Meridional Overturning Circulation transport variability at 34.5°S during 2009-2017: Baroclinic and barotropic flows and the dueling influence of the boundaries

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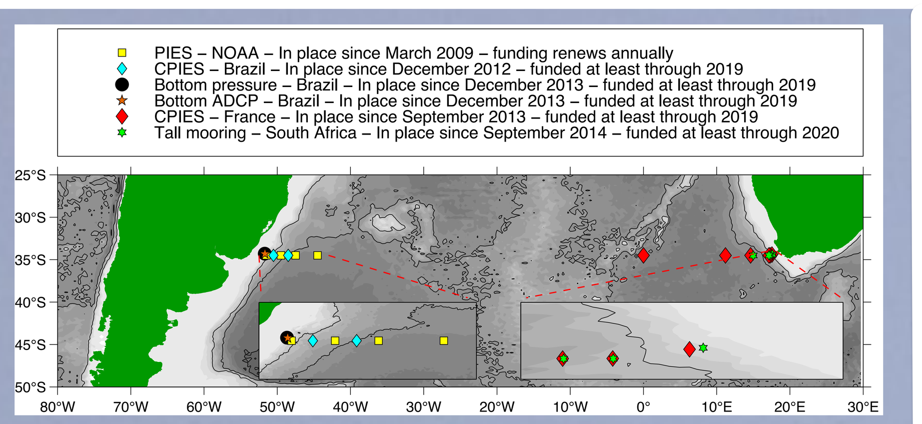
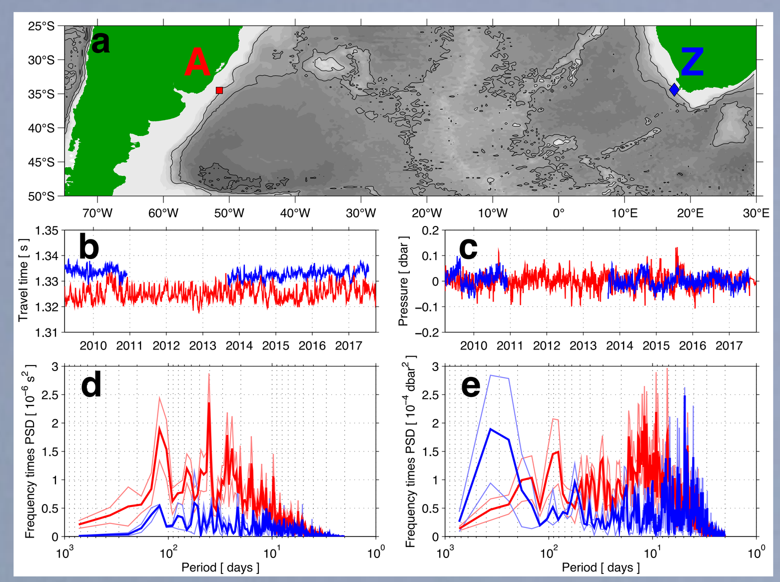
Study description

One of the 'newer' components of the MOC observing system is the "South Atlantic MOC Basin-wide Array" (SAMBA). The first pilot elements of SAMBA were put in place in 2008-2009, but it really came into being as a fully trans-basin array in 2013, with more augmentations occurring in 2014.

SAMBA is a collaborative array involving investigators from Argentina, Brazil, France, South Africa, and the United States.



