Characteristics and causes of Deep Western Boundary Current transport variability at 34.5°S during 2009-2014

Christopher S. Meinen[1], Silvia L. Garzoli[2,1], Renellys C. Perez[2,1], Edmo Campos[3,2], Alberto R. Piola[4,5], Maria Paz Chidichimo[4,5,6], Shenfu Dong[1], and Olga T. Sato[3]

[1]NOAA/Atlantic Oceanographic and Meteorological Laboratory; [2]Cooperative Institute for Marine and Atmospheric Studies, University of Miami; [3]University of São Paulo, Brazil; [4]Servicio de Hidrografia Naval, Argentina; [5]Universidad de Buenos Aires, Argentina, [6]Consejo Nacional de Investigaciones Cientificas y Tecnicas (CONICET), Argentina

Study description

In March 2009 an array of four PIES was deployed near the western boundary of the South Atlantic at 34.5°S as part of the NOAA Southwest Atlantic MOC (SAM) project. The motivation for the array is to measure the currents near the western boundary, in particular the Deep Western Boundary Current (DWBC) and the Brazil Current, with the ultimate goal of determining the western boundary components of the Meridional Overturning Circulation (MOC) along this latitude. The array was designed to be the cornerstone of an international trans-basin MOC array as well.

In December 2012, the SAM array was bolstered by the addition of two CPIES supported by Brazil. Ship time for maintaining this array is provided primarily by Argentina, with additional help from Brazil. Partners in France and South Africa have, in 2013 & 2014, deployed a parallel array near the eastern boundary. This poster highlights the DWBC measurements made during 2009-2014.

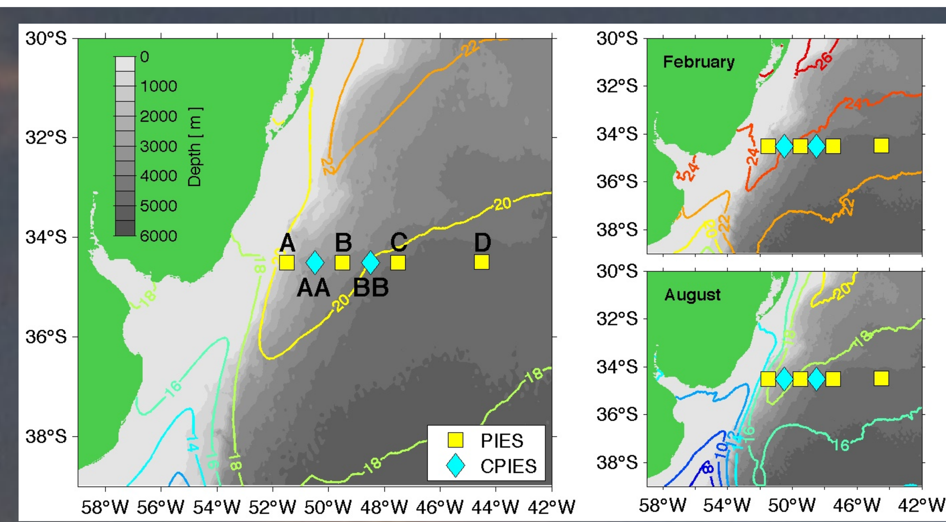

Figure: Map illustrating the location of the instruments. The NOAA PIES sites are named Sites A-D from left to right; the Brazilian CPIES sites are named Sites AA and BB from left to right. Gray scale indicates the bottom depth as indicated by the color bar; the color contours show the time-mean sea surface temperature (SST; main panel) and the climatological mean SST for the months indicated (smaller right panels).

Hydrographic observations

Cruises to collect hydrographic data (CTD and sometimes LADCP) along the SAM line, to acoustically download data from the PIES/CPIES, and/or to recover and redeploy the PIES/CPIES, are planned every six months, although ship availability at times has resulted in spans between cruises of up to 22 months. The hydrographic observations are led by our Argentine and/or Brazilian partners. In addition to the essential maintenance of the PIES and CPIES, these cruises make crucial measurements for the study of the MOC components in this region, as many of the water mass nuances cannot be understood with the moored time series data alone.

