Deep Western Boundary Current variability at 34.5°S during 2009-2012

Christopher S. Meinen[1], Renellys C. Perez[2,1], Shenfu Dong[2,1], Alberto R. Piola[3], Silvia L. Garzoli[2,1], and Edmo J. D. Campos[4]

[1]Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida; [2]Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, Florida; [3]Servicio de Hidrografía Naval, and Universidad de Buenos Aires, Buenos Aires, Argentina; [4]University of Sao Paulo, Sao Paulo, Brazil

Study description

In March 2009 an array of four PIES/CPIES was deployed near the western margin of the South Atlantic at 34.5°S as part of the 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 identifying the western boundary components of the Meridional Overturning Circulation (MOC) along this latitude. It was also hoped that the SAM array would form the cornerstone of a complete trans-basin MOC array in the South Atlantic, a hope that is beginning to come true through the involvement of France, Brazil, Argentina and South Africa.

In December 2012, and subsequently in December 2013, the SAM array was bolstered by the addition of three CPIES, an ADCP, and a BPR. Future analyses will include the data from these new instruments; this poster highlights the DWBC measurements made during the initial ~3.5 years of the SAM array from March 2009 through December 2012.

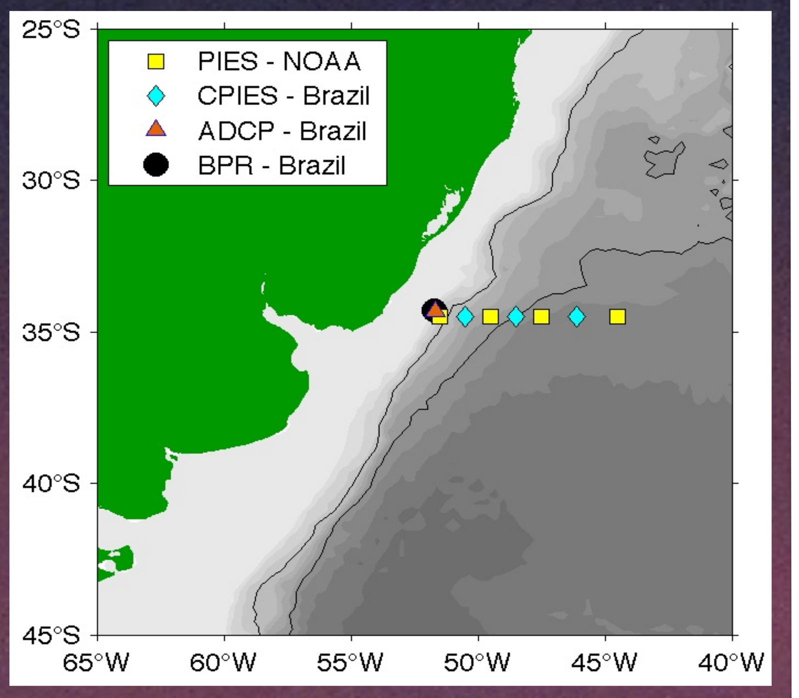

Figure: Map illustrating the location of the instruments. The NOAA sites are named Sites A-D from left to right.

