Measuring daily MOC variations at 34.5°S with PIES – An initial estimate

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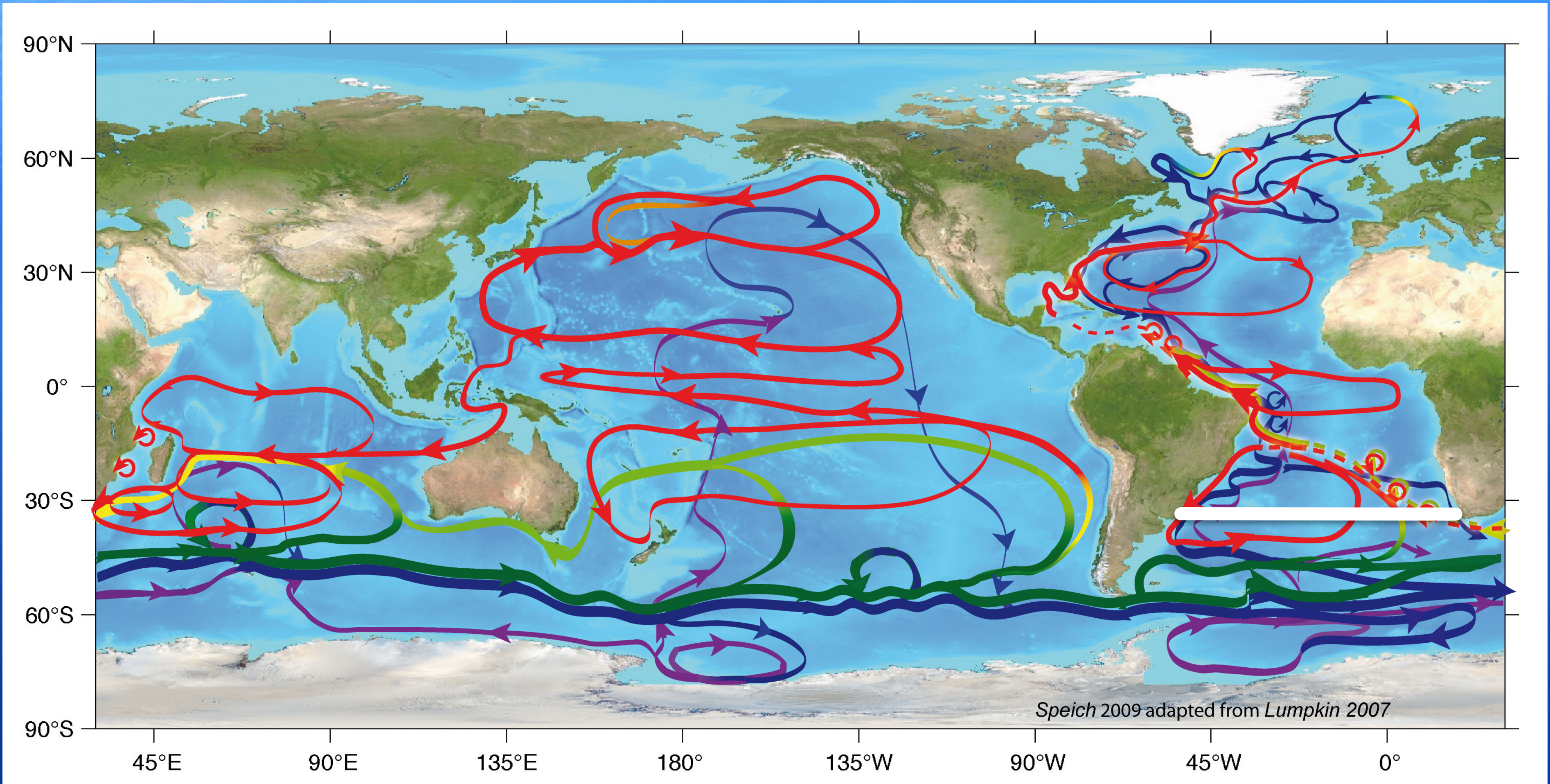
with many thanks to: Sabrina Speich, Alberto Piola, Edmo Campos, Silvia Garzoli, Renellys Perez, Shenfu Dong, Carlos Franca, Rigo Garcia, Pedro Pena, Uli Rivero, Aldo Firpo, Yoshikazu Sasai, the science teams in Miami, France, Brazil and Argentina, and the officers and crews of the ARA Puerto Deseado, the N. Oc. Alpha-Crucis, the N.H. Cruzeiro do Sul, the R/V Marion Dufresne and the S.A. Agulhas.



