Southwest Atlantic Meridional Overturning Circulation (SAM)

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

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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. This longitudinal spread is indicative of the role that the South Atlantic plays as both the 'gateway' and the '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.

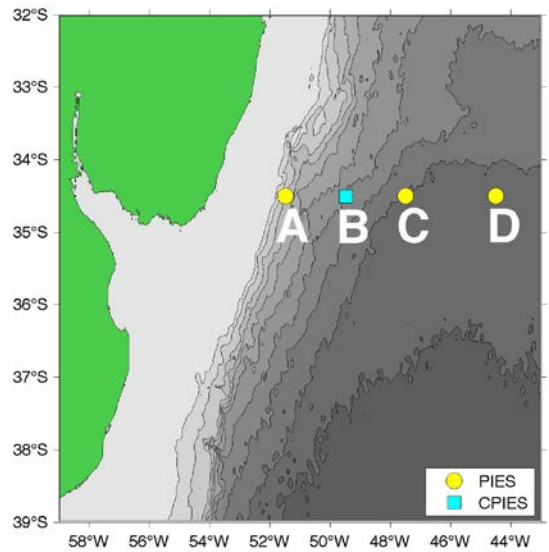

Figure 1*: Locations of the four pressure-equipped inverted echo sounders (PIES) and current-and-pressure-equipped inverted echo sounders (CPIES) deployed as part of the NOAA funded SAM project. Note in July 2011 the CPIES at Site B was replaced with a PIES.*

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. The first acoustic download of the data was completed in August 2009 aboard the Argentine research vessel SHN Puerto Deseado. Subsequent downloads were completed in July 2010, December 2010 and July 2011, each time aboard the SHN Puerto Deseado. The two initial downloads were successful, which was promising because this was the very first attempt at doing acoustic downloads from this vessel, however bad weather and what later became evident to be an instrument problem have resulted in one of the data records (Site B) having significant gaps during the first two years of the record (see Figure 2 below). After confirming that one of the instruments was malfunctioning in December 2010, a spare PIES instrument belonging to the NOAA Western Boundary Time Series project was shipped down to Argentina prior to the July 2011 cruise. This new PIES instrument was successfully deployed at the location of the malfunctioning CPIES, however the CPIES was destroyed during recovery when it was swept into the props of the research vessel. In terms of deliverables, excluding the CPIES instrument that was lost, the SAM array returned 87% of the daily estimates of acoustic travel time and 99% of the daily estimates of bottom pressure. Upon recovery (tentatively 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 the cost of the fuel and funds for a single participant for these short cruises. This aspect of the project has been successfully 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 will be the only one completed in FY12.

Near the end of FY11 some additional funds were made available on a one-time basis to bring the SAM project up to the full funding request level. The additional ~$95K in funds were used to purchase three replacement/spare PIES for use both in the SAM project and for the NOAA-funded WBTS project (from which a PIES had been borrowed). These new instruments are on order with a scheduled delivery date of May 2012.

Research highlights

The time-series data from the SAM project have now been downloaded up through July 2011. The data sets are mostly complete aside from the gaps already mentioned at the CPIES site (see Figure 2). The data have not been fully processed or subjected to quality control because those aspects of the project have not received funding yet, causing a considerably lag in the research aspects of this project. However a basic initial evaluation of the data is already indicating strong variability at a range of time scales over the first 26 months of the records. The baroclinic signals, which can be visualized by reviewing the four travel time records (Figure 2, left), demonstrate 5+ msec signals at time scales ranging from a few days (e.g. Site C in early June 2009) to two months (e.g. Site D in mid-June to mid-August 2009). The barotropic (bottom velocity) signals, determined either from the current meter on the CPIES or via differences between the deep bottom pressure gauges, also demonstrate energetic signals at time scales ranging from days to a few months (Figure 2, right). This suggests that the mooring locations are certainly within the strong western boundary current regime, however significant additional processing and quality control is still required to determine just how well the initial array design is capturing both the Brazil Current and the DWBC. At the limited funding level for the project, full quality processing and quality control has not been possible.