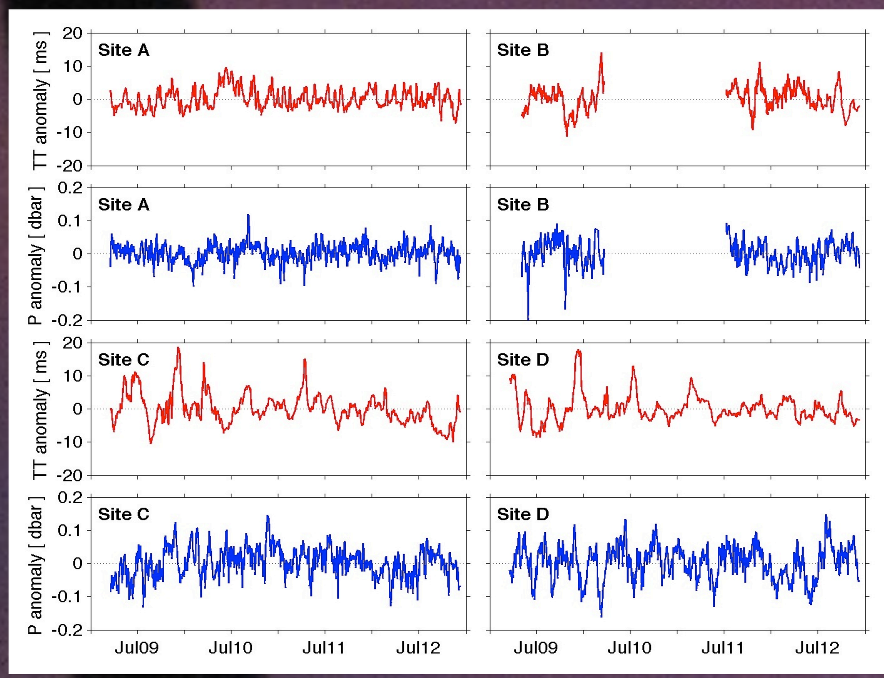

Figure: Acoustic travel time (TT) and bottom pressure (P) records from the PIES/CPIES in the SAM array. Anomalies from the record-length time mean are shown.

PIES/CPIES records

The PIES (or CPIES) measures both round-trip acoustic travel time and bottom pressure continuously for up to four years (see at left). One instrument failed due to electronics problems and was not recovered (Site B) during 2010-2011. To date the PIES/CPIES are observing energy at a wide range of time scales with no consistent dominant peaks (see below).

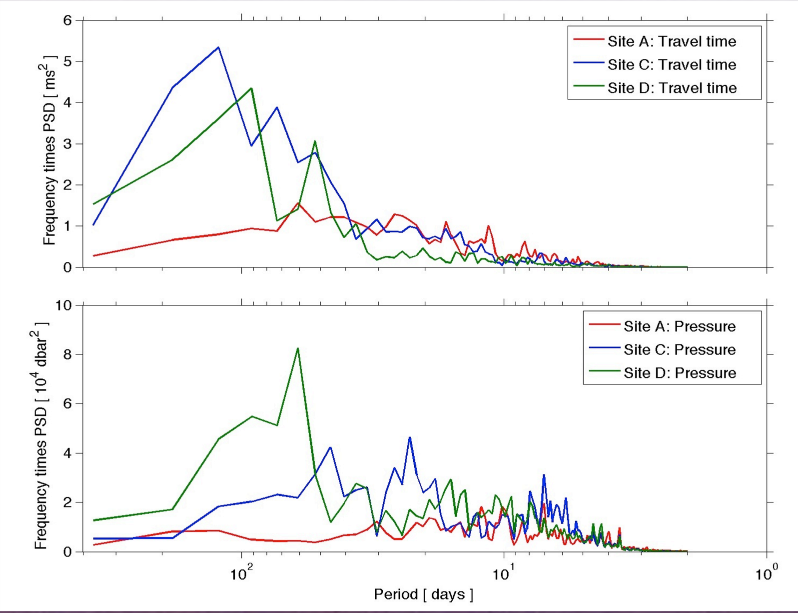

Figure: Variance-preserving spectra of the travel time and pressure records recorded by the PIES/CPIES. Note that spectra for Site B are not shown due to the time gap in the record at that site.

PIES/CPIES analysis

The travel time measurement of the PIES/CPIES is not very useful on its own, but when combined with hydrographic measurements from the region the travel time measurement can yield an estimated full-water-column profile of density, temperature, or salinity (see example at right). This "Gravest Empirical Mode", or "GEM", technique allows an individual PIES or CPIES to provide a time series of daily estimated profiles above the mooring for a period of about four years. The root-mean-squared (RMS) scatter around the GEM fields provides a direct accuracy estimate for the estimated profiles.

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, however the time mean absolute velocity cannot be obtained in this manner.