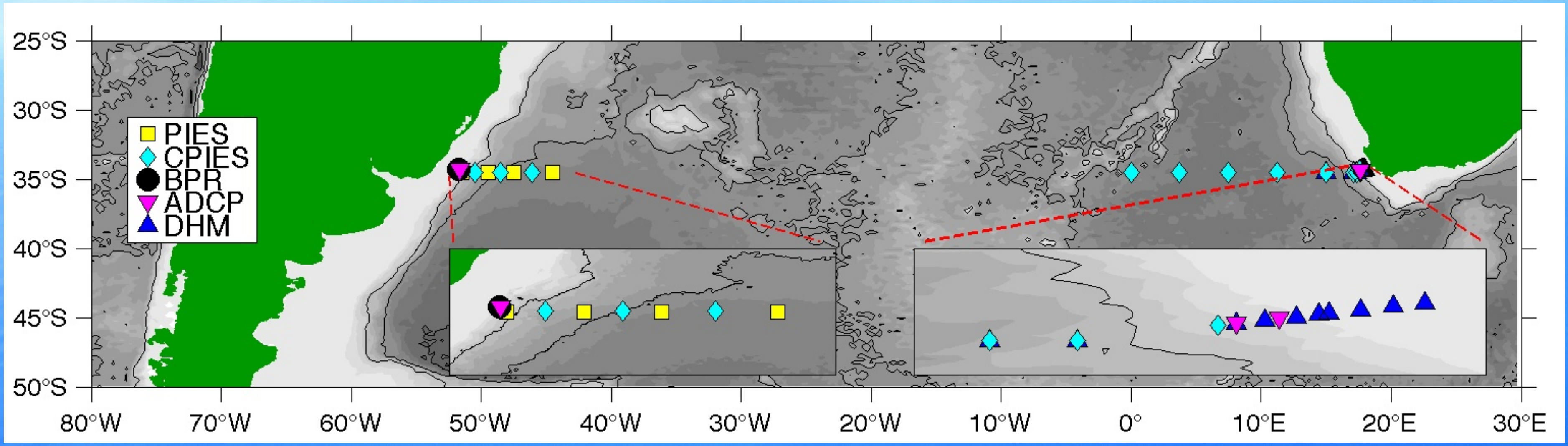
My work with Randy –

Summer 1991: Randy was my 'SURFO' adviser while I worked on Gulf Stream thermocline slopes and path curvature

July 1992-January 1998: Worked on my PhD with Randy studying TRWs, the North Atlantic Current and developing the 'GEM' technique for IES analysis

July 2000-June 2002: Collaborated with Randy during a postdoc at the Univ. of Hawaii (w/Doug Luther) on the analysis of the Subantarctic Front during SAFDE

Ever since I met him, he's been a good advisor, mentor, colleague and friend – and his help has been and is greatly appreciated.



Southwest Atlantic MOC ("SAM") project

Three PIES and one CPIES: March 2009 to July 2011

Four PIES: July 2011 to the present

South Atlantic MOC-Brazil ("SAMOC-Br") project

Three CPIES: December 2012 to present

One ADCP & one BPR: December 2013 to present

GoodHope/SAMOC-East projects

Two CPIES: February 2008 to December 2010

Eight CPIES & two ADCP: September 2013 to present

Ten moorings (tall and short): September/December 2014 to present

Concurrent time period for the pilot/initial arrays:

March 20, 2009 through December 2, 2010 (623 days total)

PIES analysis – the "GEM" technique

Each CTD/Argo profile is used to calculate a sound speed profile $c(S,T,P)$ using the empirical equation derived by Del Grosso (1974).

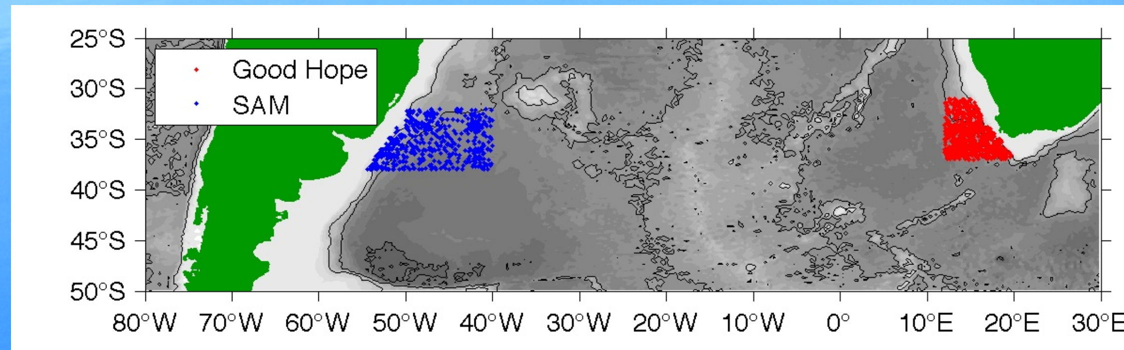
Then a simulated travel time can be determined:

