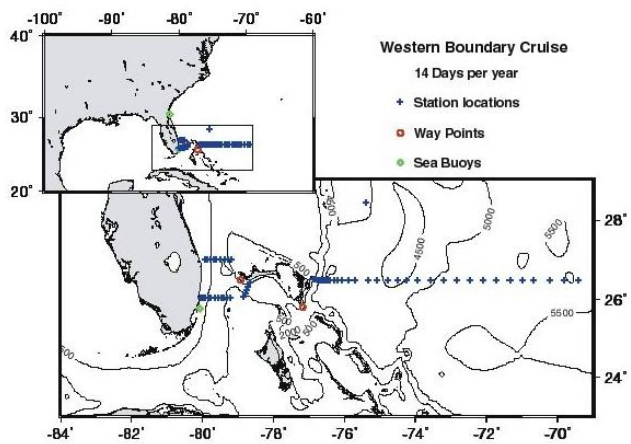

Figure 2: *Summary locations of discrete hydrographic and dropsonde locations from the Western Boundary Time Series program. All station locations are occupied with full water column samples at least annually. The stations along 27N in the Florida Straits are occupied during the quarterly Walton Smith and approximately bi-monthly small boat cruises.*

2. Scientific and Observing System Accomplishments

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.

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 the WBTS program, a large international program was started in 2004 in collaboration with the U.S. National Science Foundation, and the U.K. Rapid Watch Program to measure the remaining components of the MOC circulation not included in NOAA's long-standing program.

2.1. Contribution to Climate Program Deliverables

The WBTS Project, through its collection of temperature and salinity profile data and ocean circulation observations, contributes to the following NOAA/Climate Observation Division Program Deliverables (in rough order of impact and relevance):

- ***Ocean Heat Content and Transport***, to better understand the extent to which the ocean sequesters heat; to identify where heat enters the ocean and where it emerges to interact with the atmosphere; and to identify changes in thermohaline circulation and monitor for indications of possible abrupt climate change.

  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 and hence directly addresses the program deliverable on "***ocean heat content and transport***". 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.

- ***Sea Surface Temperature and Surface Currents***, to identify significant patterns of climate variability and change.

  WBTS data provides an integrated estimate of the strength of the Florida Current, the surface current along the coast of the United States, and profile data contributes to regional SST observations. Cruises also collect profile data of currents (via ADCP & LADCP) that provide direct estimates of the surface currents in the region.

- ***Sea Level***, to identify changes resulting from trends and variability in climate

  The WBTS project provides indirect indicators that can influence sea-level variability along the east coast of the United States through direct observations of the Florida Current and collaborative observations of the Meridional Overturning Circulation. Boundary Current fluctuations have been shown to have a kinematic impact of local sea-level rise.
- ***Air-Sea Exchanges of Heat, Momentum, and Fresh Water***, to identify changes in forcing functions driving ocean conditions and atmospheric conditions; and to elucidate oceanic influences on the global water cycle

  The WBTS project through its collaboration with the UK and NSF funded RAPID-MOC/MOCHA programs provides an *in situ* ocean heat and mass transport time series that can be used as a constraint on air-sea flux estimates and numerical model validation. This type of direct oceanic-transport-based flux estimate helps to reduce errors in surface products and assess numerical models.
- ***Ocean Carbon Uptake and Content***, to better understand the extent to which the ocean sequesters CO2 and how cycling among ocean-land-atmosphere carbon reservoirs varies on seasonal-to-decadal time scales

  As noted above, the transport of boundary currents and the overturning circulation are central to determining Carbon uptake. The WBTS project provides a boundary current estimate of the Florida Current transport that is used to produce Carbon flux estimates (e.g. Macdonald et al, 2003; Hansell et al, 2004). In additional, Carbon, nutrient and chlorofluorocarbon measurements have been taken on several WBTS cruises (unfunded projects).