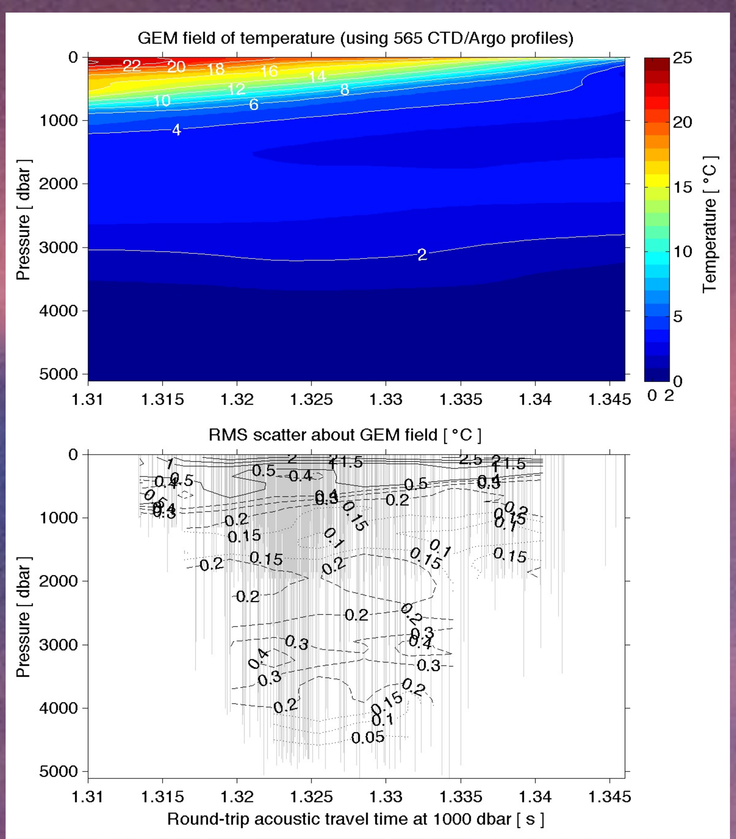

Figure: Top panel – The GEM field of temperature determined for the SAM region; Bottom panel – The RMS scatter between the original CTD & Argo profiles and the smoothed GEM field, with the original observation locations illustrated by gray dotted lines.

For the present study, the time-mean absolute velocity near the bottom from a 27-year run of the OFES model (kindly provided by JAMSTEC) is added to the time varying bottom velocity from the pressure gauges. This absolute bottom velocity is then added to the geostrophic relative velocity profiles to yield daily full-water-column profiles of absolute geostrophic velocity between neighboring sites. These velocities can then be integrated to provide absolute transports.

PIES-GEM analysis validation

The GEM fields of temperature, salinity and density were developed using historical CTD and Argo profiles from the region over the period up through 2008. The recent CTD sections collected from 2009-2012 have not been used in the creation of these smooth look-up tables, and as such they can be used to validate the GEM analysis fields. The temperature and salinity profiles from each CTD can be used to calculate a sound speed profile via the standard empirical equation, and this profile can be integrated vertically to yield a simulated travel time measurement. This simulated travel time measurement can then be used with the GEM fields to predict a profile of temperature, for example, which can then be compared to the original temperature profile.

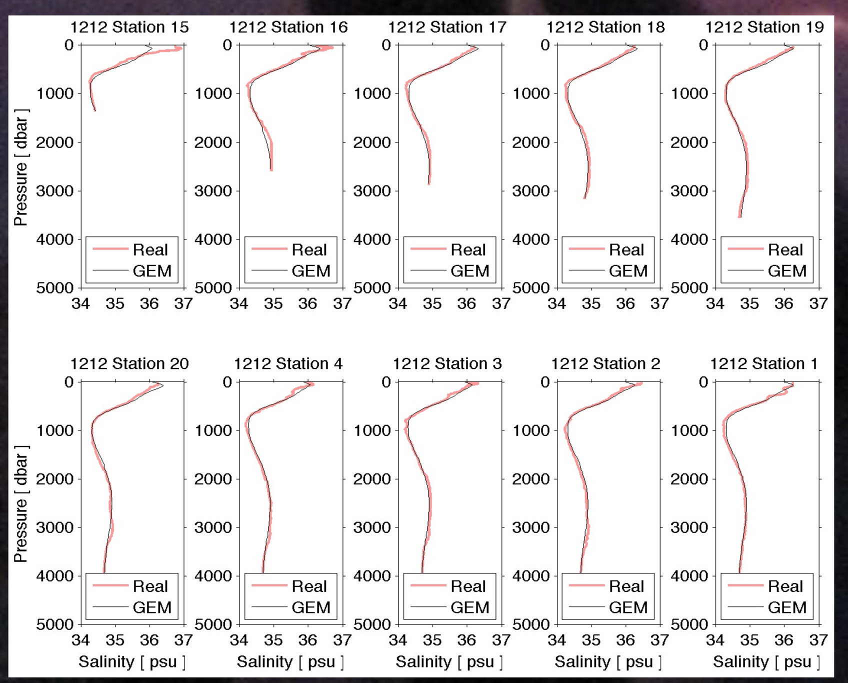

Figure: Plot illustrating the agreement between the CTD measured salinities at selected sites from a cruise in December 2012 and the estimated salinities at those same times and locations calculated using the GEM field.