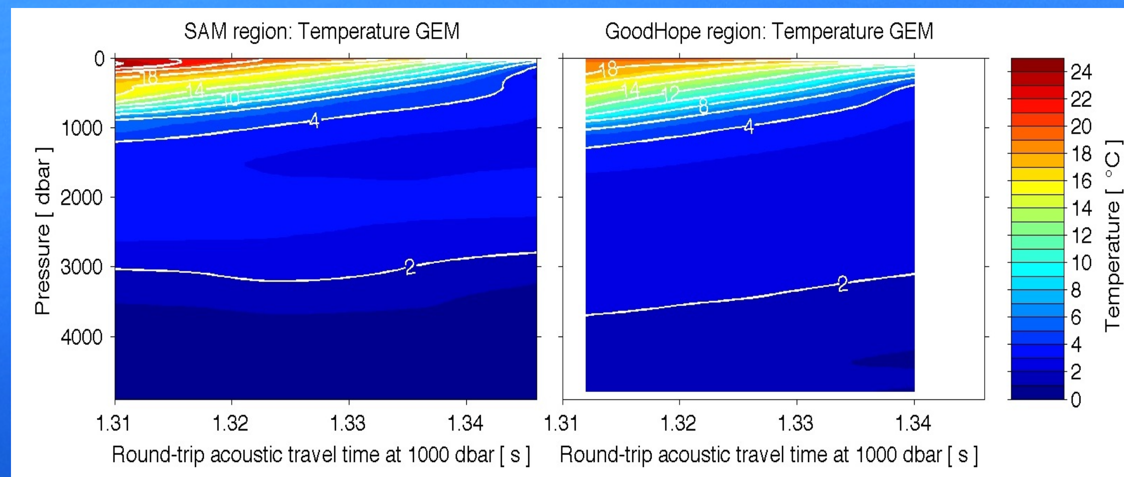
$$\tau_{sim} = 2\int_0^{1000} \frac{1}{\rho g c} dp$$

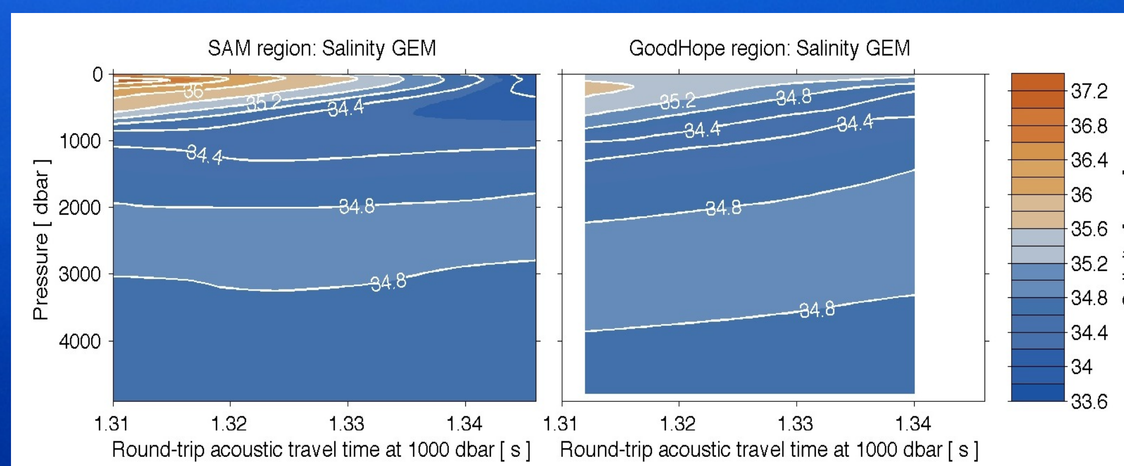
and with this, the "Gravest Empirical Mode" (GEM) look-up tables can be created (right).

We can create GEM fields for temperature, salinity, and density.

Vertically integrating the density profiles gives dynamic height anomalies…







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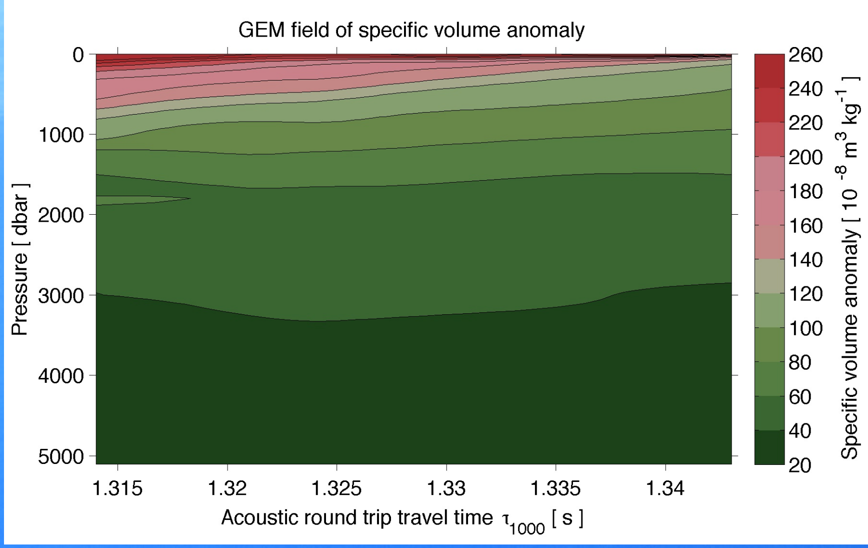
Calculating velocity using the PIES/CPIES

Density profiles => dynamic height anomaly profiles

Gradients of dynamic height anomaly profiles
=> geostrophic relative velocities (relative to LNM)

