The Atlantic Meridional Overturning Circulation: Heat Transport, Variability and Watermass Transformations in the South Atlantic

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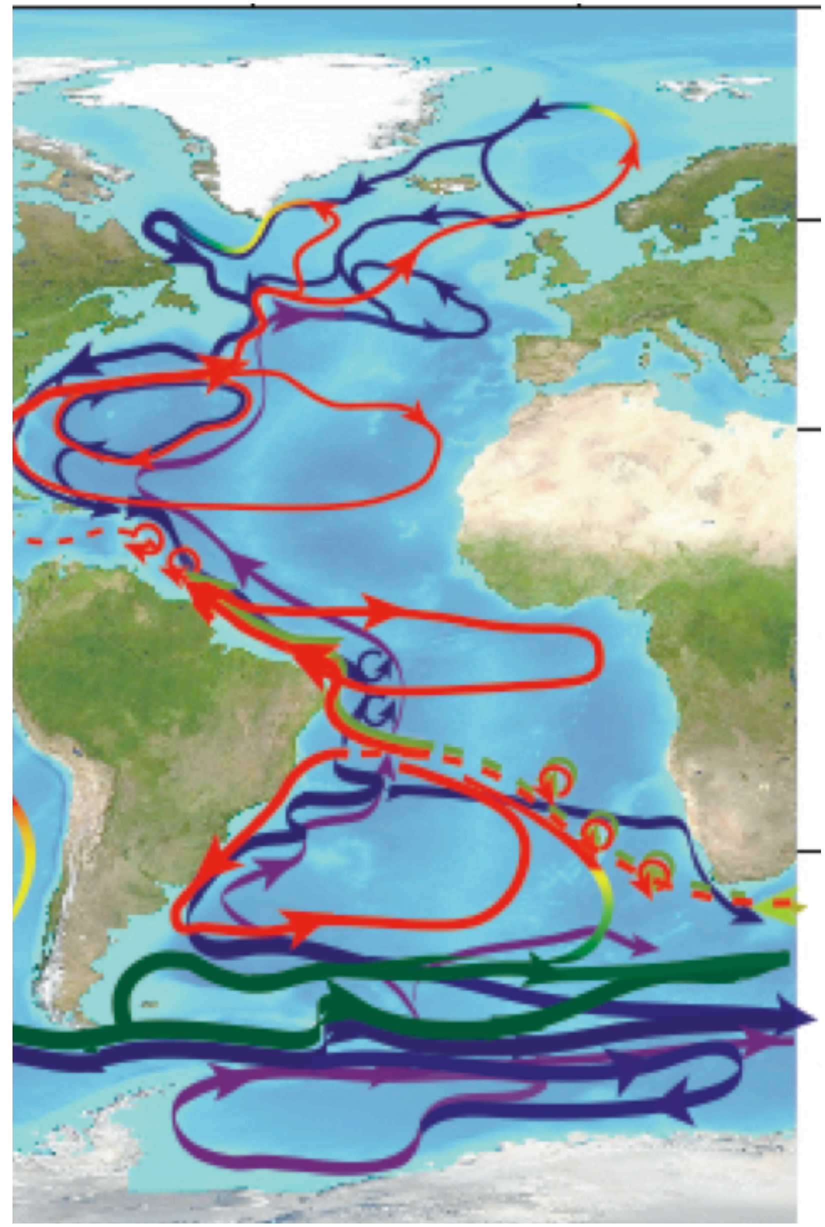
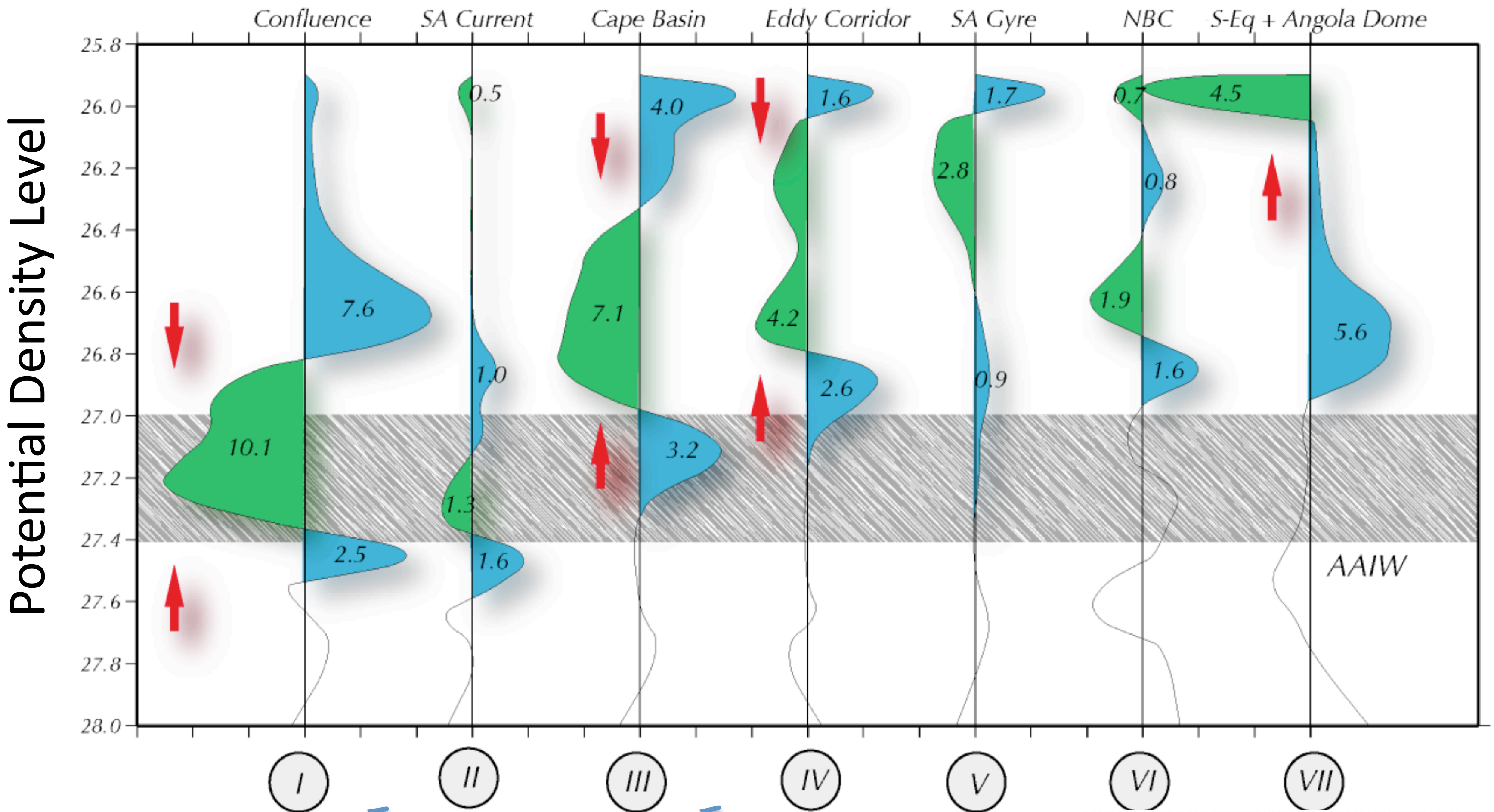
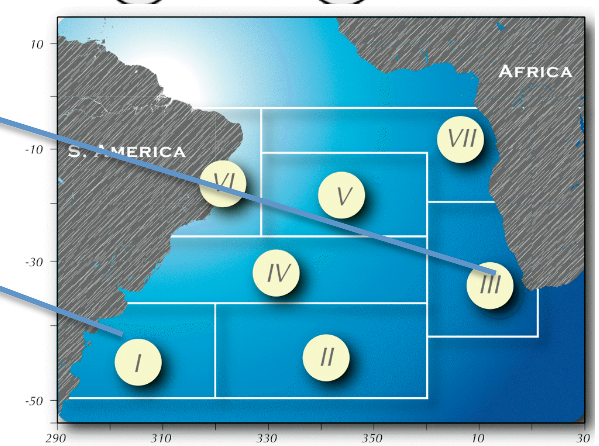


