Southwest Atlantic MOC – SAM

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Table of Contents

1. Project Summary 1
2. Scientific and Observing System Accomplishments 3
   2.1. Outreach and Education 6
3. Publications and Reports 6
   3.1. Publications by Principal Investigators 6
   3.2. Other Relevant Publications 7

1. Project Summary

Variations in the Atlantic Meridional Overturning Circulation (MOC) have been shown to have connections to changes in precipitation and air temperatures over large segments of the northern hemisphere. The 2007 US interagency Ocean Research Priorities Plan designated the study of the MOC as a key near-term priority, and the US AMOC implementation panel has identified improving the observations of the MOC in the South Atlantic as one of the critical needs to better understand MOC variability. In the subtropical South Atlantic the MOC cell has a number of characteristics that distinguish it from the MOC circulation in the subtropical North Atlantic. Unlike in the north, where the MOC consists primarily of two western boundary components, in the South Atlantic the MOC circulation is more widely spread across the basin. Near 34-35°S the warm northward flowing upper limb is carried in the basin interior (via Agulhas Rings) and along the eastern boundary (in the Benguela Current), while the cold southward limb flows in the Deep Western Boundary Current (DWBC), which is primarily located under the southward flowing Brazil Current, although it is thought that another component of the deep southward limb flows southward along the west coast of Africa. This longitudinal spread is indicative of the role that the South Atlantic plays as both a 'gateway' and a 'mixing pot' of waters exchanged simultaneously with the Indian and Pacific Oceans. Deep waters that are formed in the northern North Atlantic must pass through the South Atlantic on their way to the Southern Ocean, where they are spread throughout the global ocean. Warm waters returning to the northern North Atlantic from the Indian and Pacific must pass through the South Atlantic and mix with those waters on their way northward across the equator. The NOAA Southwest Atlantic MOC ('SAM') observing project began in March 2009 as a collaboration between the US, Argentina and Brazil; the goal is to measure key MOC flows near the western boundary of the ocean in the South Atlantic. A parallel effort is underway in the Southeast Atlantic operated by France and South Africa. Locations of the four NOAA-funded moored instruments deployed as part of SAM are shown in Figure 1.

The SAM project is designed to parallel and complement NOAA's well-established project monitoring the MOC in the North Atlantic, the Western Boundary Time Series (WBTS) project. The WBTS project has formed the cornerstone for an international trans-basin MOC

measurement array at 26.5°N; the SAM project represents the first step to initiate a similar array at 34.5°S. The SAM array is based on two different types of moored instruments: inverted echo sounders equipped with pressure sensors (PIES), and inverted echo sounders equipped with both a pressure sensor and a single-depth acoustic current meter (CPIES). Work in the WBTS project has demonstrated that this combination of instruments is capable of quantifying the upper and deep layer transports. The initial SAM pilot array involving four PIES/CPIES represents a test of the array locations and the start of a long-term monitoring project for the MOC in the South Atlantic.

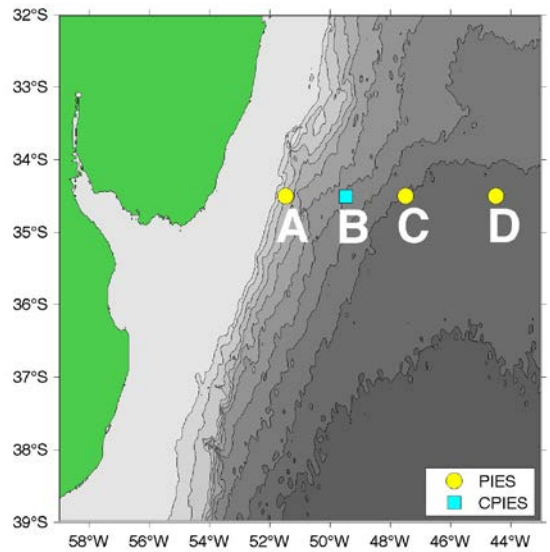

Figure 1: Locations of the four pressure-equipped inverted echo sounders (PIES) and current-and-pressure-equipped inverted echo sounders (CPIES) deployed as part of the NOAA funded SAM project. Note in July 2011 the CPIES at Site B was replaced with a PIES.

The time series observations in SAM 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 nascent international MOC monitoring system designed to measure the basin-wide meridional flows across the South Atlantic Ocean near 35°S.
- Quantifying how variations in the MOC propagate meridionally between the North and South Atlantic through comparison with the WBTS results.