Gradients of bottom pressure
=> absolute geostrophic bottom velocity anomalies

Missing: Absolute velocity bottom velocity time mean…



For time-mean reference velocities (and for flow up on the continental shelves outside our pilot arrays) we'll use the time-mean from a 27-year run of the "OFES" model:

Ocean general circulation model For the Earth Simulator
•Modular Ocean Model (MOM3) run by JAMSTEC
•0.1˚ grid with 54 vertical levels
•Forced with monthly mean NCEP/NCAR reanalysis atmospheric fluxes

Integrating to get the MOC – An admittedly "crude" initial method

To determine the MOC from the pilot arrays, we'll first try looking only at the upper limb as follows:

Geostrophic velocity will be estimated by combining:

-Relative velocity profiles from the PIES dynamic heights at Sites A and Z

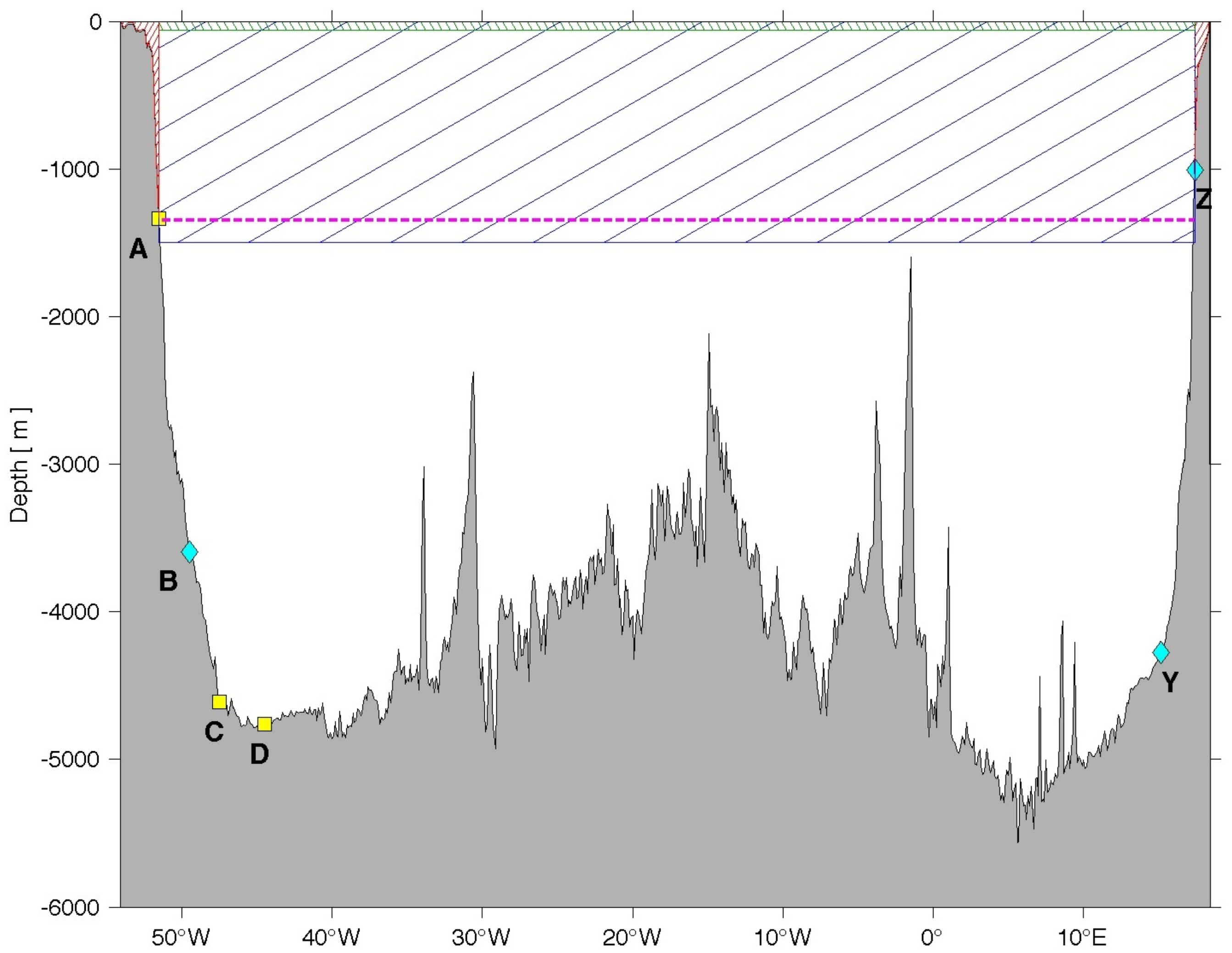
-Reference velocity time variability from the pressure differences between Sites A and Z

-Reference velocity time mean from the OFES model velocity averaged between Sites A and Z

We will also add:

-Ekman transport between Sites A and Z from CCMP winds

-Time mean transports on the West and East shelves from OFES mean velocities



Because these velocities are absolute, not relative, there is no need to do an adjustment to force the calculation to zero net flow over the full water column…