SAMOC III

May 11, 2010

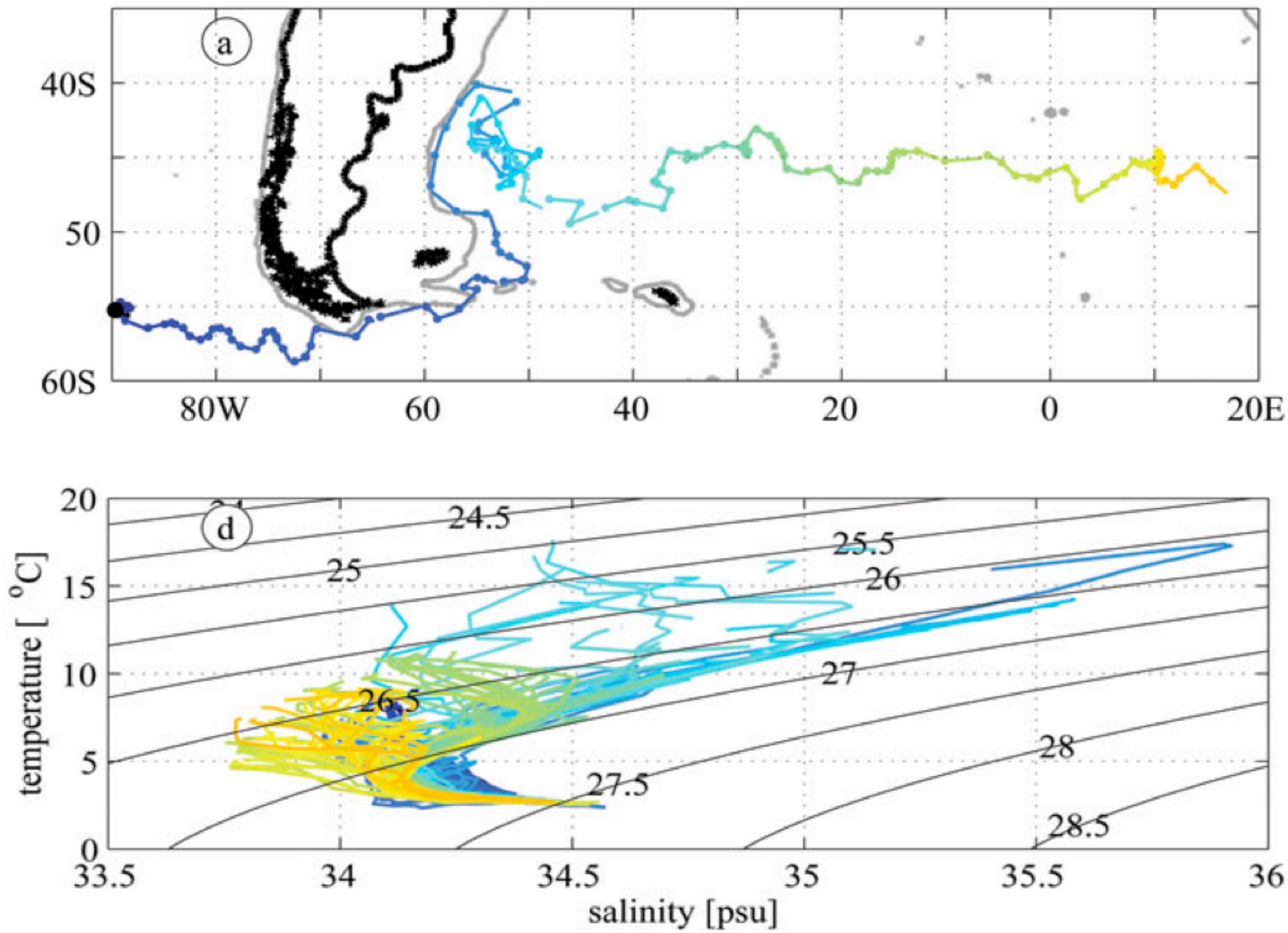


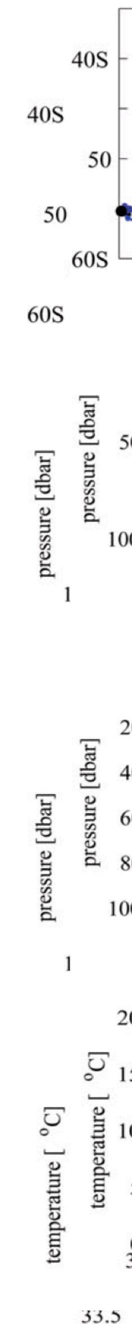


Quantifiable water mass transformations occur in the South Atlantic.

Garzoli and Matano, 2010

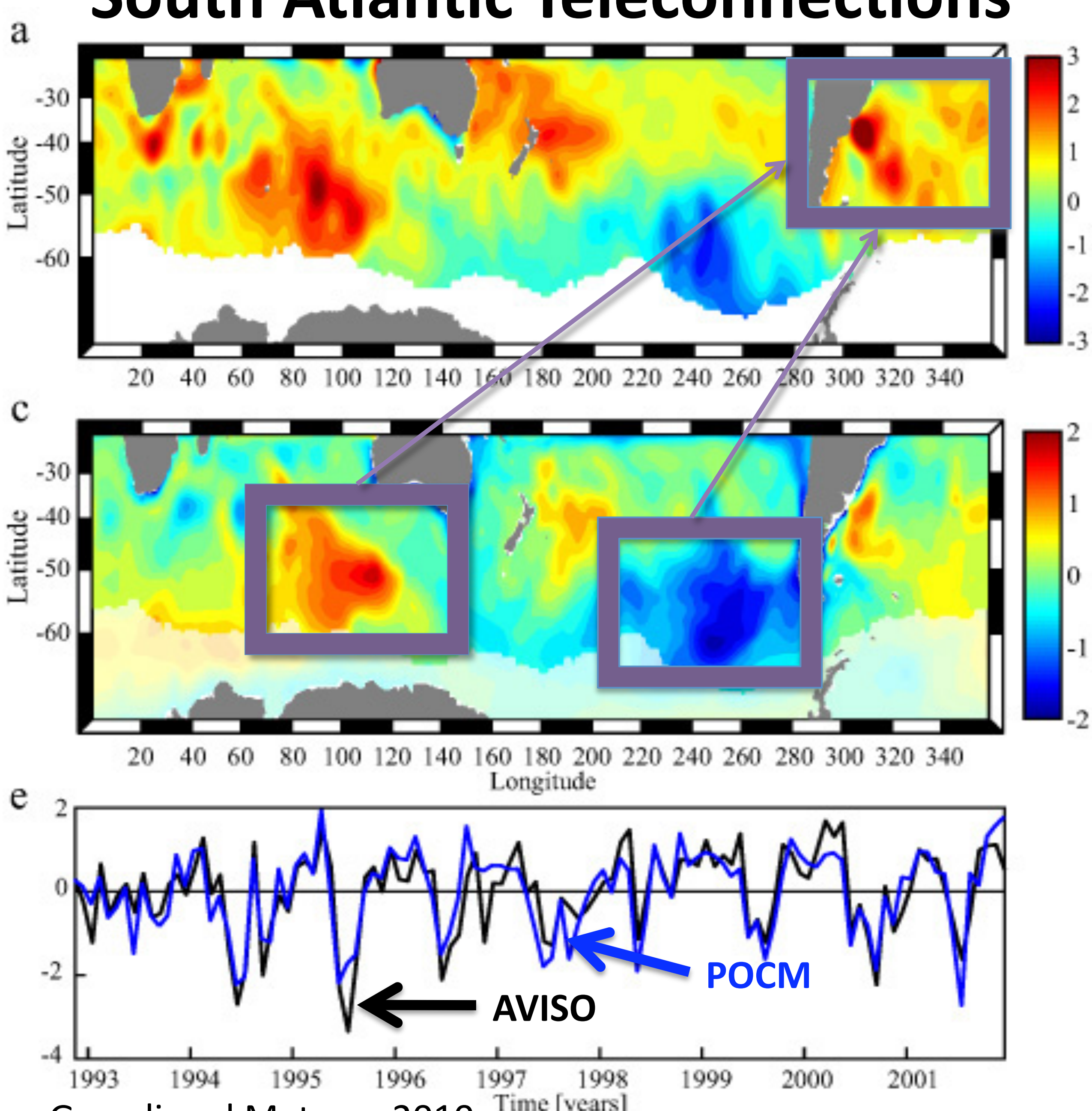
ARGO Floats show similar watermass progressions across the basin





Garzoli and Matano, 2010

South Atlantic Teleconnections



Garzoli and Matano, 2010

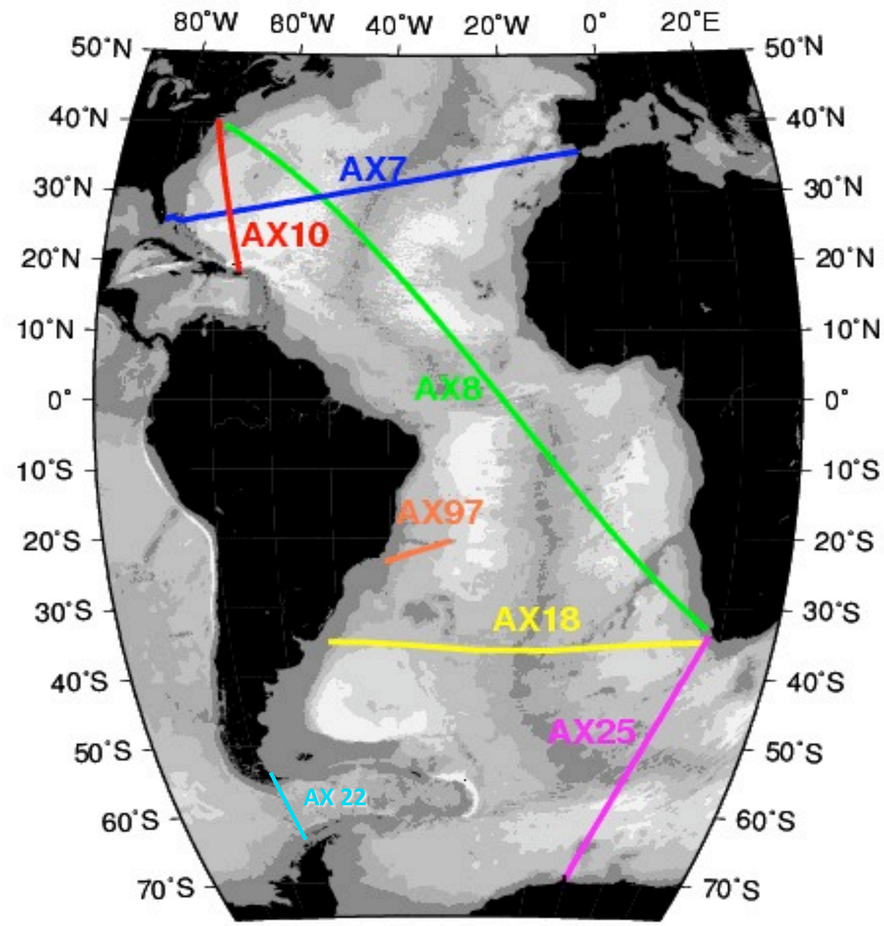
The South Atlantic is the pulse for the SO. The figure shows the Principal Estimator Patterns of SSH anomalies (top panel) and wind curl (middle panel) in the Southern Hemisphere; the bottom panel shows the time series.