2.2. Contribution to Societal Challenges

NOAA's Climate Goal is focusing on an initial set of societal challenges:

- Reduce vulnerability to extreme weather (extremes);
- Prepare for drought and water resource challenges (drought);
- Manage risks to coastlines and coastal infrastructure (coastal inundation); and
- Sustainably manage marine ecosystems (marine ecosystems)

The WBTS provides indirect contribution to these societal challenges. The program provides direct estimates of the Florida Current transport; low Florida Current transport has been linked to coastal inundation along the east coast (e.g. Sweet et al., 2009, Ezer et al., 2013). Similarly, changes in the net meridional overturning circulation can influence long-term sea-level. Extreme weather (e.g. hurricanes) and drought (e.g. rainfall) have been linked to the strength of the meridional overturning circulation. Continued monitoring of the Florida Current and the meridional overturning circulation may improve forecasts of coastal inundation, seasonal forecasts of hurricanes, etc.

2.3. Observing system accomplishments

Florida Current Cable Time Series:

Florida Current transport time-series variability is monitored using an out-of-service phone cable instrumented with a voltage recording system. Data acquisition has continued using the cable during FY2014; during this FY there 91% data return from the voltage recording system. Ironically, during FY2014 this program was approved to receive additional emergency funds to replace the cable recording systems that had been in place for almost a decade. Unfortunately these funds were not available until after several failures of the system that led to intermittent gaps in the record. Emergency funds allowed for the replacement of these PC-based systems in addition to backup systems, hence continued success of the system is likely for the next five years.

Florida Current pressure gauge time series:

Florida Current transport time series using pressure tide gauges placed into service in July 2008. 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. In FY2014, both the eastern and western pressure gauge were downloaded and redeployed with fresh batteries.

Florida Current Discrete Measurements:

Regular calibration cruises are required to convert the recorded cable voltage to flow estimates, including up to six 2-day small charter boat cruises on the R/V F. G. WALTON SMITH each year and six to ten 1-day charters onboard small fishing vessels, provided sufficient ship-time is available.

- A total of four Walton Smith cruises were conducted in FY2014 (Table 1). The fifth cruise was pushed into early FY2015 due to ship scheduling issues.

Table 1: Cruise dates for 2-3 day calibration cruises on the R/V Walton Smith. A total of 8 charter days were used for FY2014 with two days carried over to FY2015.

FY2014	FY2013	FY2012	FY2011	FY2010
Dec 20-21, 2013	June 3-4, 2013	Dec 7-8, 2011	Nov 30-Dec 1, 2010	Nov 23-24, 2009
Apr 23-24, 2014	Aug 5-6, 2013	May 30-31, 2012	Mar 8-9 2011	Feb 25-26, 2010
July 22-23, 2014	Oct 17-18, 2013	July 14-15, 2012	Jun 14-15, 2011	May 18-20, 2010
Sep 17-18, 2014		Sep 30 - Oct 2, 2012	Sep 20-21, 2011	Aug 23-24, 2010

- Charter funds paid for ten small boat cruises that were completed this FY (see Table 2). The small boat program has had the highest overall success rate than any previous year. This is largely thanks to a more stable charter operator with a more flexible schedule.

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

Planned Cruise	FY2014	FY2013	FY2012
1	28-Jan-14	18-Oct-12 dropsonde electronics failure	2-Apr-12
2	6-Feb-14	5/24/2013 dropsonde lost	31-May-12
3	25-Apr-14	27-Jun-13	9-Jul-12
4	23-May-14	2-Aug-13	17-Jun-12 GPS failure
5	15-Jul-14	8/30/2013 dropsonde lost	24-Jul-12
6	24-Jul-14		
7	8-Aug-14		
8	21-Aug-14		
9	1-Oct-14		
10	22-Oct-14		