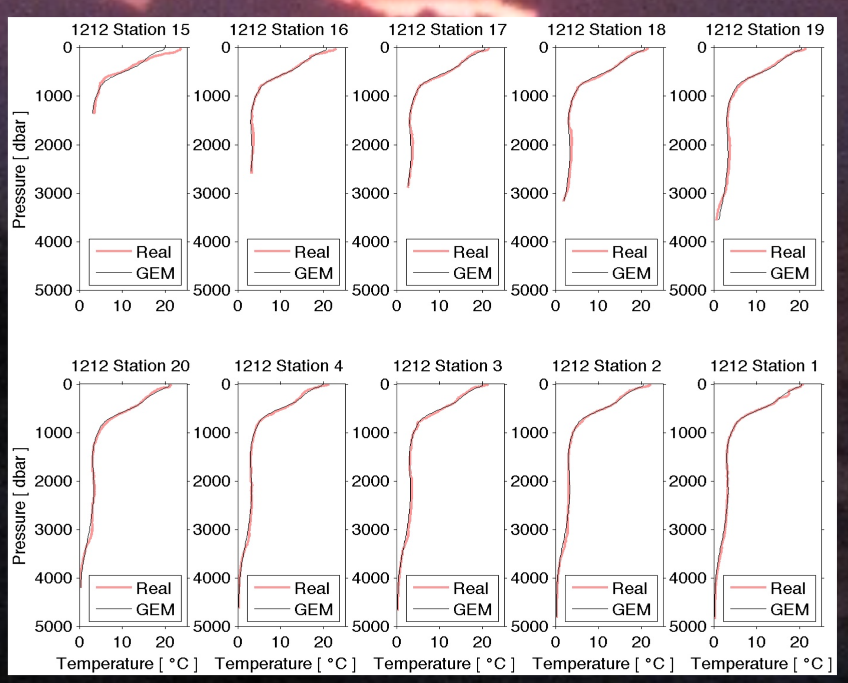

Figure: Plot illustrating the agreement between the CTD measured temperatures at selected sites from a cruise in December 2012 and the estimated temperatures at those same times and locations calculated using the GEM field.

Combined transports – Net meridional flow

The time-mean meridional geostrophic flows across the SAM array (see below) indicate a strong southward velocity at all depths between the westernmost pair of PIES (Sites A and B), while the central pair of PIES (Sites B and C) capture a mean northward flow that is intensified in the upper 500-1000 dbar. The offshore-most pair of PIES (Sites C and D) capture a weak mean southward flow near the surface and northward flow below 1500 dbar.