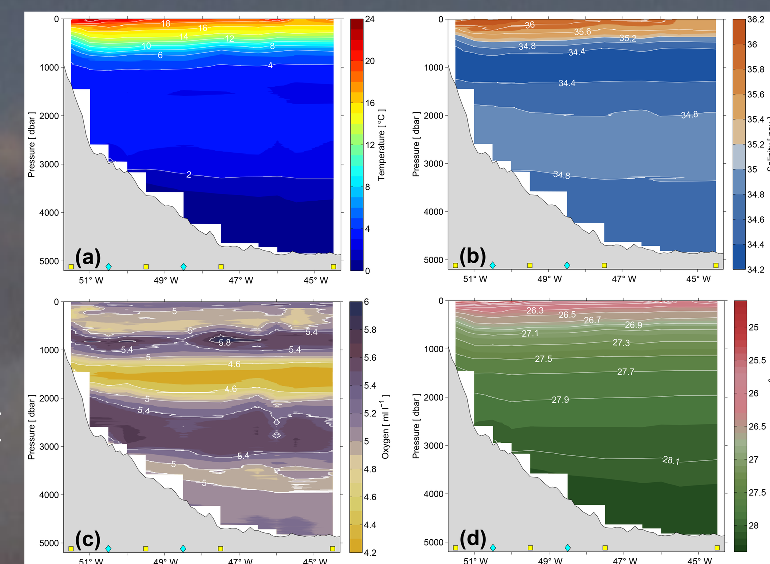

Figure: Average sections of temperature (a), salinity (b), dissolved oxygen (c), and neutral density (d) along the SAM line. Sections from July 2010, December 2010, July 2011, and December 2012 are averaged in a simple manner to illustrate the approximate vertical distribution of the water masses in the region. Gray shading indicates the approximate bottom depths estimated from Smith and Sandwell (1997).

PIES/CPIES velocity estimates

The travel time measurement of the PIES/CPIES, when combined with hydrographic measurements from the region, can yield an estimated full-water-column profiles of temperature, salinity, and density via the "Gravest Empirical Mode", or "GEM", technique. The PIES/CPIES estimated density profiles can be vertically integrated to yield dynamic height anomaly profiles, and differencing these profiles between sites yields full depth profiles of geostrophic velocity relative to an assumed level of no motion at an arbitrary depth/pressure. The pressure gauges on the PIES/CPIES can then be used to provide the needed absolute velocity reference for the profiles. Differencing the bottom pressure at neighboring sites yields the time-varying absolute velocity. Note, however, that the time-mean absolute reference velocity cannot be obtained in this manner; for this study the time-mean reference velocity is estimated from the output of a numerical model. Only the time-mean velocity at the reference level is model-based, all velocity variability and the time-mean relative component of the velocity are real ocean observations.

The time-mean velocity section (left, top panel) illustrates the southward Brazil Current in the upper ocean and the southward DWBC flowing beneath it. Offshore, recirculations dominate. Comparing these mean velocities to the mean water property information (left, bottom panel) leads to some interesting surprises (e.g. some *northward* flowing NADW and all *southward* flowing AABW) which illustrate the important roles the recirculation gyres play in this region.