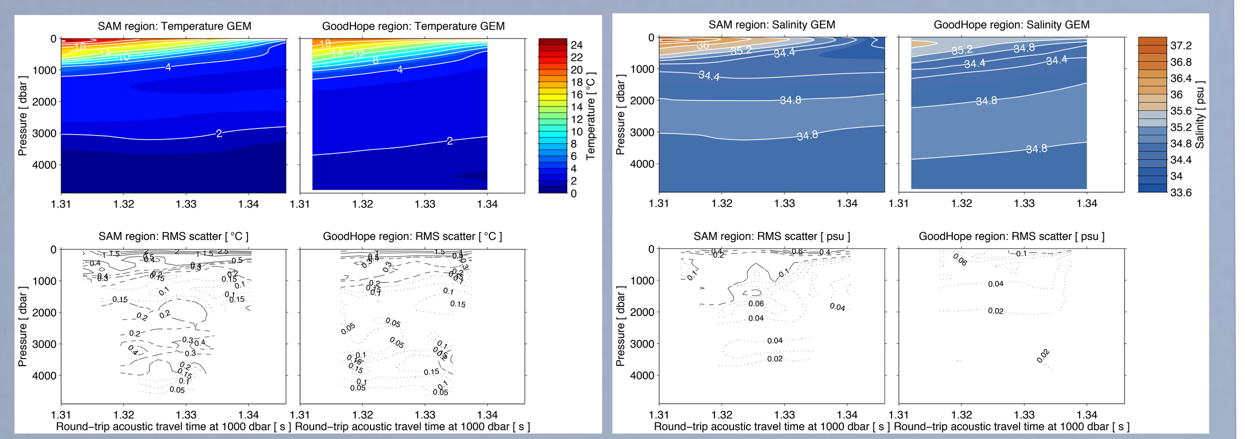


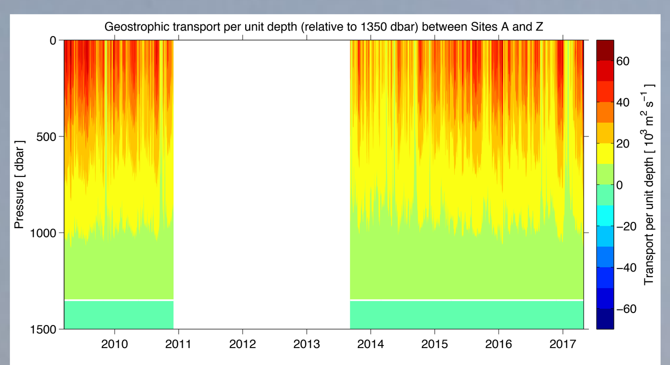
For this study, one goal was to maximize the length of time spanned for estimating a time series of the MOC at 34.5°S. As such, the analysis has focused on the two records that have been in the water for the longest contemporaneous period: Sites A and Z (see at left), which were both in the water between March 2009 and December 2010, and then again from September 2013 to July 2017.

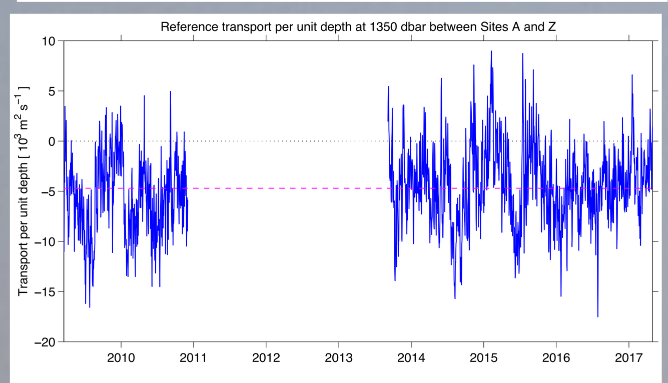
These two sites are using PIES/CPIES moorings to collect daily observations of round trip acoustic travel time and bottom pressure (at left, panels b & c).

The western site ("A") observes more variability at all time scales for travel time (a baroclinic measure), and for all time scales below semi-annual for bottom pressure (a barotropic measure).

The travel time measurements of the PIES/CPIES can be combined with hydrography-derived look-up tables to estimate full-water-column estimates of temperature, salinity, and density (examples at right). This technique, termed the Gravest Empirical Mode (GEM) method, has been carefully validated through comparison to direct observations on tall moorings at numerous locations around the globe.