The SAM project is a component of the NOAA "Ocean Reference Station" system in the Atlantic Ocean, and is one of the few time series observing sites in the Global Ocean Observing System (GOOS). SAM seeks to specifically address 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 locations 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. Measurements from the SAM project will provide critical records for use in validation and evaluation of the numerical climate models that are and will be used in the future for informing governments and agencies on climate change and planning.

2. Scientific and Observing System Accomplishments

Operational highlights

This project began in FY08; the PIES/CPIES were originally planned for deployment during a September-October 2008 cruise onboard the Argentine research vessel SHN Puerto Deseado – unfortunately before the cruise could take place the Argentine research vessel suffered an unexpected problem and the planned cruise with that ship had to be cancelled. Negotiations immediately started with the Brazilian collaborators and a replacement cruise was completed in March 2009 onboard the Brazilian Navy research vessel NH Cruzeiro do Sul. Real-time data collection from subsurface moorings is not yet technologically possible, however a key component of the SAM project is that it is possible to collect the daily average data from the moorings via acoustic telemetry from a nearby research vessel without needing to recover, download, and redeploy the instruments during each visit. Acoustic downloads of the data have been completed in August 2009, July and December 2010, July 2011, and now in this FY in July 2012, all onboard the Argentine research vessel SHN Puerto Deseado. The CPIES at Site B was malfunctioning in December 2010, so a spare PIES instrument belonging to the NOAA Western Boundary Time Series project was shipped down to Argentina and was used to replace the failing instrument in July 2011. Unfortunately the malfunctioning CPIES was destroyed during recovery when it was swept into the props of the research vessel. A replacement spare PIES to 'reimburse' the WBTS project, and a new spare PIES for the SAM project, were purchased using CPO year-end funds that were provided at the end of FY11. The new SAM spare will be used as a swap in early FY13 during the planned December 2012 cruise on the Brazilian research vessel Alpha Crusis when the rest of the SAM array will have its first turn-around.

In terms of deliverables, during FY12 the SAM array returned 90% of the daily estimates of acoustic travel time (missing data is mainly due to noise during acoustic download) and 99% of the daily estimates of bottom pressure up through July 2012 when the download cruise took place. Since March 2009, the SAM array has returned 81% of the daily estimates of acoustic travel time and 89% of the daily estimates of bottom pressure, with the bulk of the missing data being due to the malfunctioning and subsequently lost CPIES from Site B. Upon recovery (scheduled for December 2012) the complete hourly records from the three PIES at Sites A, C and D should be available for nearly four years.

Another critical aspect of the SAM project is that these joint research cruises aboard the Brazilian and Argentine research vessels are primarily funded by their home governments; NOAA covers only part of the cost of the fuel and funds for a single participant for these short cruises. Scientists from the University of Buenos Aires and the Argentine Hydrographic Service collect hydrographic, chemical, and velocity data along the mooring line from the coast to the furthest deployed instrument. These data not only provide the necessary calibration data for the PIES but also allows the study of the continental shelf/deep water masses interaction in the region. This aspect of the project has been successful with each country, and it represents a very significant cost savings to NOAA versus requiring ship time on a NOAA vessel in the South Atlantic. Ship availability issues arose in December 2011 with the Argentine vessel, however

due to the limited funds available through the NOAA Charter fund, only one cruise was possible in FY12 anyway, so the July 2012 cruise was the only one completed in FY12.

Research highlights

Due to the limited funding SAM has been receiving arising from the flat budgets, the data have not been fully processed or subjected to the best quality control because those aspects of the project have not received funding yet. However a basic clean up and processing of the data has been done so that a preliminary scientific analysis of the first year of the data could be completed together with our lead Argentine partner. The data collected in year one of SAM have provided the first look at the absolute transport variability of the Deep Western Boundary Current at 34.5°S (Figure 2). The observations demonstrate significant absolute transport variations at a range of time scales, with 40+ Sv changes happening over just a few days and 20-30 Sv anomalies lasting a month or more. The hydrographic data collected by our international partners during the joint cruises has also proven crucial for water mass identification, providing solid evidence that the SAM array is robustly capturing the Deep Western Boundary Current.