- *Deep Western Boundary Current Global Class Cruises:* During fiscal year 2013, one cruise involving full-water-column CTD, lowered ADCP, and shipboard ADCP was conducted 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 24 10-liter Niskin bottles, was lowered to the bottom. This provides profiles of velocity, pressure, salinity (conductivity), temperature, and dissolved oxygen concentration. Water samples were also collected at various depths and analyzed for salinity and oxygen concentration to aid with CTD calibration.
    - This FY the program completed a cruise from Mar 15 to Mar 31, 2014 on the UNOLS ship R/V Atlantic Explorer. A total of 41 CTD-O_2/LADCP stations were occupied and PIES/CPIES data were downloaded from 6 sites. There was a successful recovery and deployment of a PIES at the A2 site. Mooring operations include recovery and redeployment of three tall moorings with a mixture of microcats and current meters. Two bottom landers were recovered and one was

deployed equipped with bottom pressure recorders. As part of NOAA contribution to the Global Surface Drifter Program, 10 surface velocity drifters equipped with sea-surface temperature sensors were deployed. The cruise was fully successful.

- *Deep Western Boundary Current Continuous Time Series:* Since 2004, the WBTS project has produced daily time-series of the magnitude of the Deep Western Boundary Current mass transport in quasi-real-time (downloaded to research ships up to twice each year). This 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 some cases 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. This year supplemental emergency equipment funds provided for the purchase of spare PIES to improve the systems resiliency and replace one of the two instruments lost two years ago.

2.4. Scientific Highlights

While this program only funds data collection this fiscal year the lead PIs published five papers on this data (Baringer et al, 2014a; Baringer et al, 2014b; Meinen and Garzoli, 2014; Garcia and Meinen, 2014; Smeed et al, 2014), and four Data Reports were published (Hooper and Baringer, 2014a; Hooper and Baringer, 2013b; Hooper and Baringer, 2014c; Hooper and Baringer, 2014d). The published papers included the following highlights:

- Baringer et al., 2014a State of the Meridional Overturning Circulation report appeared in the State of the Climate Report that expanded the report to include 41°N, 26°N, and 16°N MOC transports as well as the Florida Current time series.
- Baringer et al., 2014b State of the Meridional Heat Transport report appeared in the State of the Climate Report that included updated heat transport estimates from 41°N, 26°N and 35°S.
- Meinen and Garzoli, 2014 published the paper "Attribution of Deep Western Boundary Current variability at 26.5°N" which explores the mechanisms that cause large transport changes in the Deep Western Boundary Current east of the Bahamas and argues that the strongest variations are associated with Rossby Wave-like features propagating westward from the interior that overwhelm the DWBC transport signal.
- "Accuracy of Florida Current volume transport measurements at 27°N using multiple observational techniques" by R. F. Garcia and C. S. Meinen was published in the Journal of Atmospheric and Oceanic Technology, 2014. The paper uses observations from a submarine cable, from free-falling dropsonde floats, and from lowered acoustic Doppler current profilers to quantify the precise accuracy of the Florida Current volume transport estimated and served to the public.
- Smeed et al., 2014 examined the first 8.5 years of the data from the 26°N MOC array to show a small but statistically significant downward trend in the MOC from the 26°N array which is primarily resulting from changes in the ocean density structure within the basin interior. This change is likely to be associated with interannual and/or decadal variability, and it is superimposed on top of much stronger subannual variations that make extracting trends difficult. This illustrates the imperative need for making continuous daily estimates over long time scales in order to tease out these very important long-period signals.

2.5. Issues

Years of level funded budgets have resulted in a less fault tolerant system, reducing the salary support for data processing, equipment calibrations and maintenance, spares and reduced travel to scientific meetings. Last year COD provided emergency funds for equipment. With these funds we purchased a replacement PIES and cable recording system. This was essential equipment that will allow the program to continue collecting good data.

The other major obstacle is that the NOAA charter fund supplied money to conduct only Walton Smith cruises and not the small boat cruise this program requires for the cable calibration. The program cannot sustain level funding and absorb the costs of $25K in unfunded charter costs.