The analysis shows that the variability in the SA is related to the forcing in the Pacific and Indian Ocean. This is the component of the variability that is related to AMOC.

Fetter and Matano, (2009)

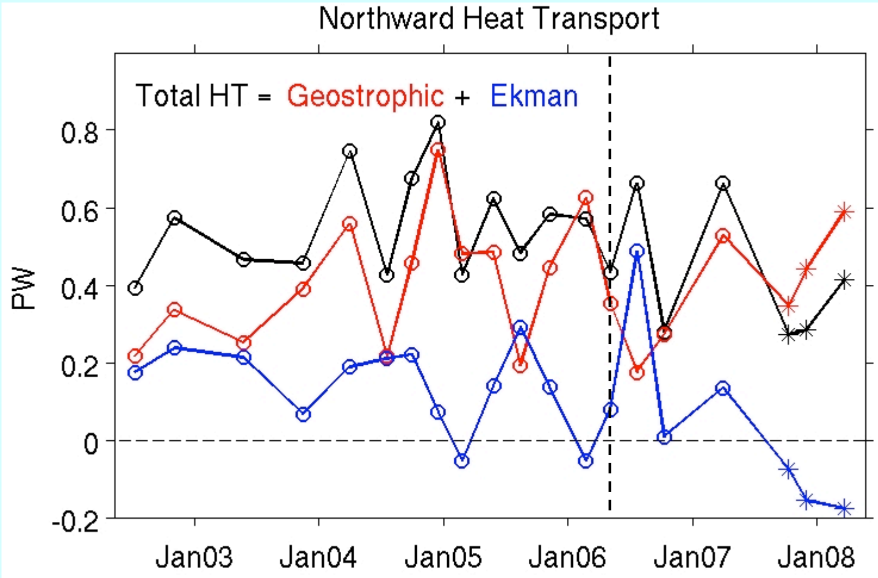
Heat budget and the role of inter-ocean exchanges in northward heat transport and air sea heat flux.

Objective: To analyze the AMOC variability in the South Atlantic using both available observations and a non data-assimilative simulation of the AMOC with the aim of defining the importance of variations in inter-ocean and inter-basin exchange and the connectivity.



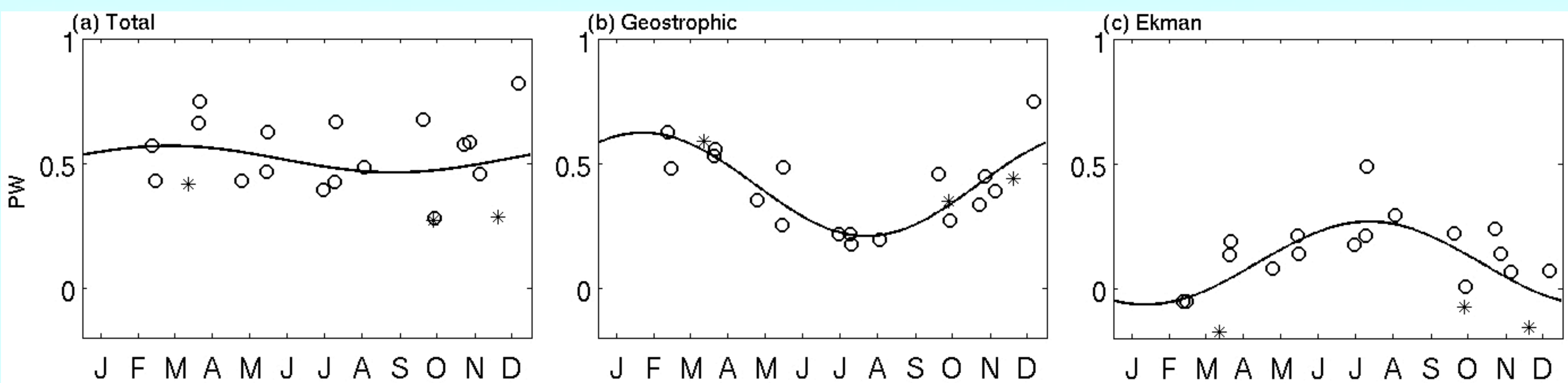
"The SA Box"

Northward Heat Transport



Total = 0.51 ± 0.15 PW
Geos. = 0.40 ± 0.16 PW
Ekman = 0.11 ± 0.16 PW

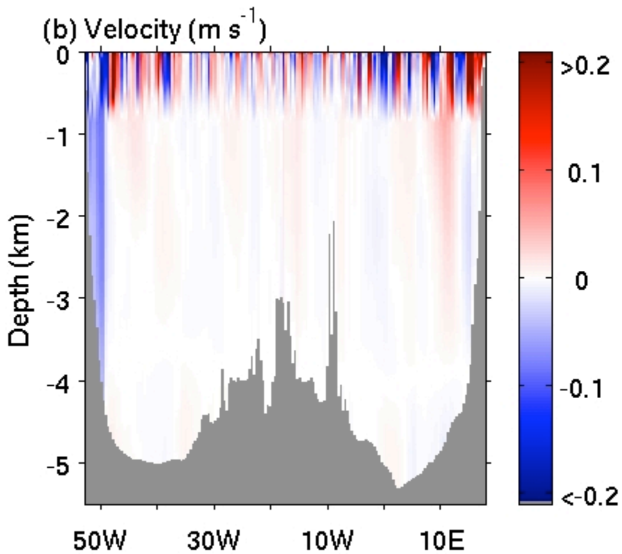
- ➢Geostrophic transport controls the total northward heat transport.
- ➢Geostrophic and Ekman transports experience comparable variability



Both geostrophic and Ekman transports experience annual cycles, but they are out of phase.

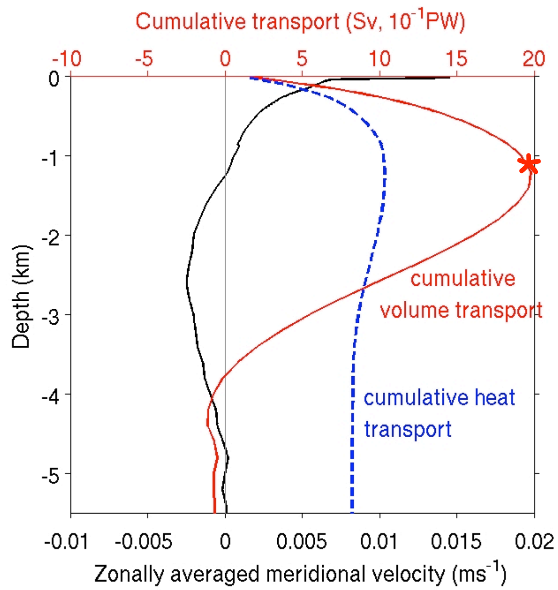
Garzoli and Baringer (2007)
Baringer and Garzoli (2007)

Meridional Velocity and Transport Across AX18

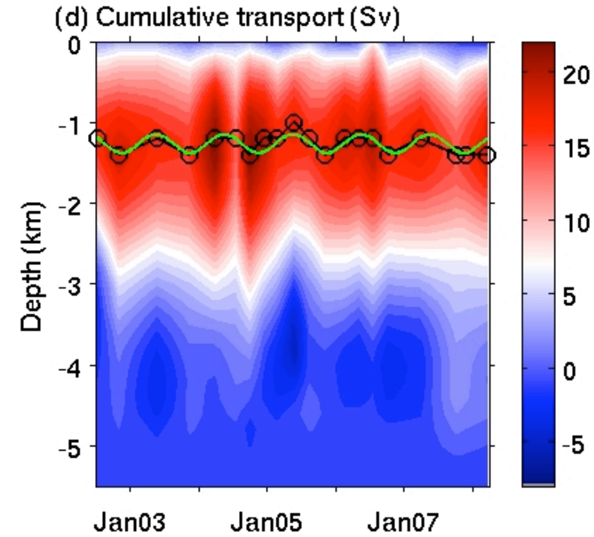


Meridional velocity distribution for December 2004 transect.

$$AMOC = \max\left(\int_0^Z \left[\int_{X_w}^{X_e} v(x,z)dx\right] dz\right)$$



Zonally averaged meridional velocity, and cumulative volume transport from sea surface to ocean floor.