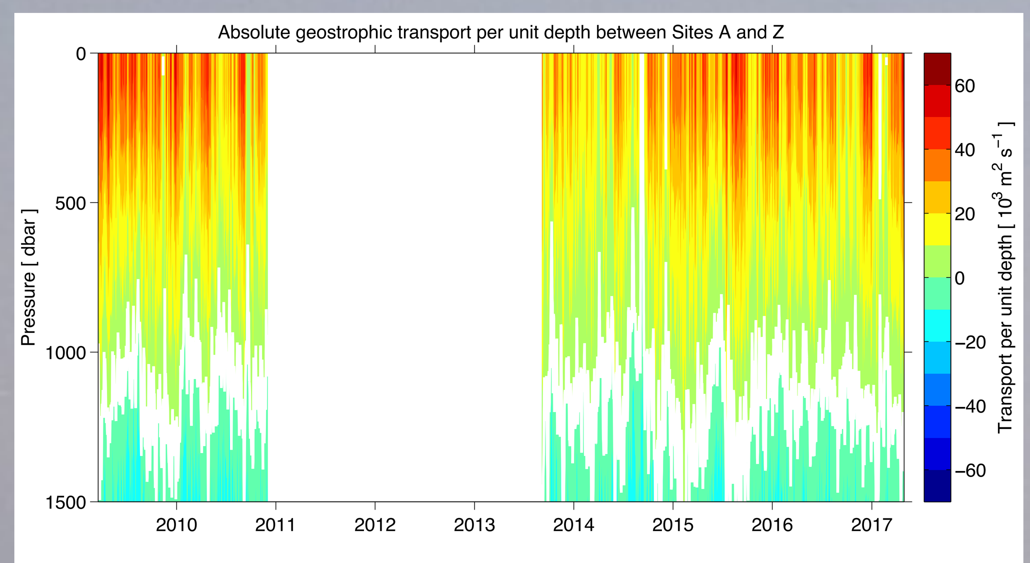


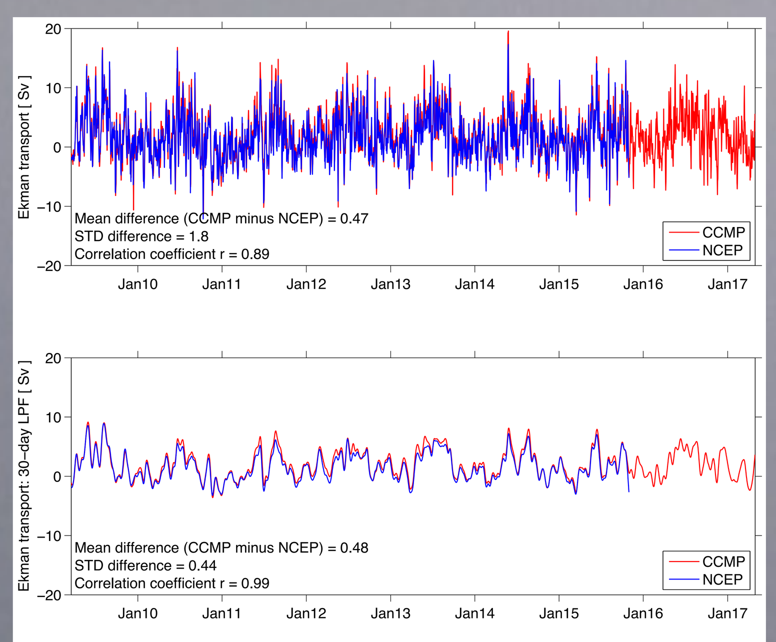


The daily density profiles produced by the PIES/CPIES at Sites A and Z can be integrated to give dynamic height anomaly profiles, and these then can be differenced to yield profiles of the meridional geostrophic velocity relative to an arbitrary level of no motion (left, with a 1350 dbar level of no motion). This represents a true integration across the entire basin between the two sites.

The daily bottom pressure values from the PIES/CPIES can be differenced to yield the time-variability of the meridional geostrophic absolute velocity at the nominal level of no motion (blue line at lower left), and if a time-mean velocity at this level is available, such as from a numerical model (magenta dashed line, derived from a 35-year run of the OFES model), then the full time varying meridional 'reference velocity' is available.

Combining the geostrophic relative velocity profile time series with the geostrophic reference velocity time series yields a time series of the absolute geostrophic meridional velocity integrated across the basin between Sites A & Z (at right).