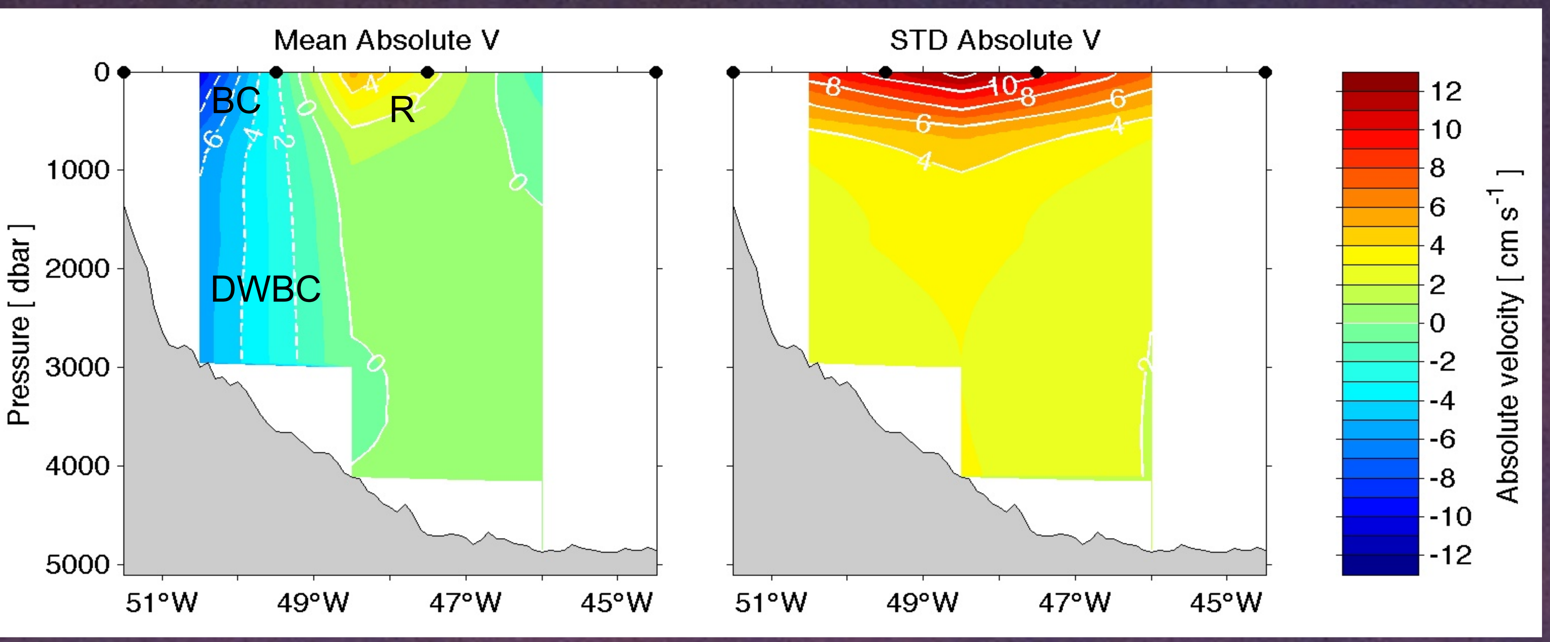

Figure: Record-length time mean flow between pairs of PIES/CPIES (left panel) and the temporal standard deviation (right panel). Bottom topography is indicated in gray; PIES locations are shown as black dots on the top axes. The labels indicate the flows of the Brazil Current (BC), Deep Western Boundary Current (DWBC) and the recirculation (R).

Integrating the transport vertically to estimate the flow associated with the Deep Western Boundary Current (DWBC) is actually quite tricky, as in this region dissolved oxygen (not observable with the PIES) can be a key tracer for DWBC-related water masses. Future work will be required to do better at this – but for now we integrate the transport between fixed pressure levels of 800 and 4800 dbar (or the bottom where it is shallower than 4800 dbar) to estimate the transports associated with the DWBC layer.

Table: Absolute geostrophic transports integrated between PIES/CPIES as well as between 800 and 4800 dbar (or the bottom). Maximum, minimum, mean and standard deviations of the transports are shown; the final row is for the totals across the entire array.

Transport Span	Minimum transport	Maximum transport	Mean transport	STD transport
A-to-B	-74 Sv	+12 Sv	-23 Sv	10 Sv
B-to-C	-57 Sv	+98 Sv	+ 1 Sv	23 Sv
C-to-D	-69 Sv	+64 Sv	+ 2 Sv	22 Sv
Total	-78 Sv	+44 Sv	-19 Sv	22 Sv