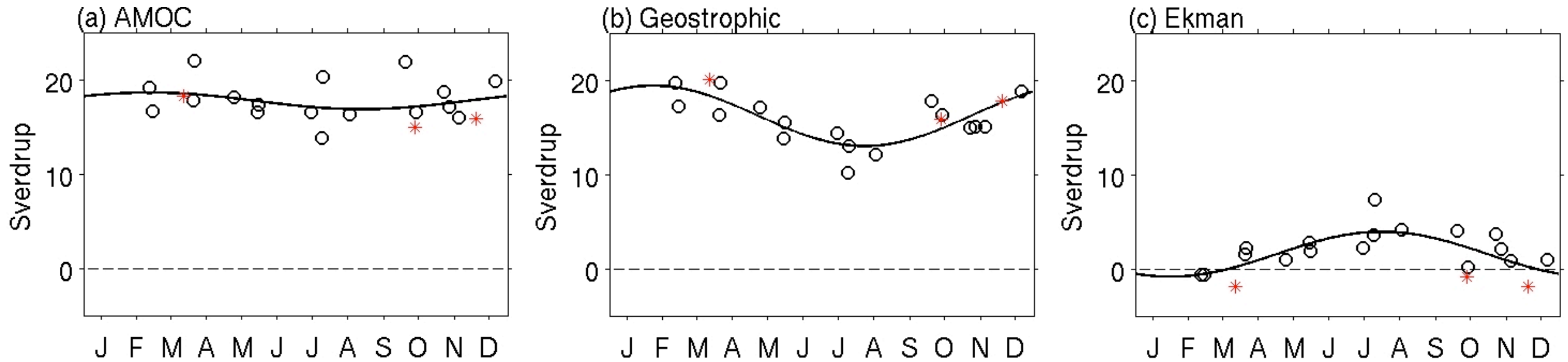


Cumulative volume transport (color), which reaches its maximum at 1300 m depth (black).

Strength of AMOC: the maximum cumulative transport (trans-basin integrated) from the sea surface to the ocean bottom, represents the total northward transport in upper water column.

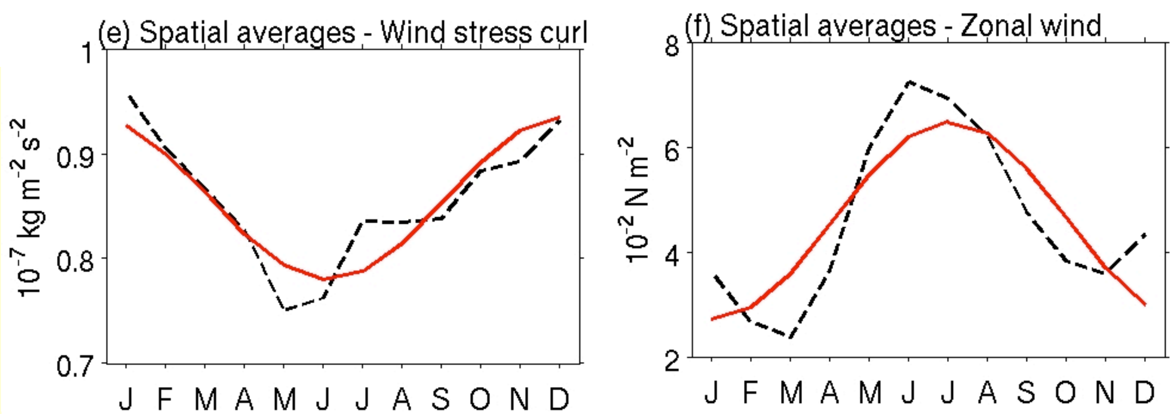
Dong et al 2009

Seasonal Variability



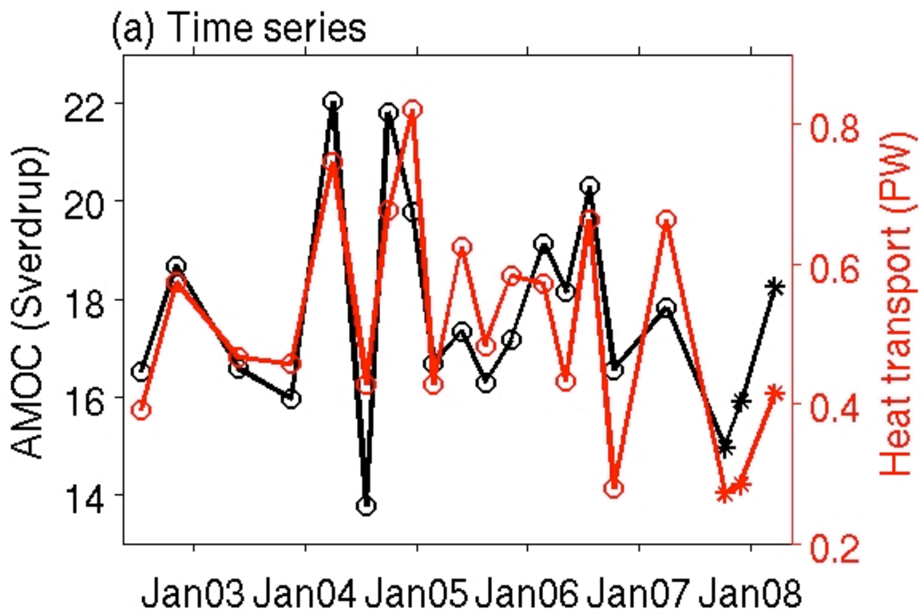
Both geostrophic and Ekman contributions to the AMOC experience annual cycles, but they are out of phase.

Seasonal cycles in geostrophic and Ekman components are consistent with the seasonal variations in wind stress curl and zonal wind stress, respectively.



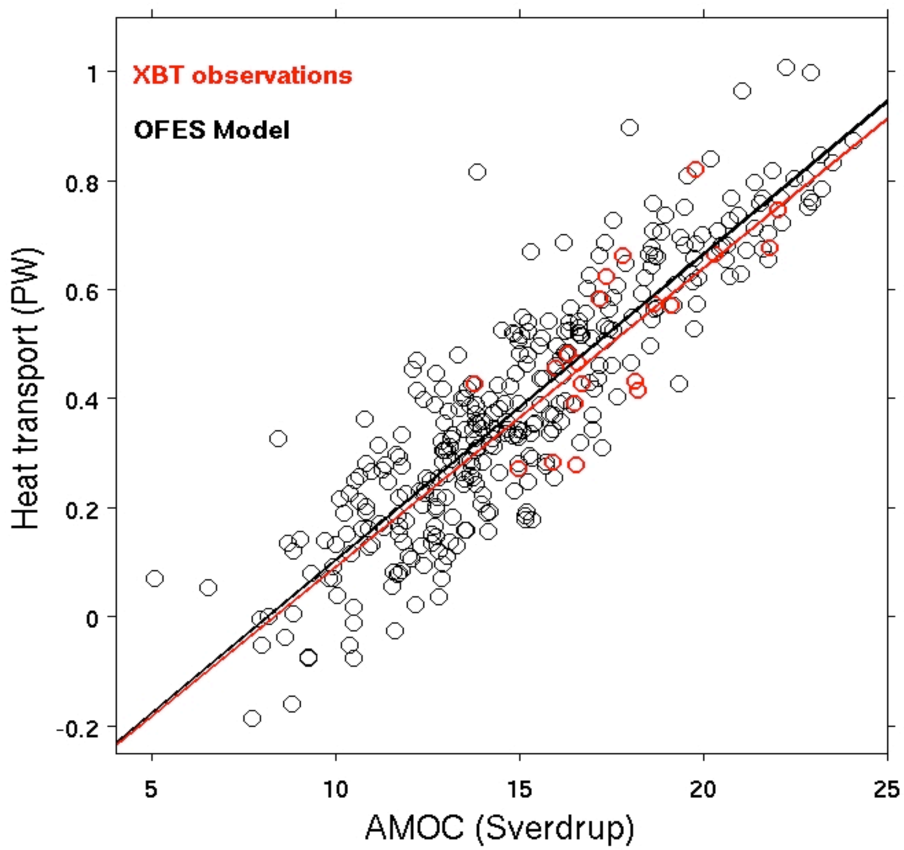
Dong et al 2009

AMOC Strength and Northward Heat Transport



Correspondence between AMOC strength and the northward heat transport across AX18.

A one Sverdrup increase in the AMOC would give a 0.06 PW increase in the northward heat transport.