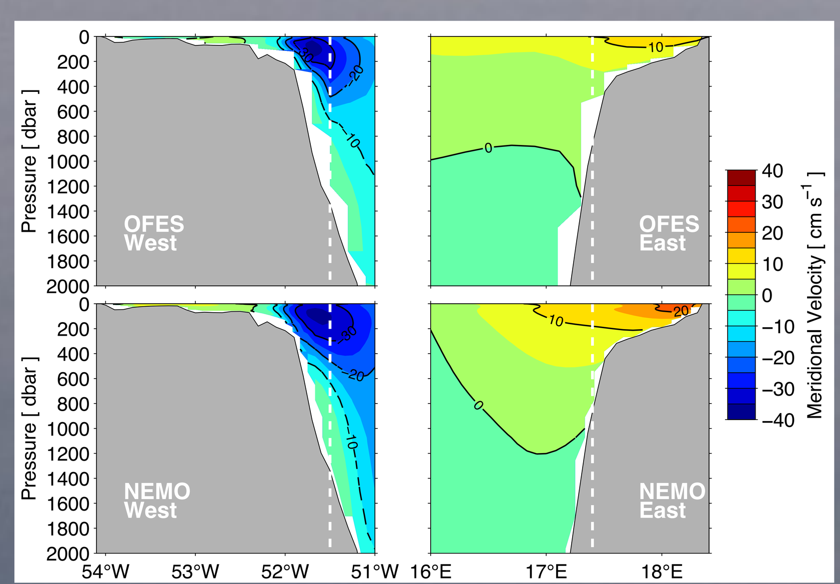
Another component of the meridional flow across 34.5°S is the directly wind-driven Ekman flow. This flow is small when integrated across the basin between Sites A and Z, with a mean value during March 2009-April 2017 of 2.0 Sv, but the peak-to-peak range of daily values spans nearly from -12 Sv to +20 Sv. (see at left)

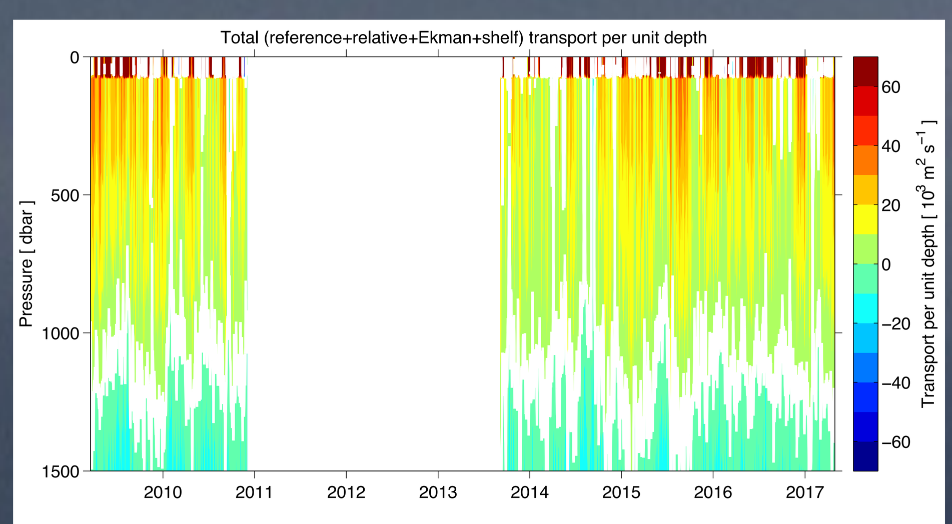
The Ekman results are not highly sensitive to which wind product is used, with the CCMP winds (used herein) and the NCEP winds producing nearly identical time series, particularly at periods longer than 30 days.

The remaining component of the meridional flow that is missing is the flow that occurs inshore of Sites A and Z. This missing flow on the shelves/upper slopes is estimated here as the time-mean velocity from a numerical model (see examples at right).

From a 35-year run of the OFES model, the missing transport west of Site A is estimated to be -5.8 Sv, while the transport east of Site Z is estimated to be +1.4 Sv.

The time variability of these flows, which represents a source of error in the final MOC estimate, is roughly 2 Sv (daily standard deviation) in two models, with slightly smaller 1-2 Sv variations observed in repeated XBT sections at this same latitude.