2.6. Miscellaneous Information

1. This data is not available on the Global Telecommunications System.
2. Project web sites (with links to near-real time data, delayed mode data and publications):
   http://www.aoml.noaa.gov/phod/floridacurrent/
   http://www.aoml.noaa.gov/phod/wbts/
   ftp://ftp.aoml.noaa.gov/phod/pub/WBTS/
   http://www.noc.soton.ac.uk/rapidmoc/
   http://www.rsmas.miami.edu/users/mocha/
3. Most recent data available:
   Near-real time Florida Current transport data is available after three days.
   Hydrographic cruise data are typically available within 6 months after the cruise
4. Data is available through the AOML web site. From this web site, the UK Rapid program collects data, archives it and makes it available through their web site. NODC (Chris Pavers) automatically adds new data posted to the web site to the NODC archives. This year we have formatted PIES and Rapid/MOCHA data to be delivered in OceanSITES format via their web site.
5. There is no formal data management plan for this project, but we adhere to the UK Rapid data policy at http://www.bodc.ac.uk/projects/uk/rapid/data_policy/ and the OceanSites/Clivar data policy at http://www.oceansites.org/docs/OceanSITES_Data_Policy.doc
6. Uses of the data are tracked through voluntary notifications from people who download the data, literature searches citing "Florida Current", "WBTS", "Rapid" or "MOCHA" acronyms and citation reports that cite articles we know are written using project supported data.
7. The data is voluntarily cited upon use using a requested citation text acknowledging the support of NOAA, AOML and COD found on the project web site data download page and now listed in the OceanSITES netcdf format.

3. Outreach and Education

The WBTS project has been involved informally with numerous graduate students and post-doctoral fellows from the University of Miami and other universities. For example, one graduate

student at the University of Miami, Jian Zhao, has just successfully completed his PhD degree using data from the WBTS project along with data from satellites and numerical model output (C. Meinen served on his thesis committee). Graduate students and post-doctoral fellows are encouraged to use this data for theses and papers, although no explicit analysis is funded under this proposal (e.g. Ricardo Dominguez, a M.S. student at University of Miami has used WBTS data and sea-level data along the east coast of the United States to study kinematic sea-level changes as part of a class project). Over the past several years the program has hosted five Teachers at Sea to participate in the Western Boundary Time Series cruises on the NOAA Ship Ronald H. Brown.

M. Baringer mentored a summer intern (Lindsay Roupe) from the Mentoring Physical Oceanographers to Increase Retention (MPOWIR) program. Ms. Roupe is a masters degree student at Stony Brook University, and she completed a 10 week internship at AOML and is preparing a paper to submit for scientific publication. M. Baringer also mentored a summer intern (Ryan Winslow) from the Marine & Science Technology Senior High School (MAST). Mr. Winslow completed his 8-week internship with a written report and oral presentation of his results. Several additional outreach activities included providing tours of the AOML facilities in August 2014 for RSMAS undergraduate students and in July 2014 for congressional staffers. M. Baringer worked with G. Rawson for the creation of two project videos now hosted on the PHOD web site (one about the AOML Argo project and one about the Western Boundary Time Series project). M. Baringer joined Mentoring Physical Oceanography Women to Increase Retention (MPOWIR) executive team. The goal of the team is to apply for funding for NOAA to continue to support NOAA MPOWIR interns (June 2014).

C. Meinen was interviewed by a researcher working to develop a new climate program at North Carolina State University. C. Meinen participated in a television interview with the Irish public broadcaster RTE to discuss several issues associated with the MOC. C. Meinen is on the USAMOC Executive Committee and the IAPSO Executive Council.

Silvia L. Garzoli is a member of the Executive Steering Committee and a mentor for MPOWIR.

Finally, several presentations were given by the PIs at national and international science conferences including the US AMOC/RAPID meeting, the UK sponsored workshop on Ocean Heat Uptake and the IAHS-IAPSO-IASPEI joint assembly. All the PIs contributed to a submitted manuscript about NOAA's portfolio of MOC measurements (Perez et al., 2015).