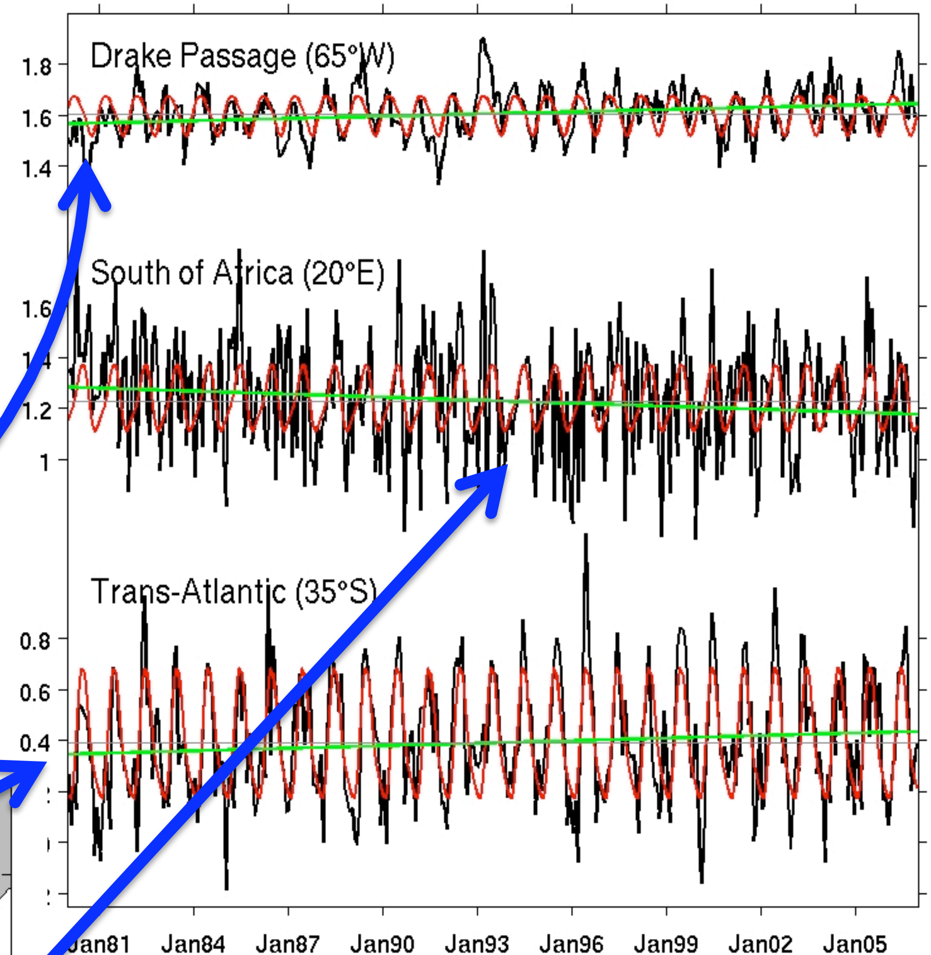
Dong et al 2009

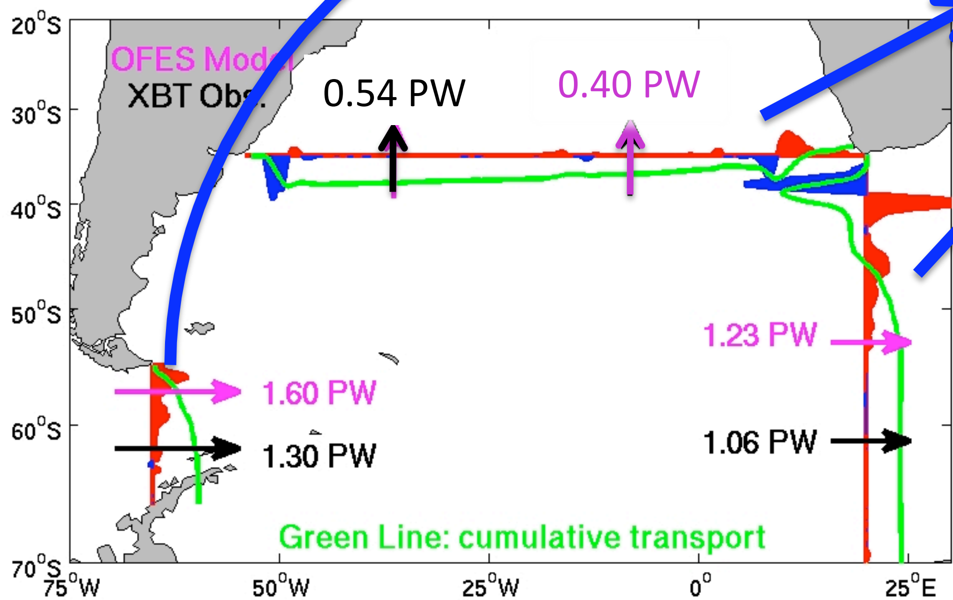
Heat Transport in the SA Box

+0.032 PW/decade

-0.036 PW/decade

+0.031 PW/decade





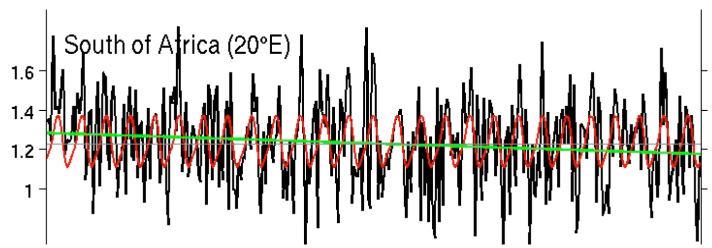
- •Surface Hest Fluxes decreasing
- •Heat Content tendency constant