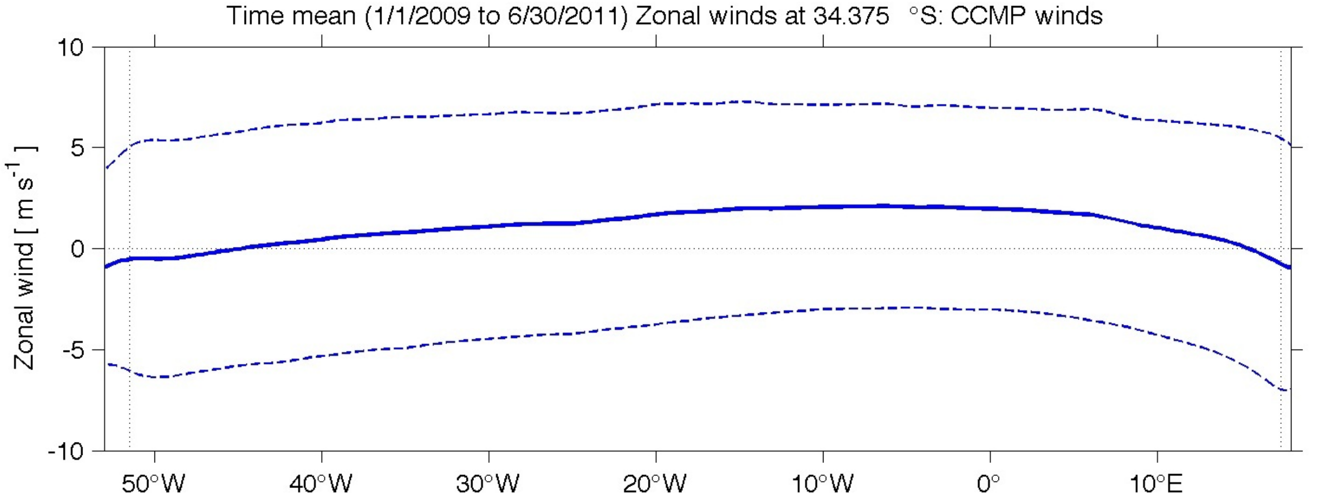
Ekman Transport

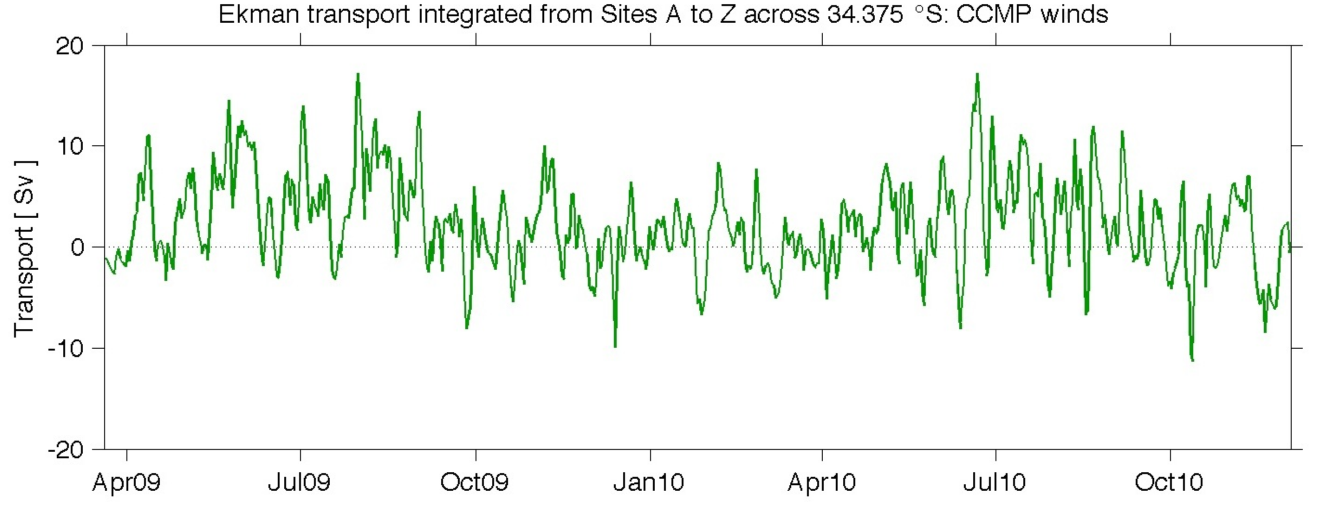
Winds from the CCMP 6-hour product (Atlas et al., 2011) are averaged to once per day.

For this preliminary study the wind speeds are converted into wind stress using a constant drag coefficient (1.43×10^{-3}) and air density (1.225 kg m^{-3}) following Weisberg and Wang (1997)

At a later date we'll investigate more 'modern' and/or 'high tech' wind speed dependent drag coefficients.