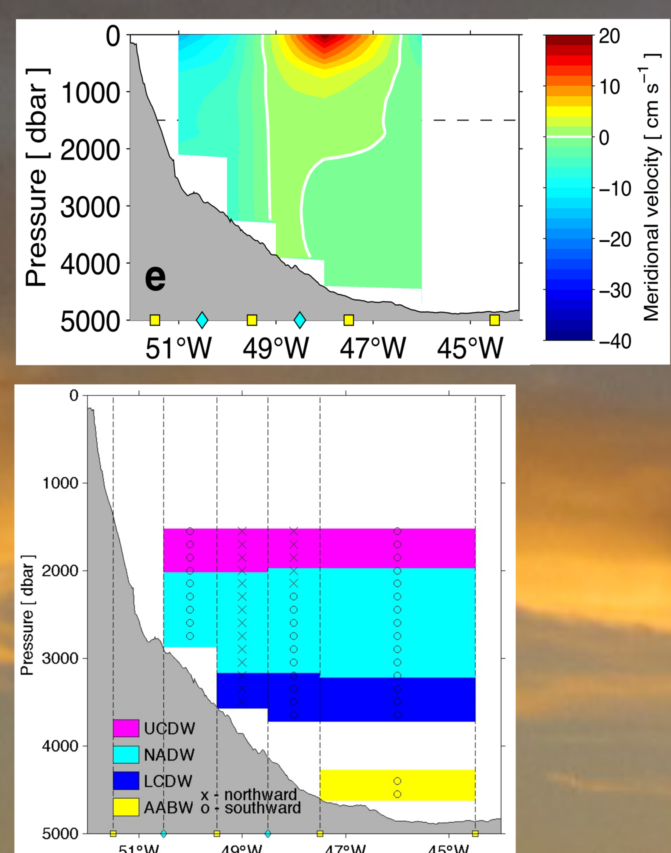

Figure: Top panel – The time-mean meridional geostrophic velocity estimated from the PIES+GEM data. White contour indicates zero flow; gray shading indicates the bottom topography. Bottom panel – Illustration indicating the direction of flow within various mean water mass boundaries as labeled in the legend.

Transport variability

Integrating the transport across the array within 800 to 4800 dbar (or the bottom where it is shallower) gives an estimate of how the DWBC transport is changing over time. The resulting time series ranges between -89 Sv and +50 Sv with a mean of -15 Sv and a standard deviation of 23 Sv.

The baroclinic component relative to the 800 dbar reference layer is generally small, although one event in Dec. 2009 reaches nearly -50 Sv. The barotropic, or in this case reference layer, transport clearly dominates the total absolute transports most of the time. The baroclinic and barotropic terms are uncorrelated with each other.

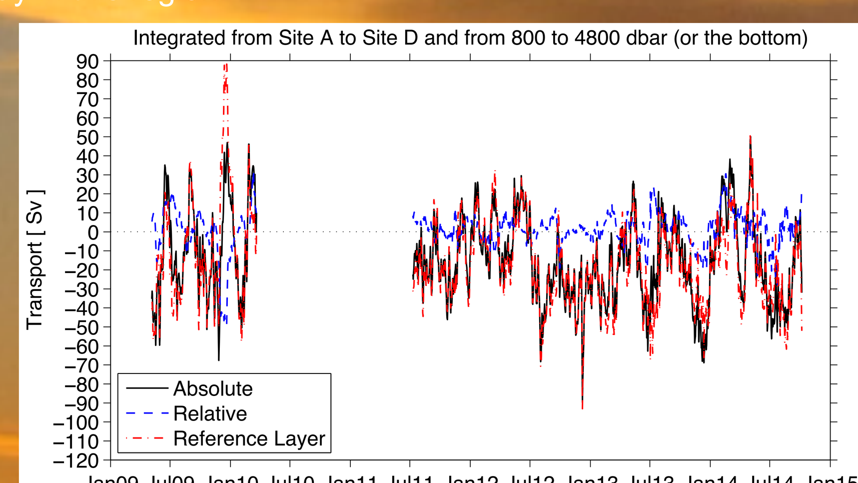

Figure: Time series of meridional geostrophic transports from the SAM array. The baroclinic term relative to a level of no motion at 800 dbar (blue) and the barotropic-reference layer terms (red) are also shown.

The majority of the variance observed in the DWBC transport is at relatively high frequencies, with periods shorter than semi-annual representing the largest energy levels (spectrum below).

Little energy is present at either the annual or semi-annual periods. This is true regardless of whether the DWBC transport is integrated across the entire array between Sites A and D (right top) or in the narrower span between Sites A and B (right bottom). This may be a result of the limited record length.

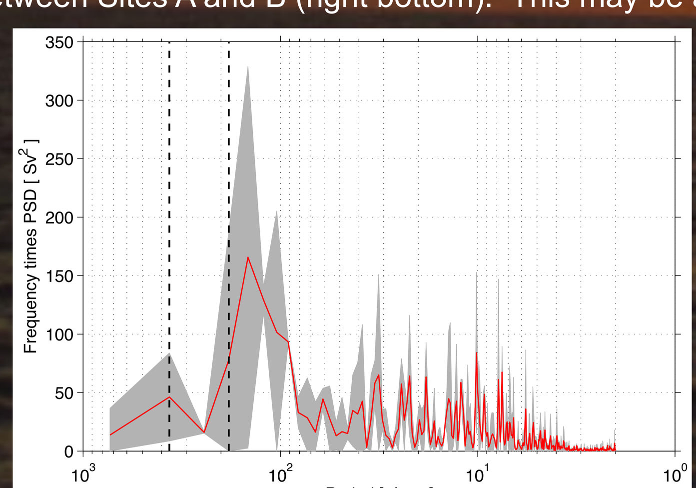

Figure: Variance-preserving spectrum of the DWBC transport integrated between Sites A and D. Gray shading indicates 95% confidence limits; vertical dashed lines identify the annual and semi-annual periods.