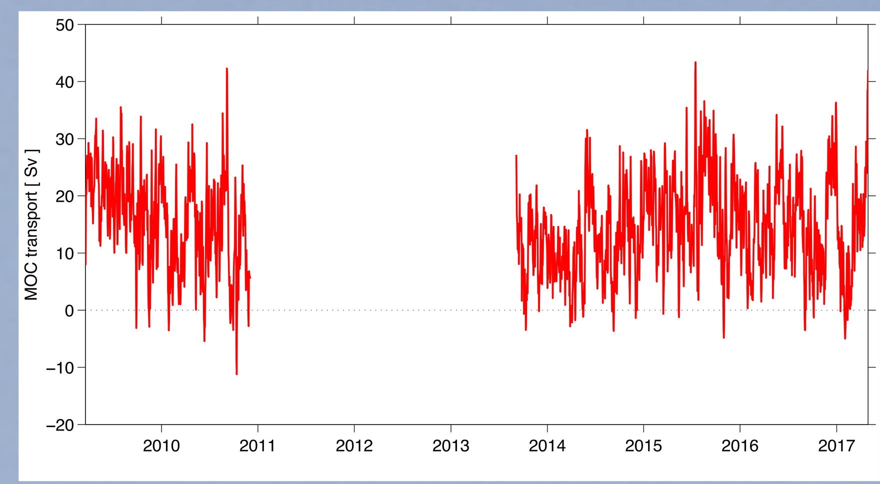




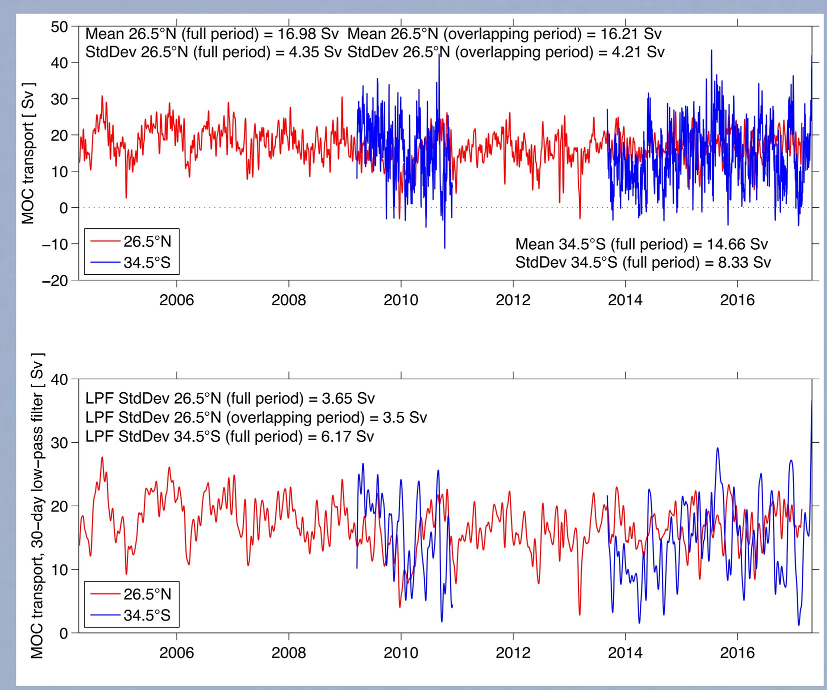
Summing up the absolute geostrophic, Ekman, and shelf flows yields profiles of the total absolute transport across the basin.

One advantage of this method is that it does not require a 'mass correction' residual based on an assumed zero net flow integrated surface to bottom.

Integrating from the surface down to the zero crossing (white line at left) yields the transport of the MOC upper limb at 34.5°S. The time mean location of the zero crossing is 1160 dbar, with a daily standard deviation of 175 dbar.