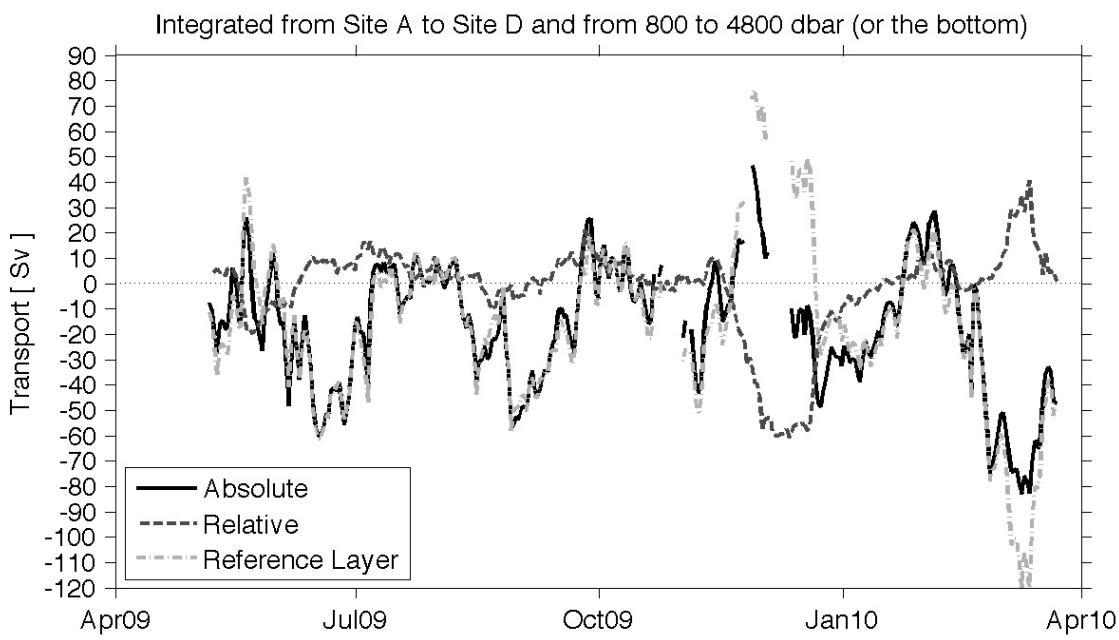

Figure 2: *Time series of absolute geostrophic transport determined using data collected by pressure-equipped inverted echo sounders in the SAM array and CTD and Argo data from the region. The absolute, baroclinic (relative to an assumed level of no motion at 800 dbar) and the barotropic (reference layer) transports are all shown. Modified from Meinen et al., (2012).*

The raw data from these moored instruments is presently maintained at NOAA-AOML; at present it is not being provided to the data centers (e.g. NODC) because without processing and

quality control this data would not be generally useful. The raw data is provided upon request, however, to those interested. Without appropriate funding it will be possible to continue collecting data but it will not be possible to consistently process the raw data to the highest quality needed for good estimates of ocean transport.

Information about the SAM project can be found at:
www.aoml.noaa.gov/phod/research/moc/samoc/sam/

Answers for data collection questions:

a. Are your data distributed in real time on the Global Telecommunications System?

   The PIES/CPIES data collected in this project are internally recorded in subsurface moored instruments and can only be obtained via visits with research vessels (either acoustic download or recovery of the instruments from the ocean bottom). As such it is not possible for these data to be distributed in real time.

b. Where do your real time data reside? Are the data available online?

   Real-time data are not available for the reasons mentioned above.

c. Where do your delayed mode data reside? Are the data available online? What is the date of the most recent data available publicly?

   Raw data collected in this project reside on computers at AOML, and they are available to researchers upon request up through July 2012 (the most recent visit via ship to the mooring sites). Because the project does not at present have funds for quality control or processing of the data being collected, the processed data is not available.

d. Where are your data archived and with what frequency?

   Because the data collected in this project have not been quality controlled or processed beyond a preliminary evaluation (due to funding limitations), the data are not yet being archived beyond completing backups of the raw data on computers at AOML.

e. ***REVISED***: What is the web site where the data for your program can be accessed? If you haven't updated your web site recently, please do so now.

   Because the data collected in this project have not been quality controlled or processed beyond a preliminary evaluation (due to funding limitations), the data are not at present being made available via the web. However, the raw data are available upon request from the project PIs, and this is noted on the project web page:
   www.aoml.noaa.gov/phod/research/moc/samoc/sam/

f. ***REVISED***: Have you successfully retrieved your program's data from the website or Data Assembly Center where your data reside, just to ensure the accessibility of the data? If not, please do this now and address any problems with data access.

As noted above, the data have not yet been sent to a DAC or been made available via the web.

g. ***NEW***: Do you have a data management plan for the data collected as part of your project? If so, list the url where the data management plan can be found.