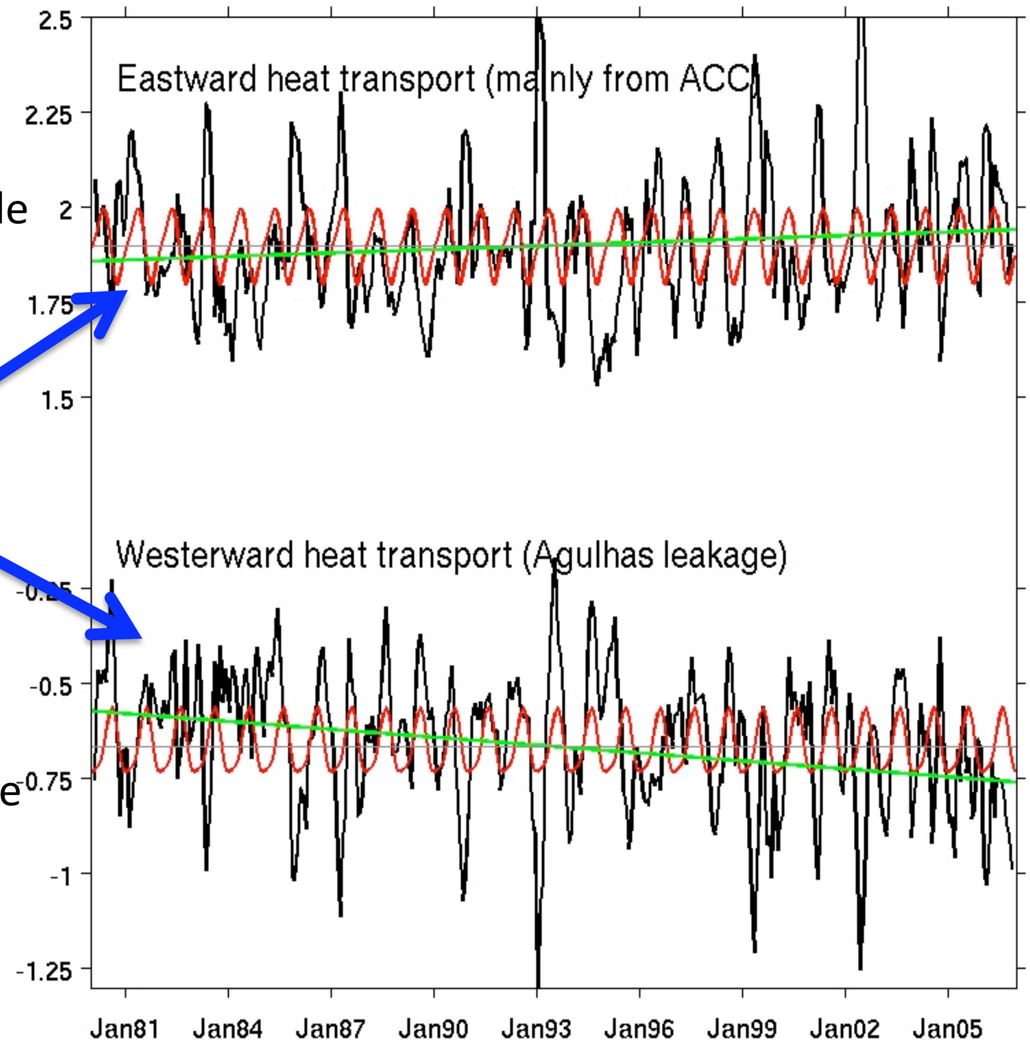
Annual and semi harmonic fit

Dong et al 2010

0.03 PW/decade

South of Africa Decomposed





-0.07 PW/decade

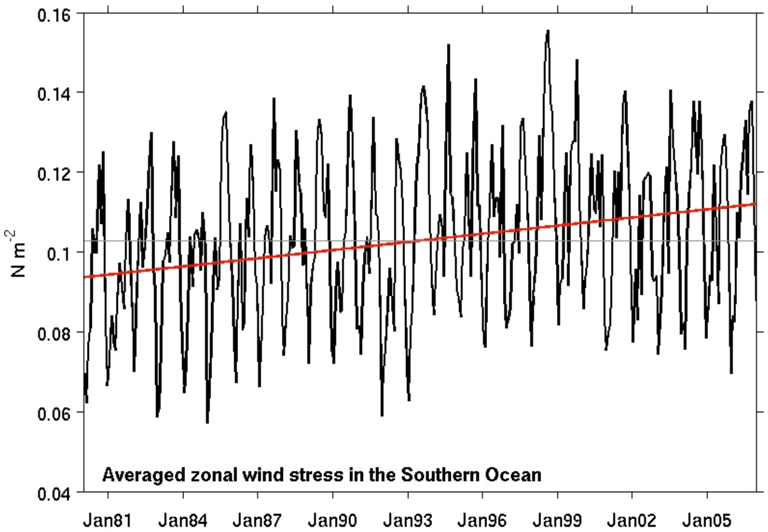
d HC/dt = Q – divergence of heat

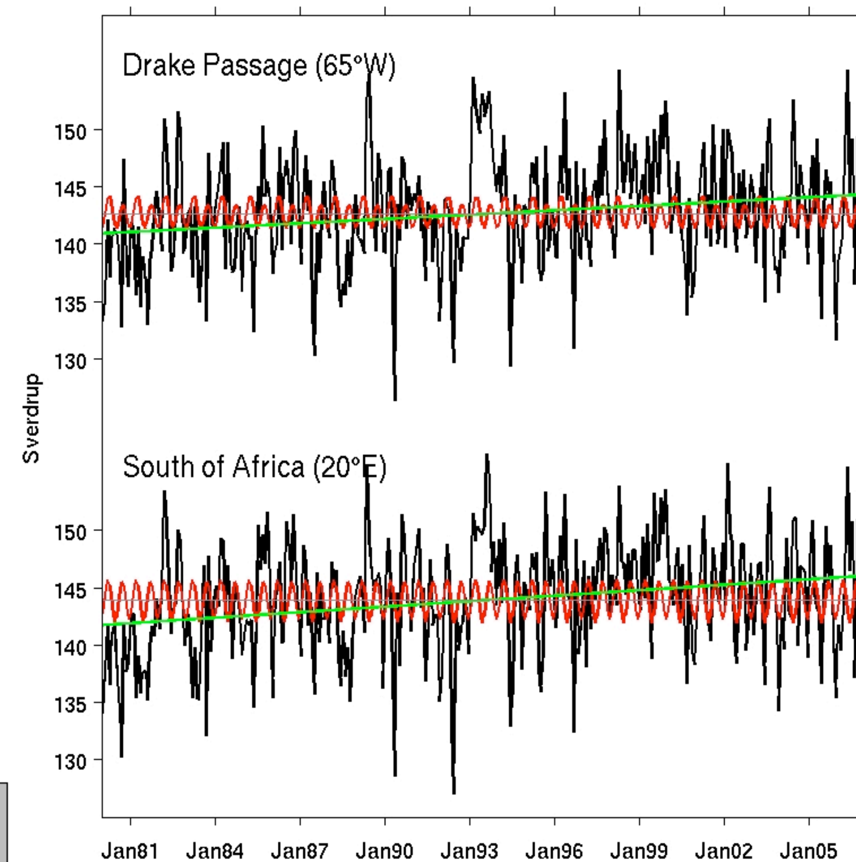
Half of this increasing trend supplies the increasing trend along 35S
Half goes to providing more heat goes to atmosphere (decreasing Q over time)

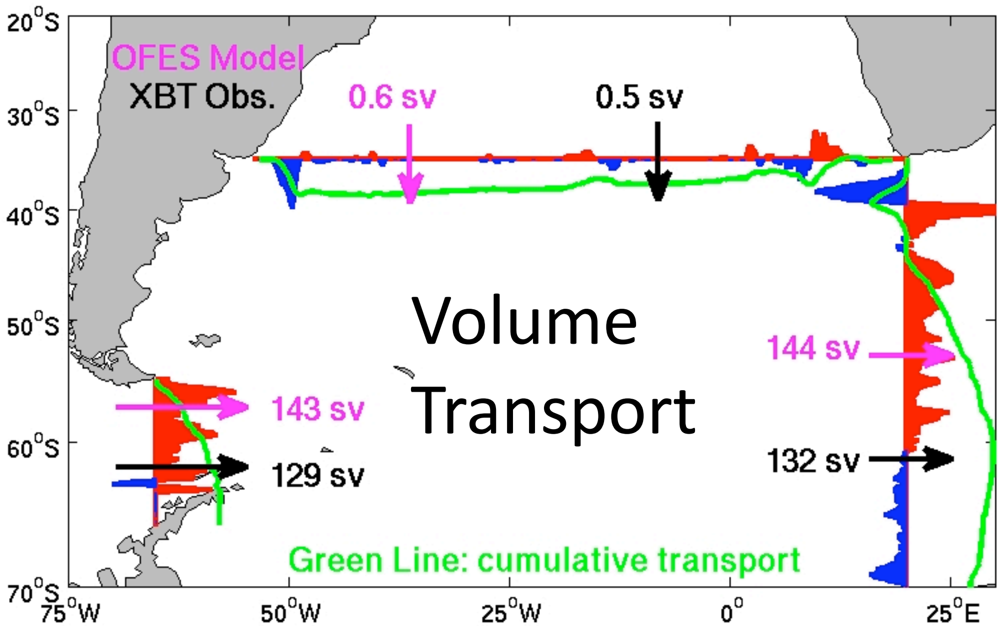
D HC/dt is constant (linear trend increasing heat content +/ 0

Dong et al 2010

Zonally average wind stress increasing

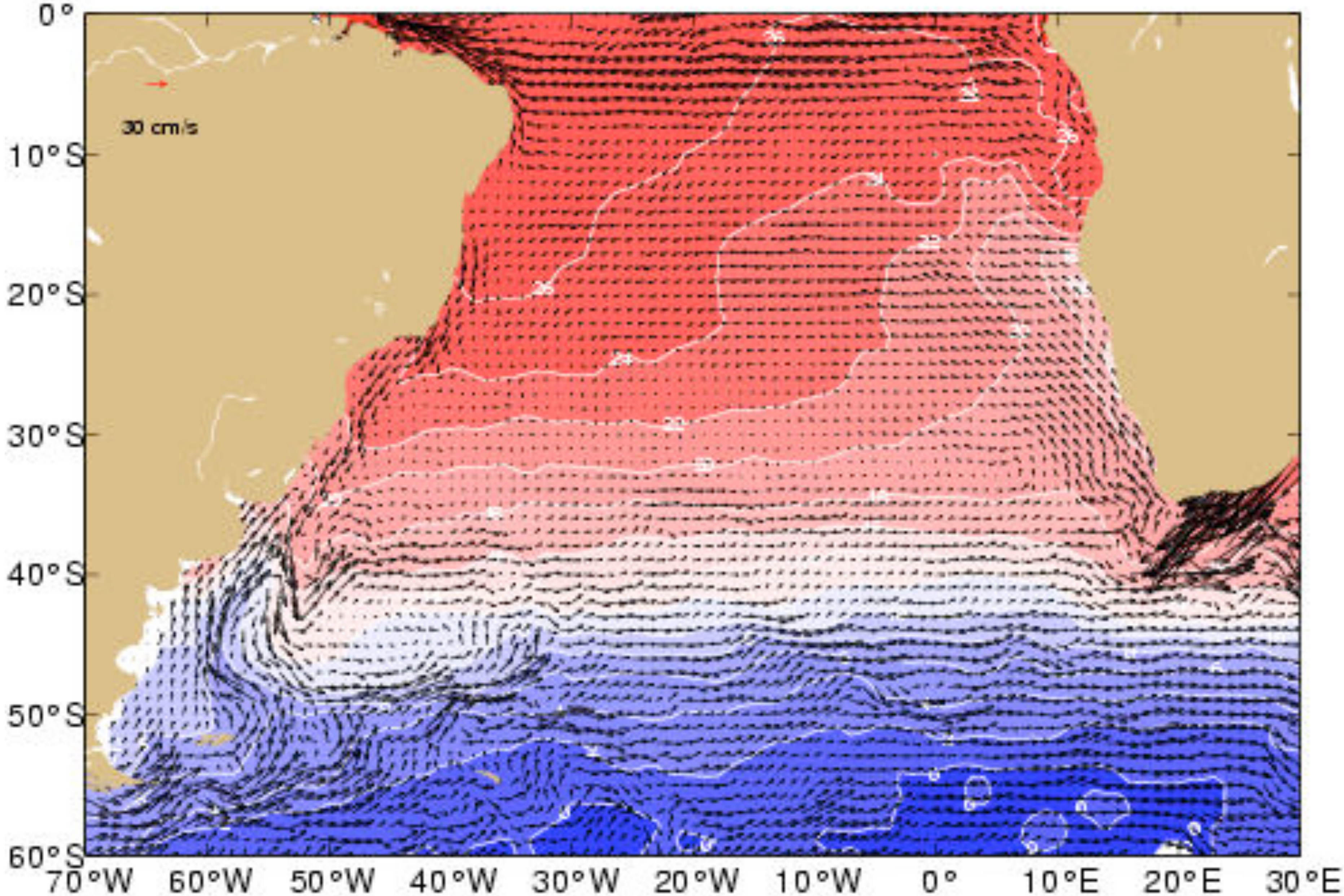






Southern Annual Mode strengthening and shifting southward

Dong et al 2010



Merged drifter and altimeter data confirm importance of boundary currents

South Atlantic MOC project (SAM)

Baringer and Garzoli (2007) demonstrated the critical need for DWBC observations to reduce uncertainties in meridional heat transport estimates at 35°S.