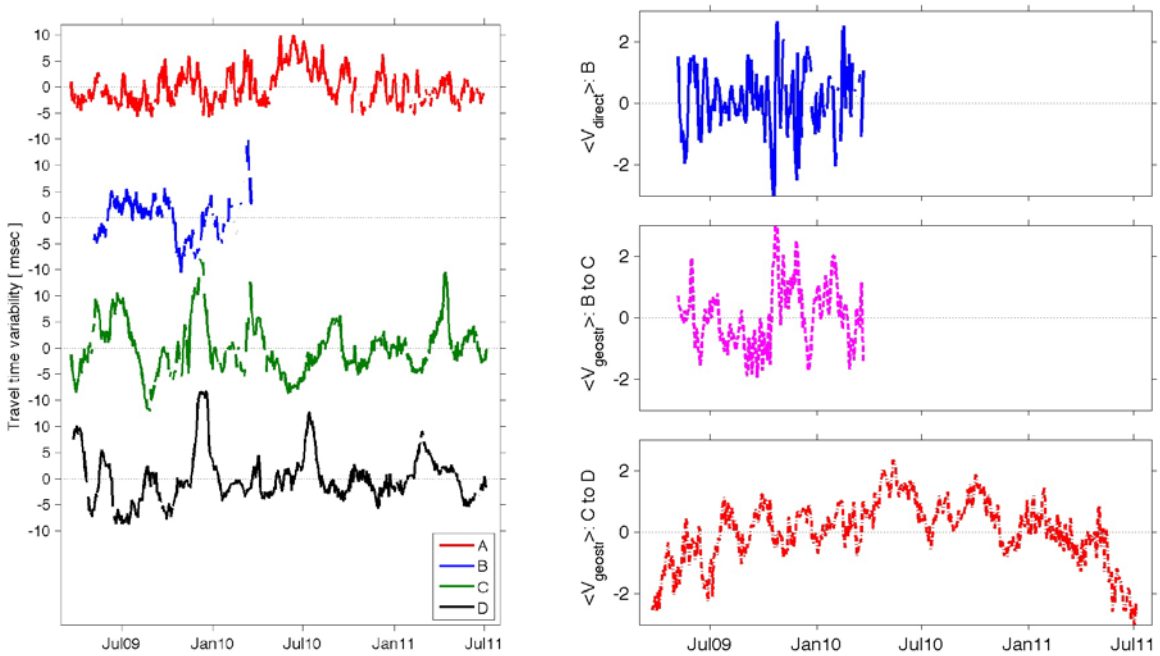

Figure 2: *Preliminary time series from the moored SAM instruments. Left: Travel time variability (time mean removed) from the four instruments, with the instrument identified in the legend – see Figure 1 for locations of each instrument. Right: Bottom velocity variability from the direct current meter on the CPIES at Site B (right top) and from the geostrophic velocity estimated between the pairs of the bottom pressure records from Site B and C (right middle) and from Sites C and D (right bottom). Note: Brackets <> indicate that these bottom velocities have been normalized by removing a mean and dividing by their standard deviation, and hence are unit-less.*

The raw data from these moored instruments is presently maintained at NOAA-AOML and is not served on the GTS system because without processing and quality control this data would not be generally useful. Without appropriate funding it will be possible to continue collecting data but it will not be possible to process the raw data into high quality estimates of ocean transport. Nevertheless, an initial analysis of the preliminary data is underway to demonstrate both the utility of the observations and the implications of the observed signals.