Because the project does not have funding for quality control or processing, no formal data management plan has been formulated.

2.1. Outreach and Education

The SAM project is still in its early stages, so the degree of education and outreach that the project will ultimately be able to attain has not yet been reached. However, opportunities to train young scientists are already underway, with numerous postdoctoral fellows and graduate students from Argentina and Brazil participating in the SAM research cruises. The project will continue to provide opportunities for students and postdoctoral fellows to participate in research cruises, and should funding opportunities become available there will be options for media involvement in the cruises as well. Our lead Argentine collaborator, Dr. Alberto Piola, is seeking funding within Argentina for a Ph.D. student who will work on data from SAM as his doctoral research topic. One of the PIs (Meinen) served on an expert panel discussing the MOC and western boundary currents at the annual meeting of the Society of Environmental Journalists in October 2011. The locations of the SAM moorings are also shown along with many other NOAA-GOOS related observing projects in a Google Earth application created by one of the PIs (Goni). NOAA/AOML scientists use this application to explain to visitors (students, potential employees, administrators) many different aspects and implications of the global ocean observing system.

3. Publications and Reports

3.1. Publications by Principal Investigators

SAM is a fairly new project, with the first data collected in August 2009 and as yet the project has very limited funding for quality control or processing of the data. Therefore there are not yet many publications based solely on data from the project. The first paper based on the data collected is now under review, and several related papers were published and/or submitted this FY by the PIs:

<u>Published:</u>
Perez, R.C., S.L. Garzoli, C.S. Meinen, and R.P. Matano, Geostrophic velocity measurement techniques for the Meridional Overturning Circulation and meridional heat transport in the South

Atlantic. J. Atmos. Ocean. Tech., 28(11), 1504-1521, doi:10.1175/JTECH-D-11-00058.1, 2011. www.aoml.noaa.gov/phod/docs/Perez_etal_2011_JTECH.pdf

In Press:
Garzoli, S. L., M. O. Baringer, S. Dong, R. C. Perez, and Q. Yao, South Atlantic meridional fluxes, Deep Sea Res. I, (in press), 2012.

Submitted:
Meinen, C. S., A. R. Piola, R. C. Perez, and S. L. Garzoli, Deep Western Boundary Current transport variability in the South Atlantic: Preliminary results from a pilot array at 34.5°S, Ocean Science, (submitted), 2012.

Abstracts:
Meinen, C. S., S. Speich, A. R. Piola, R. C. Perez, S. Dong, and S. L. Garzoli, Boundary Current measurements at 34.5°S in the South Atlantic: Preliminary results of MOC-related variability, 2012. (2012 AMOC Annual PI Meeting, August 15-17, Boulder, Colorado.)

Meinen, C. S., S. L. Garzoli, R. C. Perez, and A. Piola, Atlantic Meridional Overturning Circulation: Deep Western Boundary Current transport variability in the South Atlantic – Preliminary results from a pilot array at 34.5°S, 2011. (2011 World Climate Research Program Open Science Conference, October 24-28, Denver, Colorado.)

3.2. Other Relevant Publications

Funding for quality-control and processing of the SAM data has not yet been available, and as such the data are not at present being used in research by outside groups for publications. Nevertheless, several North Atlantic MOC related publications by the project PIs are relevant to the goals of SAM:

Other relevant publications by project PIs

Baringer, M. O., S. A. Cunningham, C. S. Meinen, S. Garzoli, J. Willis, M. Lankhorst, A. Macdonald, U. Send, W. R. Hobbs, E. Frajka-Williams, T. O. Kanzow, D. Rayner, W. E. Johns, and J. Marotzke. Global oceans: Meridional overturning circulation observations in the subtropical North Atlantic, in State of the Climate in 2011, J. Blunden and D. S. Arndt (eds.), Bull. Am. Met. Soc., 93(7), S78-S81, 2012.

van Sebille, E., M. O. Baringer, W. E. Johns, C. S. Meinen, L. M. Beal, M. F. de Jong, and H. M. van Aken, Propagation Pathways of Classical Labrador Sea Water from its Source Region to 26◦N, J. Geophys. Res., 116, C12027, doi:10.1029/2011JC007171, 2011.

Meinen, C. S., W. E. Johns, S. L. Garzoli, E. van Sebille, D. Rayner, T. Kanzow, and M. O. Baringer, Variability of the Deep Western Boundary Current at 26.5◦N during 2004-2009, Deep Sea Res. II, (in press), 2012.