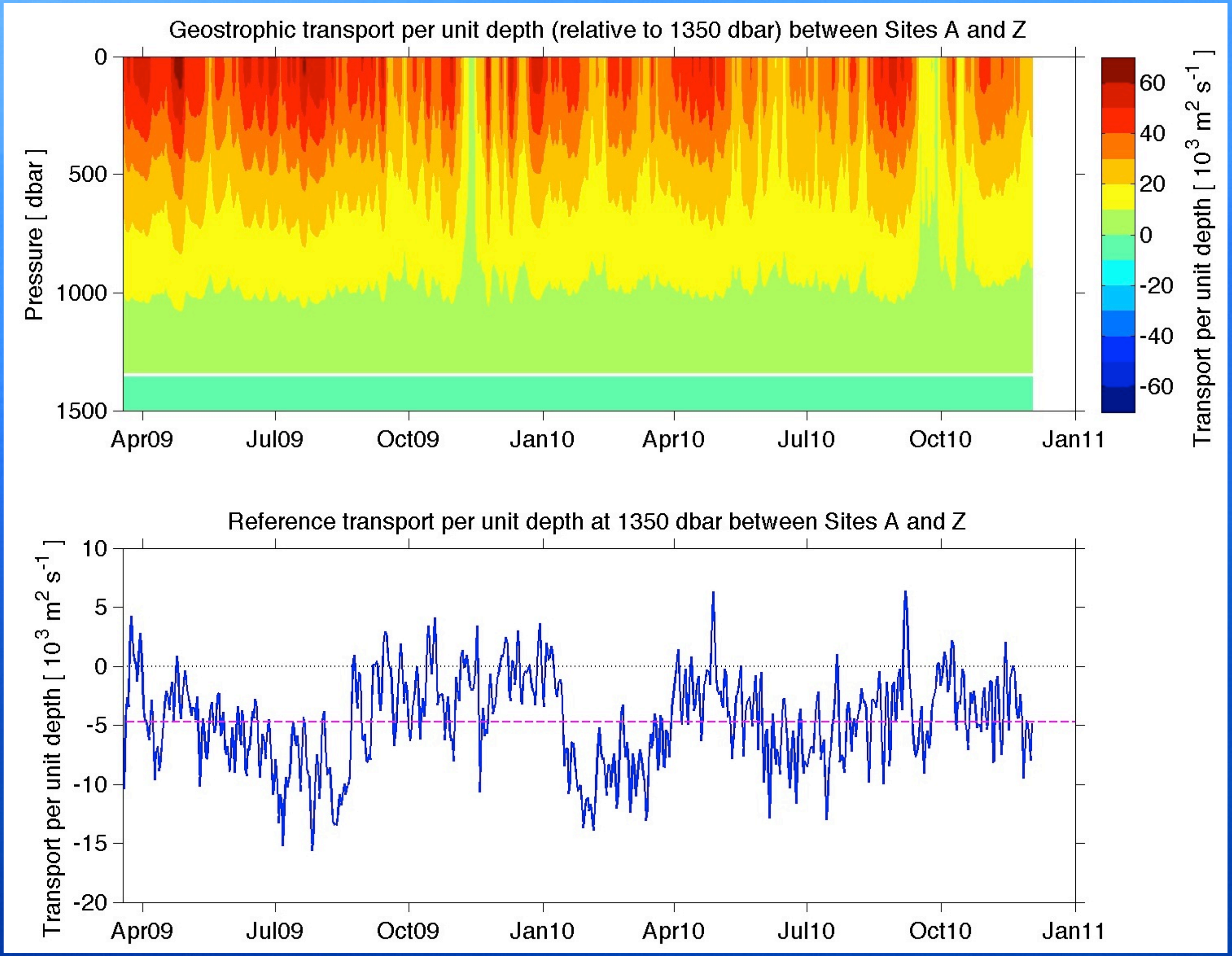
Using this simple method, the Ekman transports during the March 20, 2009 to December 2, 2010 time period have a time mean of 2.2 Sv, which is very close to the 2.5 Sv found by Dong et al. (2009) using monthly NCEP winds during the AX18 crossings.





Geostrophic Transport

Geostrophic transports are determined relative to the surface initially. These are transports per unit depth; which means this would be the transport in a 1-meter thick layer in the ocean.



The reference transports are determined from the pressure differences. A time-mean reference transport is added using the 27-year average from the OFES model at the selected reference level (1350 dbar). The magenta dashed line at right illustrates the OFES mean value.