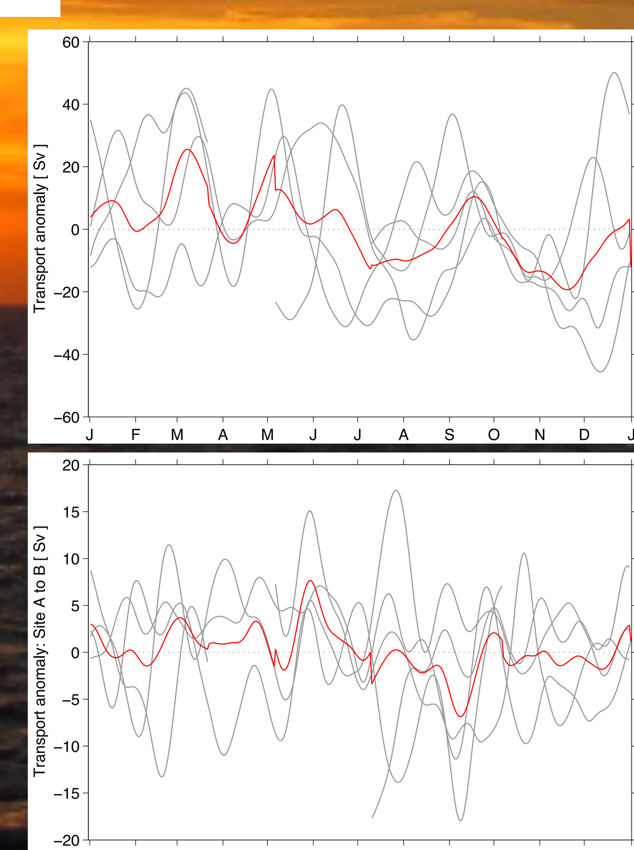

Figure: Annual cycle of DWBC transport integrated between Sites A and D (top panel) or between Sites A and B (bottom panel). Gray lines indicate annual cycle in each year; red line indicates the mean of all years.