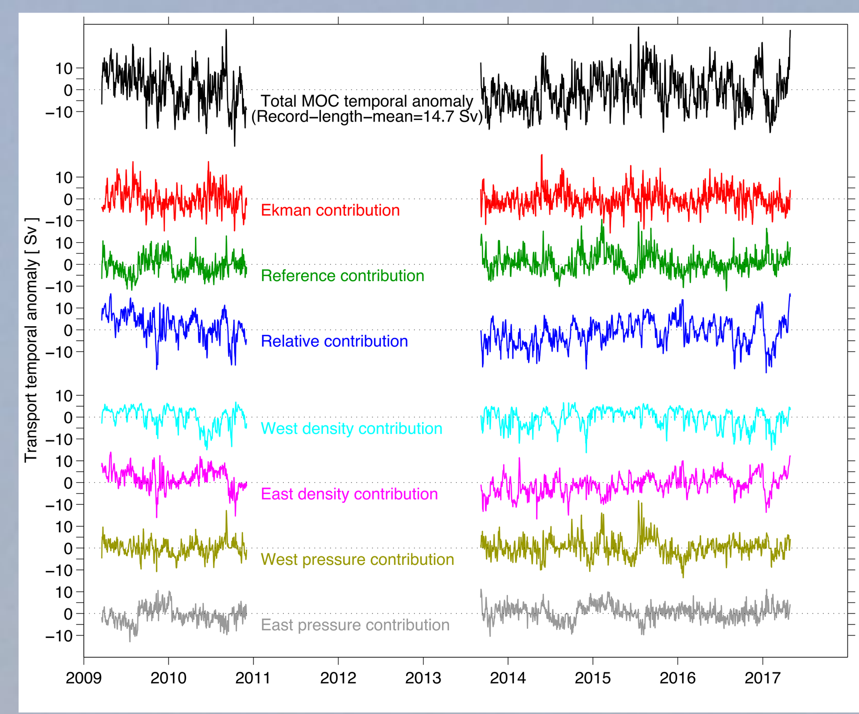
The resulting time series of daily MOC transport estimates is highly variable, with a mean value of 14.7 Sv and a daily standard deviation of 8.3 Sv. Recall that the mean value is somewhat dependent on the OFES model shelf and reference velocity mean values, while the time variability of the MOC is completely independent of the model.



The MOC time series observed at 26.5°N is much longer than the 34.5°S record, and probably is more accurate as well, although the 26.5°N calculation does involve a residual technique.

The two time series show no correlation, which is perhaps not surprising since the much closer 16°N MOVE array has also shown little correlation with the 26.5°N array record.

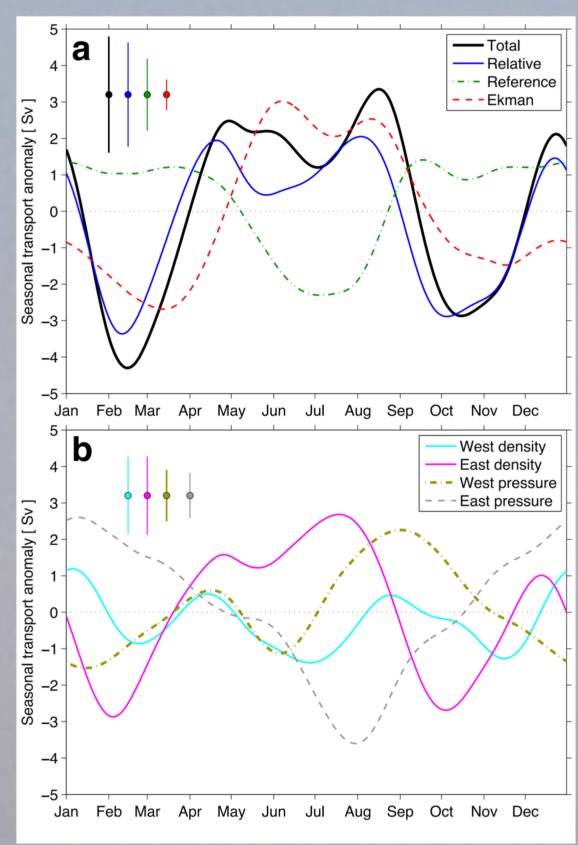
The 34.5°S and 26.5°N records do show fairly similar characters on time scales ranging from days to interannual. The daily standard deviation at 34.5°S is almost twice as large as at 26.5°N, which may be due to missed variability inshore of Sites A and Z at 34.5°S or may be due to 'smoothing' of the barotropic variability by the residual calculation at 26.5°N.



Focusing on the time variability of the MOC at 34.5°S, the peak-to-peak range exceeds 50 Sv.

The relative (baroclinic, density-driven) term has the largest contribution to the overall MOC variability, with the Ekman (wind-driven) and reference (barotropic, pressure-driven) terms having roughly equal contributions. (Daily std. devs. = 6.0, 4.7, 4.6 Sv, respectively.) These terms are uncorrelated with one another.

The relative and reference terms are driven roughly equally by variations at the western and eastern boundary. (Daily std. devs. within ~10% east vs. west.)



Analyzing the variability at seasonal time scales finds a quasi semi-annual seasonality to the MOC, which has not previously been observed. The Ekman and relative terms have the largest peak-to-peak variations (roughly 3 Sv), while the reference variability at the seasonal time scale is a little bit smaller (peak-to-peak range of about 2 Sv).