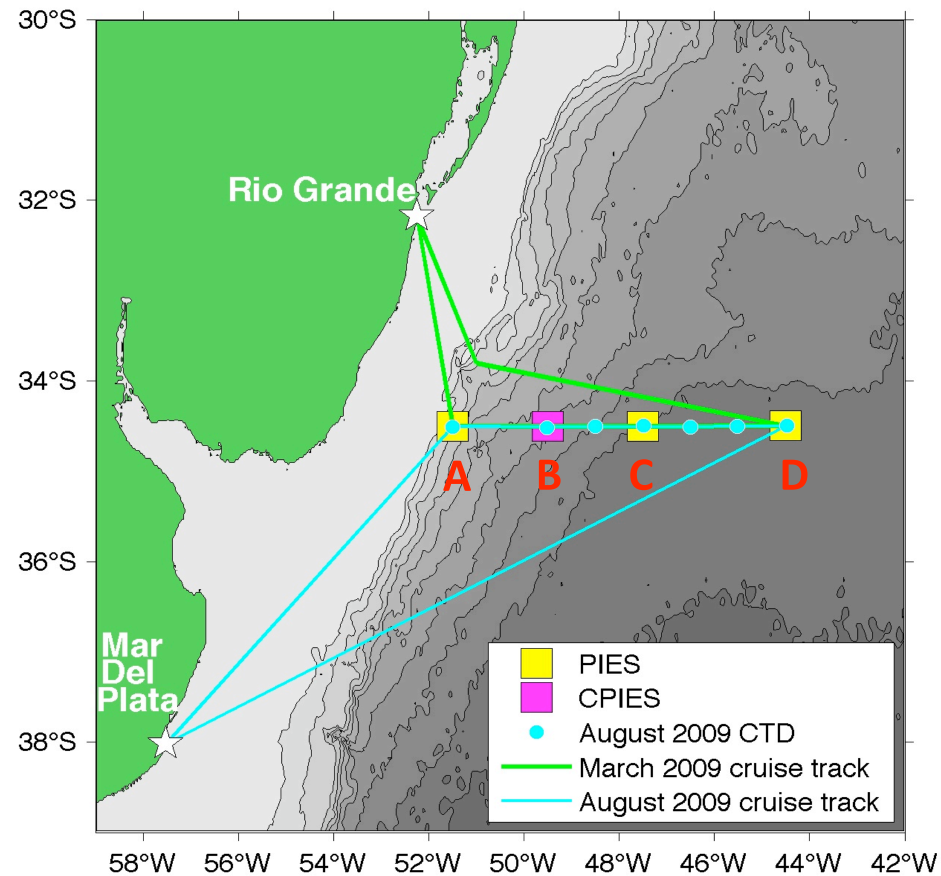
Western boundary observations are a collaboration between the USA, Argentina, and Brazil.

A parallel project is going on at the eastern boundary (Good Hope) as a collaboration between France and South Africa (see Speich et al presentation IT53D-06 on Friday afternoon).

The initial deployment of three pressure-equipped inverted echo sounders (PIES) and one current and pressure equipped inverted echo sounder (CPIES) took place in March 2009 from the Brazilian Navy research vessel Cruzeiro do Sul.

Hydrographic data was collected on both cruises.

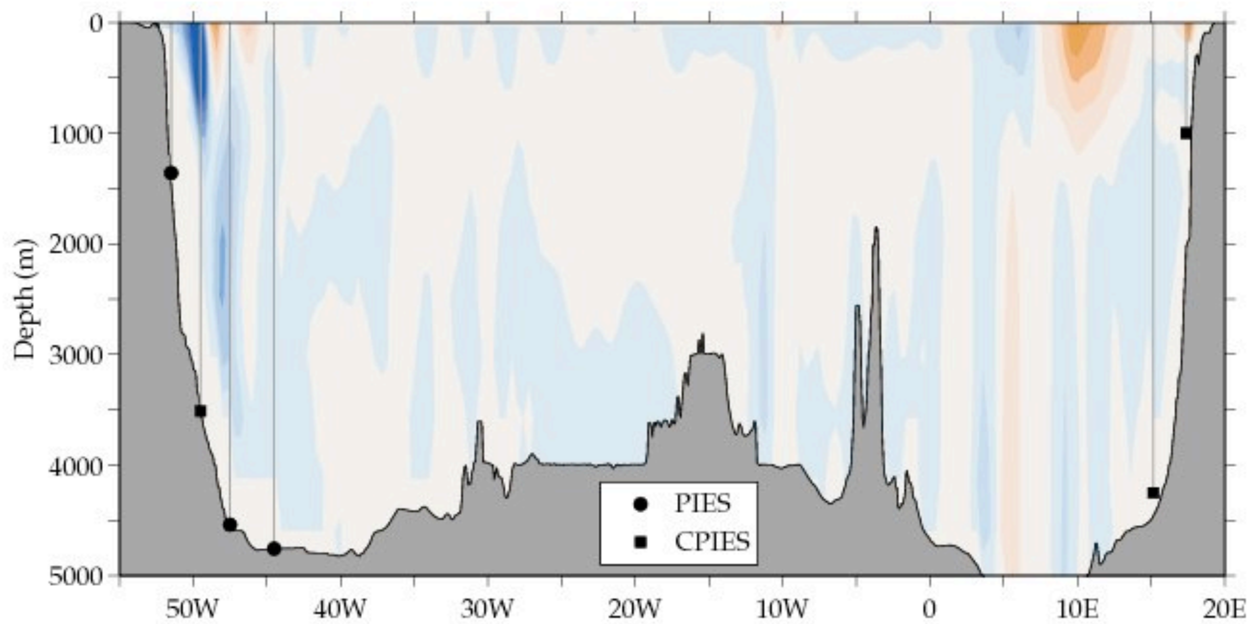
The first download of data from the PIES and CPIES was done in August 2009 via the Argentine research vessel Puerto Deseado



This presentation represents the preliminary analysis of the first five months

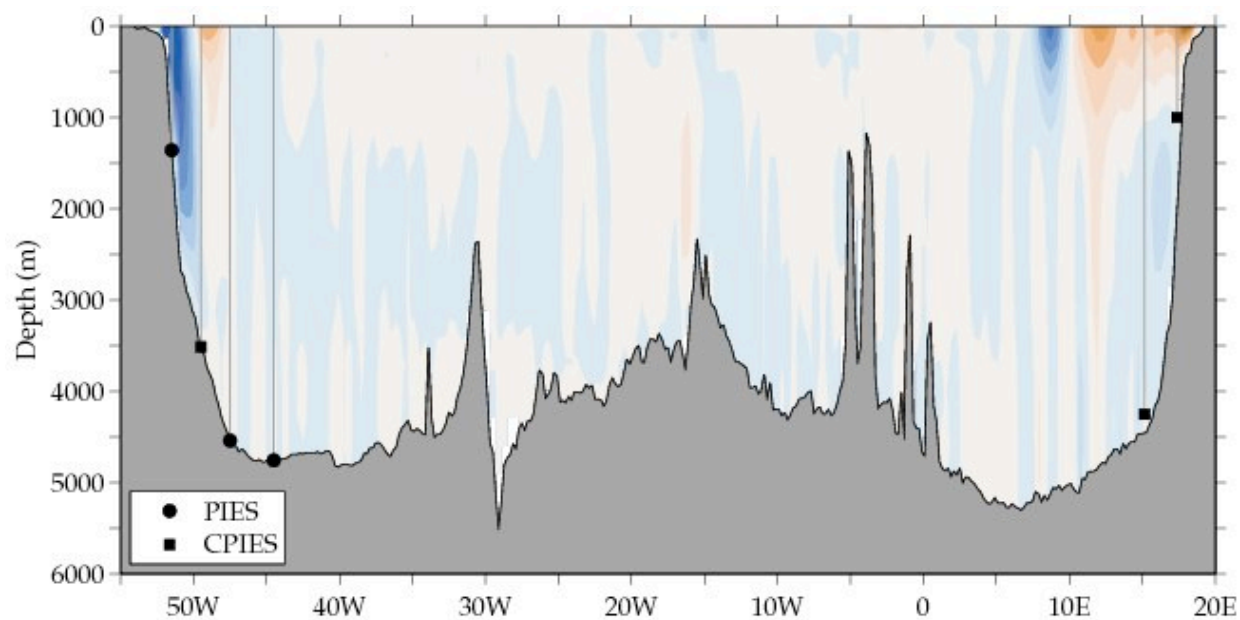
Parallel Ocean Circulation Model – POCM

•Primitive equation, hydrostatic, z-level model (Tokmakian and Challenor, 1999)
•Mercator B-grid with an average horizontal resolution of 1/4˚ and 20 vertical levels
•Forced with daily atmospheric fluxes from ECMWF reanalysis from 1979 to 1994, and with operational ECMWF data sets after 1994
•12 year average ('86-'97)



Ocean general circulation model For the Earth Simulator – OFES

•Modular Ocean Model (MOM3) run by JAMSTEC
•0.1˚ grid with 54 vertical levels
•Forced with monthly mean NCEP/NCAR reanalysis atmospheric fluxes
•12 year average ('86-'97)