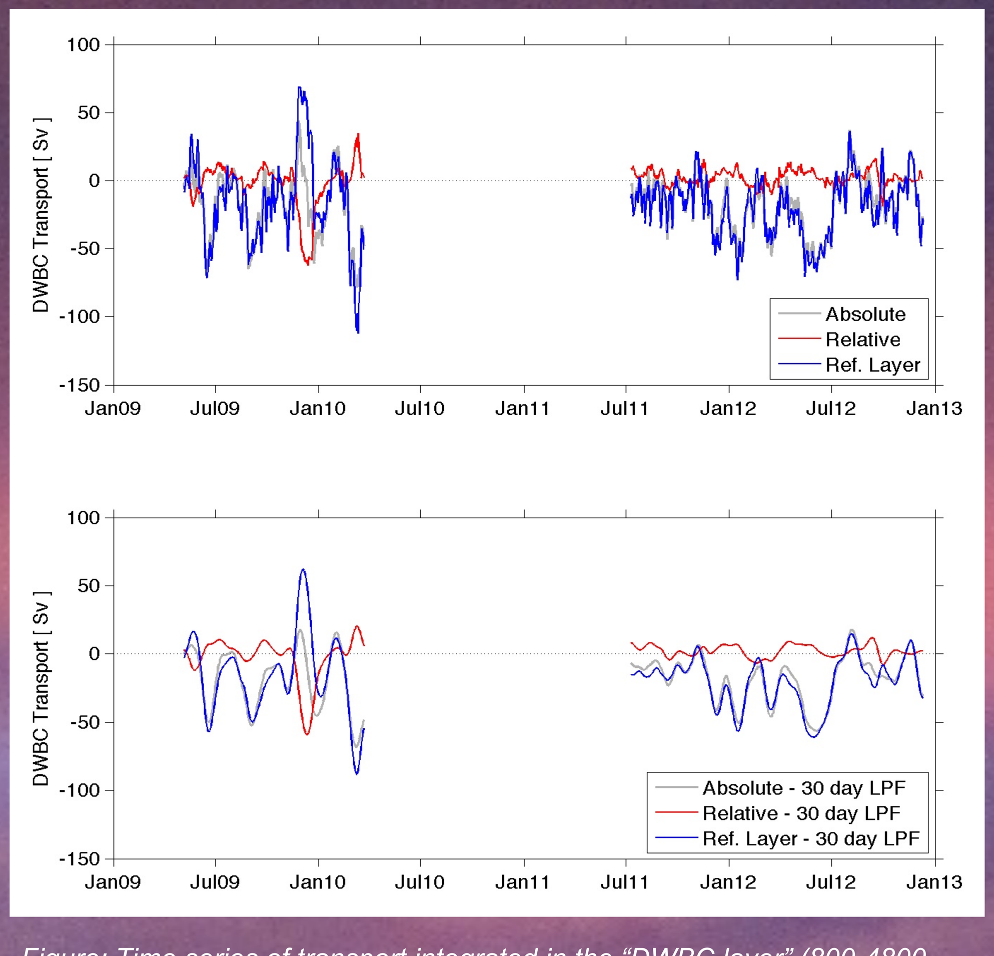

Figure: Time series of transport integrated in the "DWBC layer" (800-4800 dbar). Top panel – Time series of daily values; Bottom panel – Time series after a 30-day low-pass filtering using a 2nd order Butterworth filter passed both forward and back to eliminate phase shifting. For both panels, the absolute transport is shown in addition to the transports relative to an assumed level of no motion at 800 dbar (red) and the transports associated with the flow at the 800 dbar reference level (blue).

The loss of data at Site B during 2010-2011 leaves an unfortunate gap in the record in the estimated DWBC transports (see at left), however despite this the array has provided us with several years of data with which we can estimate the range of variability observed in this keep deep ocean current.

The temporal standard deviation of the DWBC transports exceeds the mean (see table above) and the measurements exhibit changes of up to (or exceeding) 100 Sv; even after a 30-day low-pass filtering the time series of DWBC transport shows (lower panel at left) variations in absolute transport exceeding 50 Sv in time periods of only a month or two.

The transport can be broken into the flow relative to an assumed level of no motion at 800 dbar and the flow associated with the velocity at 800 dbar; neither is trivial but the dominant component is normally the reference layer flow (blue at left). This illustrates the necessity of capturing the absolute flow and not using an assumed level of no motion for the calculations of DWBC transports.

Conclusions

- The SAM array has provided 3.5 years of data to date, admittedly with a roughly one-year gap at a key site due to equipment failure. An additional 21 months of data should be downloaded during a September 2014 cruise completed jointly with our international partners on a Brazilian research vessel (N. Oc. Alpha-Crucis).
- The data analyzed to date indicate that the deep flow in this region is highly variable, with the temporal standard deviation exceeding the mean by about 15%.
- Similar to what has been previously observed in the North Atlantic at 26.5°N, the variability of the DWBC flow at 34.5°S greatly exceeds that of the MOC itself, illustrating the need for a basin-wide measurement system.
- The flow variability has both strong baroclinic and barotropic contributions, demonstrating the need for absolute velocity measurements to understand DWBC variability.

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 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). The SAM project is also a key portion of the developing South Atlantic MOC Basin-wide Array ("SAMBA") that involves collaboration between all of the aforementioned institutions as well as the University of Brest (France) and the University of Cape Town (South Africa). The authors gratefully thank the funding agencies involved as well as the scientists and agencies that collected 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.

Further reading

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.

Meinen, C. S., S. Speich, R. C. Perez, S. Dong, A. R. Piola, S. L. Garzoli, M. O. Baringer, S. Gladyshev, and E. J. D. Campos, 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 (12), 6461-6478, doi:10.1002/2013JC009228, 2013.