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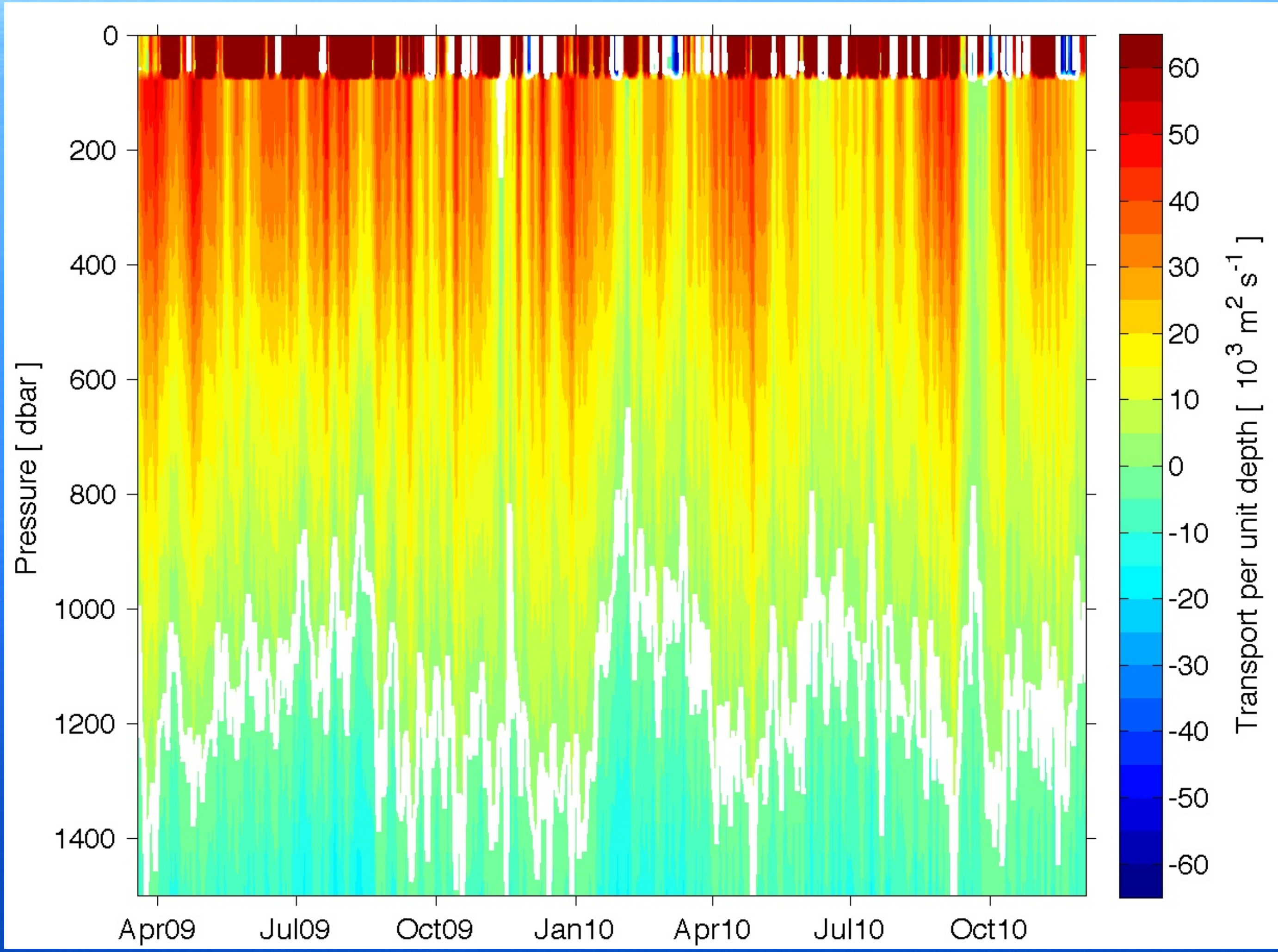
Time variability of the transport per unit depth profiles

The total transport per unit depth is highly variable with time, with large changes occurring over periods as short as a few days.

The transition point between the northward and southward flowing layers is also highly variable, ranging from 1630 dbar to as shallow as 762 dbar. (The 10-day lowpass filtered data range from 801 to 1449 dbar.)

If you want to badly enough you can see some hint of an annual cycle in the transition depth, with deeper values in austral spring, but with less than two years of data, its very premature to put too much weight on this.