Interesting the Ekman and reference terms are roughly 180° out of phase. Recall these terms are purely independent of one another because no residual technique is used here – so this is telling us about the MOC physics. Despite this nearly out of phase relationship, all three terms are contributing to the total.

The relative seasonality is driven almost entirely by density variations at the eastern boundary (compare magenta line in panel b at left to blue line in panel a).

The reference seasonality is also driven strongly by the eastern boundary, although the west pressure variations are not negligible.

Looking at interannual variations (table at right), we find that the relative contribution is again largest, but reference terms dominate the total in about the same number of years as the relative due to canceling influences of the two boundaries. The Ekman term has very small impacts at interannual time scales when only the full-year averages are considered (i.e. ignore gray italics years in table where only a few months are available for averaging).

Both the western and eastern boundaries have important contributions at the interannual time scale, although eastern boundary signals tend to be larger amplitude.

	2009	2010	2013	2014	2015	2016	2017	SEM
Total MOC	**4.6 Sv**	**−1.8 Sv**	***−3.4 Sv***	**−3.8 Sv**	**3.2 Sv**	**0.3 Sv**	***−1.9 Sv***	**1.7 Sv**
Ekman contribution	0.7 Sv	−0.6 Sv	*−1.2 Sv*	−0.0 Sv	−0.1 Sv	0.5 Sv	*−2.3 Sv*	0.9 Sv
Relative contribution	4.2 Sv	0.3 Sv	*−3.5 Sv*	−4.2 Sv	0.9 Sv	−0.1 Sv	*−2.5 Sv*	1.5 Sv
Reference contribution	−0.3 Sv	−1.3 Sv	*1.0 Sv*	0.4 Sv	2.1 Sv	−0.4 Sv	*2.6 Sv*	1.0 Sv
West density contribution	1.8 Sv	−1.3 Sv	*−0.4 Sv*	−1.3 Sv	1.8 Sv	−1.4 Sv	*−2.3 Sv*	1.1 Sv
East density contribution	2.5 Sv	1.6 Sv	*−3.2 Sv*	−2.9 Sv	−0.9 Sv	1.3 Sv	*−0.2 Sv*	1.2 Sv
West pressure contribution	0.4 Sv	−0.3 Sv	*0.4 Sv*	0.0 Sv	0.9 Sv	−0.3 Sv	*0.2 Sv*	0.9 Sv
East pressure contribution	−0.8 Sv	−1.1 Sv	*0.5 Sv*	0.2 Sv	1.0 Sv	−0.1 Sv	*2.2 Sv*	0.8 Sv

Conclusions

- The MOC at 34.5°S is highly variable (STD = 8.3 Sv) during 2009-2017, with strong variations at time scales ranging from a few days to interannual. There is no statistically-significant trend.
- Seasonal MOC variability due to the Ekman transport is roughly 180° out of phase with the seasonal variations associated with the reference (bottom pressure – i.e. barotropic) term. As such, the seasonal cycle in the MOC is primarily driven by the relative (density) term, although the other terms do have non-trivial impacts. The seasonal cycle of the relative term is most strongly associated with the density variations at the eastern boundary.
- Interannual (year-to-year) variations are most strongly driven by relative (density) term changes, although in some years the reference (pressure) term dominates. At interannual time scales both the western and eastern boundary variations are important, although the eastern side tends to be more important for both relative and reference terms most years.
- A key take-away of this analysis is that it is essential to measure both the relative and reference components of the MOC at 34.5°S, as both vary strongly and independently, and that it is essential to measure them at both the western and eastern edges of the basin.

For additional details, please see the following paper and references therein:

Meinen, C.S., S. Speich, A.R. Piola, I. Ansorge, E. Campos. M. Kersale, T. Terre, M.-P. Chidichimo, T. Lamont, O.T. Sato, R.C. Perez, D. Valla, M. Van den Berg, M. Le Henaff, S. Dong, and S.L. Garzoli. Meridional Overturning Circulation transport variability at 34.5°S during 2009-2017: Baroclinic and barotropic flows and the dueling influence of the boundaries, *Geophysical Research Letters*, 45(9):4810-4188, doi:10.1029/2018GL077408, 2018.