4. Publications and Reports

4.1. Publications by Principal Investigators

- **Published**

Abraham, J.P., M. Baringer, N.L. Bindoff, T. Boyer, L.J. Cheng, J.A. Church, J.L. Conroy, C.M. Domingues, J.T. Fasullo, J. Gilson, G. Goni, S.A. Good, J. M. Gorman, V. Gouretski, M. Ishii, G.C. Johnson, S. Kizu, J.M. Lyman, A. M. Macdonald, W.J. Minkowycz, S.E. Moffitt, M.D. Palmer, A.R. Piola, F. Reseghetti, K. Schuckmann,K.E. Trenberth, I.

Velicogna, J.K. Willis, 2013. A review of global ocean temperature observations: Implications for ocean heat content estimates and climate change, *Rev. Geophys.*, 51, 450–483, doi: 10.1002/rog.20022.

Ansorge, I.J., M. O. Baringer, E. J. D. Campos, S. Dong, R. A. Fine, S. L. Garzoli, G. Goni, C. S. Meinen, R. C. Perez, A. R. Piola, M. J. Roberts, S. Speich, J. Sprintall, T. Terre, and M. A. Van Den Berg, 2014. Basin-Wide Oceanographic Array Bridges the South Atlantic. Eos, Vol. 95, No. 6, 53-54.

Baringer, M. O.,W. E. Johns, S. Garzoli, S. Dong, D. Volkov, W. R. Hobbs, J. Willis, 2014a. [Global Oceans] Meridional Oceanic Heat Transport in the Atlantic Ocean, [in "State of the Climate in 2013"]. Bull. Am. Met, 95(6):69-71, doi:10.1002/2014EO060001.

Baringer, M.O., G. McCarthy, J. Willis, M. Lankhorst, D. A. Smeed, U. Send, D. Rayner, W. E. Johns, C. S. Meinen, S. A. Cunningham, T. O. Kanzow, E. Frajka-Williams, and J. Marotzke, 2014b. [Global Oceans] Meridional Overturning Circulation Observations in the North Atlantic Ocean, [in "State of the Climate in 2013"]. Bull. Am. Met., 95(7):67-69, doi:10.1002/2014EO060001.

Dong, S., M. Baringer, G. Goni, C. Meinen, and S. Garzoli, 2014. Seasonal Variations in the South Atlantic Meridional Overturning Circulation from Observations and Numerical Models. Geophysical Research Letters, 41(13):4611-4618, doi:10.1002/2014GL060428.

Garcia, R. F., and C. S. Meinen, 2014: Accuracy of Florida Current volume transport measurements at 27°N using multiple observational techniques, J. Atmos. Ocean. Tech., 31 (5), 1169-1180, 10.1175/JTECH-D-13-00148.1.

Goni, G., J. Sprintall, D. Roemmich, A. Gronell Thresher, R. Couley, and M. Baringer, 2014: The Global Network of XBT Temperature Sections in Support of Oceanographic and Climate Studies. Chapter 7: Oceans and Society: Blue Planet, ed. Samy Djavidnia, Victoria Cheung, Michael Ott and Sophie Seeyave, Cambridge Scholars Publishing, Newcastle upon Tyne, UK, (ISBN 978-1-4438-5639-3), 37-45.

IPCC, 2013. Observations: Ocean (Chapter 3) [Rhein, M., S.R. Rintoul, S. Aoki, E. Campos, D. Chambers, R.A. Feely, S. Gulev, G.C. Johnson, S.A. Josey, A. Kostianoy, C. Mauritzen, D. Roemmich, L.D. Talley and F. Wang, 2013]. [in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp (M. Baringer, contributing author).

Macdonald, A., and M. Baringer 2013. Ocean heat transport. In Ocean Circulation and Climate: A 21st Century Perspective, G. Siedler, S.M. Griffies, J. Gould, and J.A. Church (eds.). International Geophysics Series, Volume 103, Academic Press, 759-785.

Meinen, C. S. and S. L. Garzoli, 2014: Attribution of Deep Western Boundary Current variability at 26.5°N. paper in *Deep-Sea Res.I,*, 90, 81-90, doi:10.1016/j.dsr.2014.04.016, 2014.