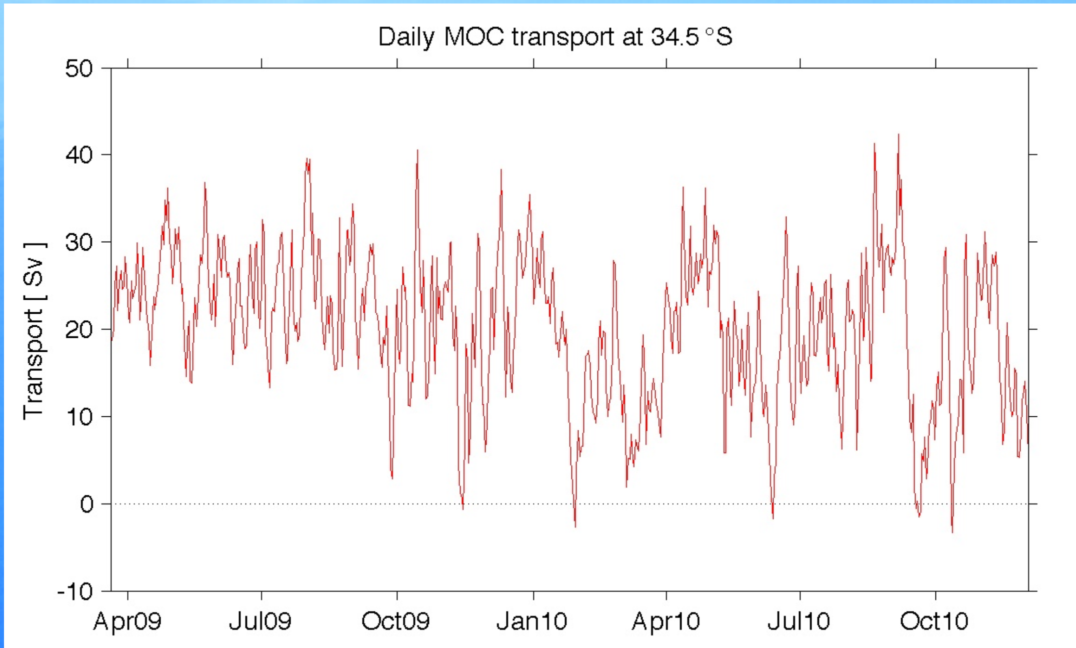
Time varying MOC

Statistics – Daily data
Maximum = 42 Sv
Mean = 21 Sv
Minimum = -3 Sv
STD = 9 Sv

Statistics – 10-day low pass filtered data
Maximum = 37 Sv
Mean = 20 Sv
Minimum = 0 Sv
STD = 8 Sv

For comparison, at 26°N the peak-to-peak range after a 10-day low pass filter is 36 Sv (see also table at right). In general the observed 34.5°S variability is similar to, or slightly larger than, the variability that is observed at the northern latitudes.

One consideration is that the standard deviation we've found is almost certainly a bit 'exaggerated', because we are missing the time-varying flows up on the continental shelves/upper slopes on the west and east sides.



Latitude of MOC Observation	Low-Pass Filter Periods: No Filter	10 Days	90 Days	120 Days
41°N [*Willis*, 2010]			**2.4 Sv**	
26°N [*Cunningham et al.*, 2007]		**4.9 Sv**	3.7 Sv	3.6 Sv
16°N [*Send et al.*, 2011]				**3.8 Sv**
34.5°S [This study]	8.7 Sv	7.6 Sv	4.5 Sv	3.9 Sv

[a]Bold standard deviation estimates were published in the listed papers—the other estimates at 26°N were determined using the 26°N MOC time series for 2004–2011 (available from www.noc.soton.ac.uk/rapidmoc/). The final row shows the standard deviation results for the present study at 34.5°S for comparison.

From Meinen et al. (2013)

Accuracy of the MOC estimates

Because we are not applying a 'residual' method to our calculation, we can make a more direct estimate of the accuracy of our calculated MOC (see table at right).

For this we need to quantify both the potential random sources of error, and the potential biases.

The total random error bar ends up being about **6 Sv**; the comparable error bar for the 26°N array is 3 Sv (Kanzow et al. 2007).

We expect the errors for this first crude MOC estimate for 34.5°S to be higher, and it is. This is one of the main areas where we will do better with the more recent array that captures the shelf/upper slope and which will allow us to look at the deep limb of the MOC also.

	Accuracy Estimate
Random Sources	
GEM look-up table accuracy	3.1 Sv
Scatter in τ_{PIES} versus τ_{1000} relationship	0.5 Sv
Measured τ accuracy	1.2 Sv
Baroclinic shear 1000–1500 dbar	2.3 Sv
Measured pressure accuracy	1.9 Sv
Ekman accuracy	1.4 Sv
West shelf missed variability	2.5 Sv
East shelf missed variability	2.5 Sv
Total random	5.9 Sv ←
Bias Sources	
Calibration of τ_{PIES} with concurrent CTDs	4.2 Sv
Accuracy of reference velocity time-mean	1.4 Sv
Ekman time-mean accuracy	0.02 Sv
Combined shelf missed time-mean	0.2 Sv
Total bias	4.4 Sv

[a]Totals are determined as the square root of the sum of the squares as appropriate.

Conclusions

•A first (crude) estimate of the MOC at 34.5°S using PIES/CPIES in concert with the CCMP winds and time-mean shelf estimates and reference velocity from OFES find a time varying MOC of comparable magnitude to that observed with the more complete array at 26.5°N; i.e. for 10-day low-pass filtered records the variability STD (peak-to-peak range) was 7 Sv (37 Sv) at 34.5°S and 5 Sv (36 Sv) at 26.5°N.

•There is some agreement between the PIES/CPIES based estimates and concurrent XBT based estimates, although the asynopticity inherent in the 2+ week completion time for the XBT sections makes the comparison difficult.

•The MOC variations at 34.5°S are driven in roughly equal parts by direct Ekman flows and geostrophic flows with these terms being uncorrelated with one another on time scales of days to months. The geostrophic (relative) flows are driven nearly equally by density variations on both sides of the basin.

The accuracy/quality of the MOC estimates at 34.5°S will be greatly improved by several forthcoming enhancements to the existing pilot arrays:

- •The effective 'doubling' of the SAM array with the Brazilian instruments
- •Significant enhancement/expansion of the earlier French CPIES array in the east
- •The addition of on-shelf (and upper slope) measurements on both the western boundary (ADCP and BPR from Brazil) and the eastern boundary (line of ADCP and tall moorings from South Africa)

Thank you for your attention!

Questions?

For more information, please see:

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.