In an effort to understand the background circulation around the PIES locations, satellite altimetry observations are being utilized. In a preliminary analysis, the altimetry-derived sea height anomaly values (SHA) are being regressed against the dynamic height anomaly (DHA) values estimated from the raw PIES travel time data. In general the correlation between SHA and DHA is lowest towards the west (Figure 3), which is most likely due to the large barotropic contributions to the SHA. The results from this preliminary comparison will be applied to SHA fields in the region to try and identify and quantify the baroclinic and barotropic contributions of the Brazil and Malvinas Currents and associated rings where there is lack of in situ observations.

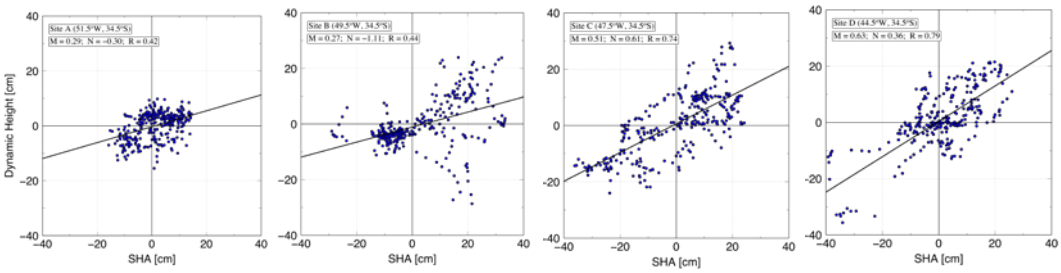

Figure 3: *Preliminary comparison of dynamic height anomaly (estimated from the raw PIES travel time records) to surface height anomaly (measured via altimetry). The relationship is shown for Sites A, B, C and D from left to right.*

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

<u>Answers to data distribution questions:</u>

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 2011 (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. What is the web site where the data for your program can be accessed?

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.

f. 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?

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

2.1. Outreach and Education

The SAM project is just in its beginning 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. One of the PIs (Meinen) also gave an invited seminar on the variability of the MOC at Millersville University in March 2011 and spoke with groups of undergraduate students on the importance of physical oceanography to climate research. One of the PIs (Meinen) gave a radio interview on MOC variability in January 2011 for Premiere Radio Networks. Finally, one of the PIs (Meinen) participated as a panel member at the Society of Environmental Journalists annual meeting in October 2011 discussing the importance of ocean observations for studying the MOC and climate. 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, adminstrators) many different aspects and implications of the global ocean observing system.

3. Publications and Reports

3.1. Publications by Principal Investigators

SAM is a very new project, with the first data collected in August 2009 and as yet the project has no funding for quality control or processing of the data. Therefore there are not yet many publications relating to the project, however, several related papers were published and/or submitted this FY by the PIs:

Peer-reviewed publications

Dong, S., S.L. Garzoli, and M.O. Baringer, The role of interocean exchanges on decadal variations of the meridional heat transport in the South Atlantic, J.Phys. Oceanogr., 41(8), 1498-1511, doi: 10.1175/2011JPO4549.1, 2011. www.aoml.noaa.gov/phod/docs/Dong_Garzoli_Baringer_2011.pdf

Dong, S., M.O. Baringer, G.J. Goni, and S.L. Garzoli, Importance of the assimilation of Argo float measurements on the Meridional Overturning Circulation in the South Atlantic, Geophys. Res. Lett., 38, L18603, 6 pp., doi:10.1029/ 2011GL048982, 2011. www.aoml.noaa.gov/phod/docs/Dong_etal_2011.pdf

Garzoli, S.L., and R. Matano, The South Atlantic and the Atlantic meridional overturning circulation, Deep-Sea Res. II, 58 (17-18), 1837-1847, doi:10.1016/j.dsr2.2010.10.063, 2011. www.aoml.noaa.gov/phod/docs/2011_DSRII_Garzoli_Matano.pdf

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

Conference presentations

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.)

Meinen, C. S., Variability of the Meridional Overturning Circulation: Ocean Dynamics that Matter to Climate, 2011. (2011 Paul J. McInerney Memorial Lecture, March 17, Millersville University, Millersville, Pennsylvania.)

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.