Meinen, C. S., S. Speich, R. C. Perez, S. Dong, A. R. Piola, S. L. Garzoli, M. Baringer, S. Gladyshev, and E. Campos, 2013: Temporal variability of the meridional overturning circulation at 34.5°S: Results from two pilot boundary arrays in the South Atlantic. *J. Geophys. Res.*, 118, 1-18, doi:10.1002/2013JC009228.

Smeed, D. A., McCarthy, G. D., Cunningham, S. A., Frajka-Williams, E., Rayner, D., Johns, W. E., Meinen, C. S., Baringer, M. O., Moat, B. I., Duchez, A., and Bryden, H. L., 2014.

Observed decline of the Atlantic meridional overturning circulation 2004-2012, Ocean Sci., 10, 29-38, doi:10.5194/os-10-29-2014.

- **In press**

McDonagh, E. L., B. A. King, H. L. Bryden, P. Courtois, Z. Szuts, M. Baringer, S. A. Cunningham, C. Atkinson and G. McCarthy, 2014. Continuous estimate of Atlantic oceanic freshwater flux at 26°N. J. of Climate, in press.

McCarthy, G., D. A. Smeed, W. E. Johns, E. Frajka-Williams, B. I. Moat, D. Rayner, M. O. Baringer, C. S. Meinen, H. L. Bryden, 2014. Measuring the Atlantic Meridional Overturning Circulation at 26ºN. Progress in Oceanography, in press.

Garzoli, S. L., S. Dong, R. Fine, C. S. Meinen, R. Perez, C. Schmid, E. van Sebille and Q. Yao, 2014. The fate of the Deep Western Boundary Current in the South Atlantic, Deep Sea Research, in revision.

- **Technical reports**

Hooper, J.A., and M.O. Baringer. Hydrographic measurements collected aboard the UNOLS Ship R/V Atlantic Explorer, 15 March-1 April 2014: Western boundary time series cruise AE1404 (AB1403). NOAA Data Report, OAR-AOML-46, 181 pp., 2014 FY2014

Hooper, J.A., and M.O. Baringer. Hydrographic measurements collected aboard the NOAA Ship R/V Ronald H. Brown, 19 February-5 March 2013: Western boundary time series cruise RB-1302 (AB1302). NOAA Data Report, OAR-AOML-45, 257 pp., 2014 FY2014

Hooper, J.A., and M.O. Baringer. Hydrographic measurements collected aboard the UNOLS Ship R/V Endeavor, 24 September-10 October 2012: Western boundary time series cruise EN-517 (AB1209). NOAA Data Report, OAR-AOML-44, 190 pp., 2014 FY2014

Hooper, J.A., and M.O. Baringer. Hydrographic measurements collected aboard the NOAA Ship Ronald H. Brown, 15 February-5 March 2012: Western boundary time series cruise RB-12-01 (AB1202). NOAA Data Report, OAR-AOML-43, 267 pp., 2013 FY2014

- **Data reports**

Wanninkhof, Rik, and Molly Baringer (2014). Dissolved oxygen, temperature, salinity, and other variables measured from profile observations using CTD and other instruments from the Ronald H. Brown in the East Coast of the United States and Gulf of Mexico from July 24, 2012 to August 13, 2012 (NODC Accession 0117943). National Oceanographic Data Center, NOAA. Dataset. doi:10.7289/V59W0CDS.

Wanninkhof, Rik, Leticia Barbero, Molly Baringer, Robert Byrne, Wei-Jun Cai, Chris Langdon, Steven Lohrenz, Joe Salisbury, and Jia-Zhong Zhang, (2014). Dissolved inorganic carbon, total alkalinity, pH, fugacity of carbon dioxide, and other variables from profile and surface observations using CTD, Niskin bottle, flow through pump and other instruments from the Ronald H. Brown in the Gulf of Mexico and East Coast of the United States from 2012-07-22 to 2012-08-13 (NODC Accession 0117971). National Oceanographic Data Center, NOAA. Dataset. doi:10.7289/V5542KJ0.