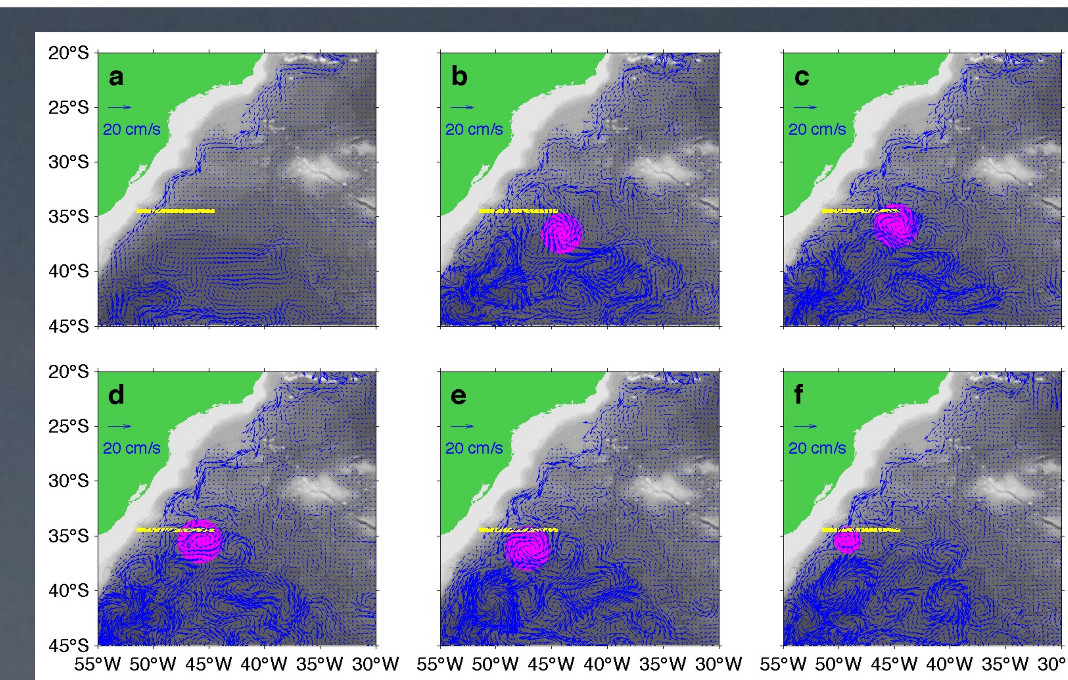

Figure: Velocities from the OFES model at the core of the NADW near 2600 m depth: (a) average over the full 27-year run; (b) average over August 1987; (c) average over September 1987; (d) average over October 1987; (e) average over November 1987; and (f) average over December 1987. Land is denoted by green; bottom topography is gray. Yellow line denotes the nominal location of the PIES/CPIES array in the real ocean. Magenta disc highlights the propagating feature.

Diagnosing the causes of DWBC transport variability

The large variations in the DWBC transport time series (23 Sv standard deviation) lead one to wonder – what is causing these strong variations?

Through analysis of the SAM data together with output from a high quality numerical model (OFES), the largest variations can be traced back to westward propagating Rossby Wave-like features. (Example from the OFES model at left.)

These features have transport signals comparable to the mean DWBC itself, so when they propagate in and superimpose on the observed flow they can cause an apparent doubling and/or apparent reversals of the flow.

Selected conclusions

- The 34.5°S SAM western boundary array has provided 5+ years of data to date that are allowing us to begin to tease out the character and time scales of variability for the DWBC, a key MOC component.
- Recirculation gyres are present and are quite strong near the DWBC at this latitude, as is true at other latitudes as well. These recirculations are sufficient to push water masses back toward their formation regions in multi-year time-means.
- With the 5+ year records collected to date, the majority of the variability appears to be at periods shorter than semi-annual. Whether this will continue to hold as the time series lengthens remains to be seen.
- The strongest variations in the DWBC transport appear to be caused by the westward propagation of Rossby Wave-like features from the interior.

Extending the time series

Subsequent to the analysis that led to the results above, which were published in the recent Meinen et al. (2017) paper, additional data have been collected that extend the NOAA time series to 7+ years and extend the Brazilian records to 3+ years. (See time series at right.) These records will be used together with recently obtained data from the eastern boundary to extend the DWBC and MOC estimates at 34.5°S with support from our international partners as well as from the NOAA SAM project and a recent NOAA CVP proposal.

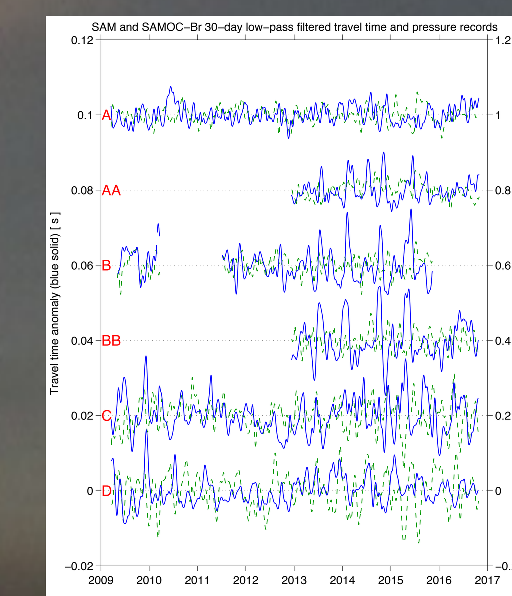

Figure: Travel time and bottom pressure anomalies from the NOAA & Brazilian PIES/CPIES.

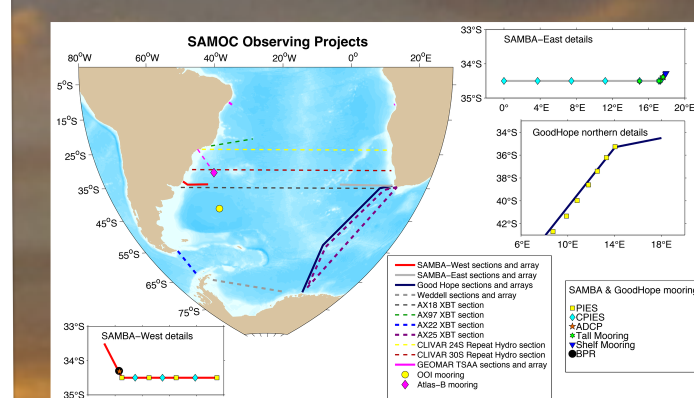

Figure: Map illustrating the many contributions to the international South Atlantic Meridional Overturning Circulation (SAMOC) initiative. NOAA supports several of these components, including SAM, AX18, and more.

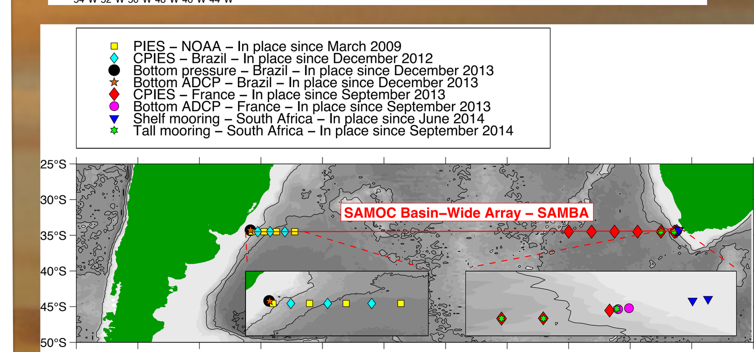

Figure: Map illustrating the presently deployed instruments building up the 'SAMBA' trans-basin MOC array. Partners involved in the array include the U.S. (NOAA); Argentina (SHN and UBA), Brazil (USP), France (ENS and IFREMER), and South Africa (DEA and UCT).

The broader picture: SAMOC

The SAM project is a major contributor to the larger SAMOC initiative that has been endorsed by international CLIVAR. The results from SAM will be combined with results from these other programs to aid in basin-scale studies of the MOC in the South Atlantic. (See map at left.) Recent model studies have found connections between MOC variations in the South Atlantic and changes in extreme weather patterns across much of the globe, demonstrating one example of the importance of measuring and understanding MOC variability in the South Atlantic.

International recognition of the importance of SAMOC continues to lead to collaborative studies like the SAMBA array (left). As has occurred in the North Atlantic, where MOC studies began 5-10 years earlier, crucial understanding of the character and variability of the MOC will come in future years as the SAMOC time series grow longer.

Acknowledgements

The U.S. PIES/CPIES deployed to date in the SAM array have been supported by the NOAA Climate Program Office, with additional support provided by the NOAA-Atlantic Oceanographic and Meteorological Laboratory. The Brazilian CPIES are supported via a grant from FAPESP. The SAM project is a collaboration between the U.S. NOAA, the Argentine Naval Hydrographic Service and the Universities of Buenos Aires (Argentina) and Sao Paulo (Brazil). Ongoing ship time support and hydrographic (CTD/LADCP) support from Argentina and Brazil has been crucial to the project's continuing successes. The SAM project is also a key portion of the South Atlantic MOC Basin-wide Array ("SAMBA") that involves collaboration between all of the aforementioned institutions as well as the University of Brest, the Laboratoire de Physique des Océans, Ifremer and the École Normale Supérieure (France) and the University of Cape Town and the Department of Environmental Affairs (South Africa). Thanks also to the scientists, institutions, funding agencies, and research vessel crews involved in collecting the historical CTD and Argo data used in building the GEM fields. Thanks also to JAMSTEC for providing the OFES model output used for the time-mean bottom velocity and for comparison with the moored data.

Related papers

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Valla, D., A. R. Piola, C. S. Meinen, E. Campos, Strong mixing and recirculation in the northwestern Argentine Basin, in preparation, 2017.

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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 Sci., 8, 1041-1054, doi:10.5194/os-8-1041-2012, 2012.