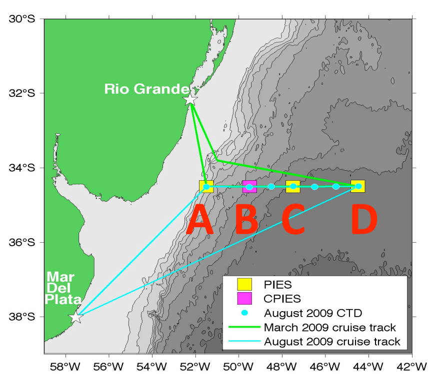


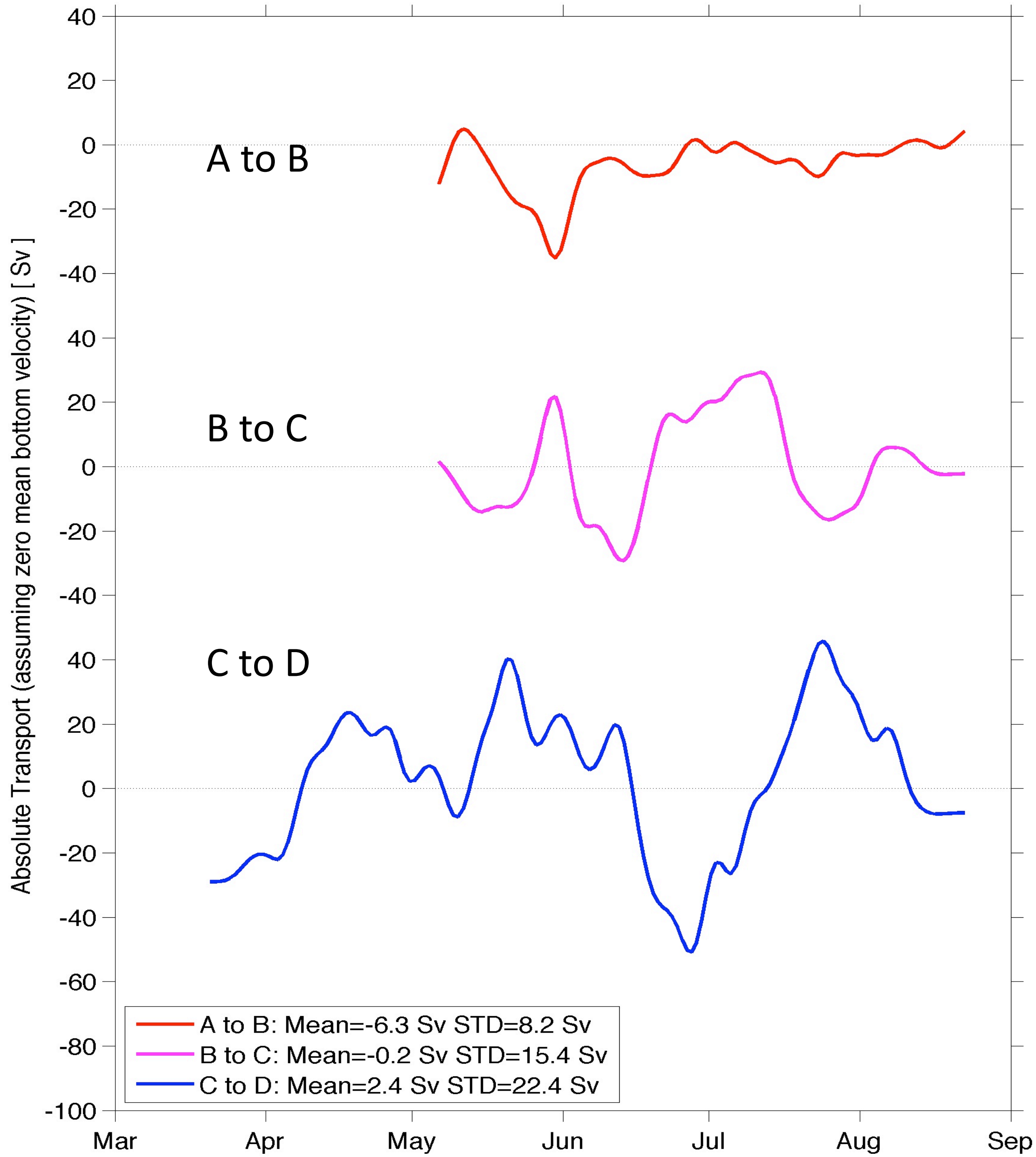
Figures courtesy Renellys Perez, UM/CIMAS, NOAA/AOML

Transport integrated in the deep layer (defined as below 800 dbar)

Previous studies have been ambiguous regarding how much of the Deep Western Boundary Current (DWBC) exists along the coast at this latitude versus having shifted offshore to the North.

Results from the first 3-5 months of data from the SAM array suggest that there is a mean southward flow along the coast, however the time variability is quite strong and it is too early to say for certain that a mean DWBC is observed





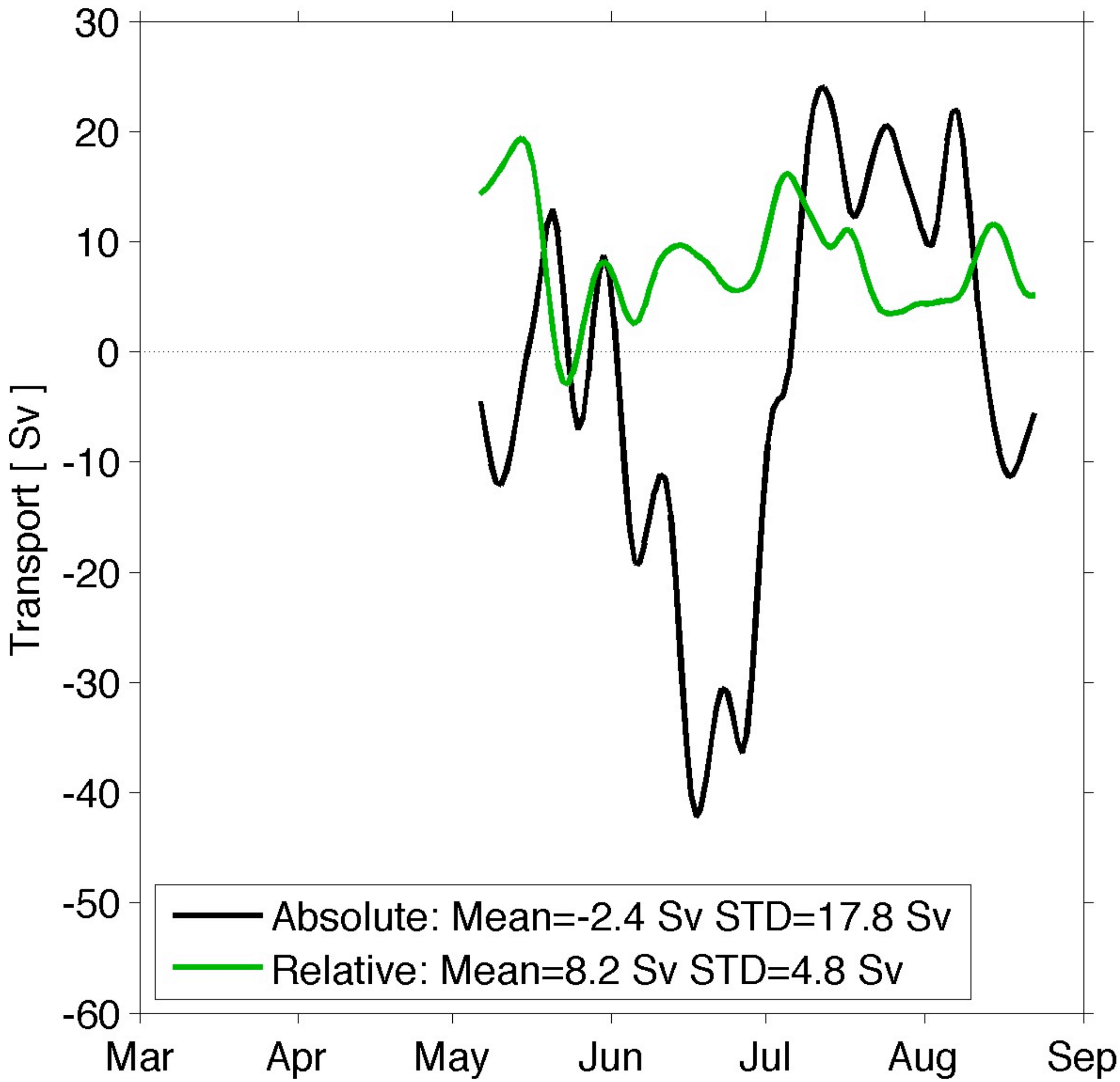
Transport integrated in the deep layer (defined as below 800 dbar)

•mean absolute southward flow across whole array just over -2 Sv,

•large variability with a minimum value just over -40 Sv.

•baroclinic transport relative to 800 dbar has a factor of 3 smaller variability than the absolute transport.

The disparity between variances confirms the model-results presented in Baringer and Garzoli (2007) and Garzoli and Baringer (2007) illustrating the significant barotropic flows near the western boundary at this latitude



Conclusions

1. The strength of the AMOC is significantly correlated with the northward heat transport across AX18 (~35S).
2. Ekman transport contributes only 9% of the on average, however, it accounts for 22% of the total northward heat transport.
3. The OFES model suggests an increase in the northward heat transport across 35°S from 1980 to 2006.
4. The increasing trend in the northward heat transport is likely due to the increase in Agulhas leakage into the South Atlantic.
5. One possible explanation for the increase in the transport of the Antarctic Circumpolar Current is the increase in wind stress.
6. The larger variance of the absolute transports compared to the transports relative to an assumed level of no motion confirms the importance of barotropic variations on the western boundary when calculating meridional heat fluxes basin-wide.
7. Preliminary analysis of the PIES/CPIES data from March-August 2009 suggests that there is a non-trivial mean southward flow of around 6 Sv at 34.5°S potentially associated with the Deep Western Boundary Current.

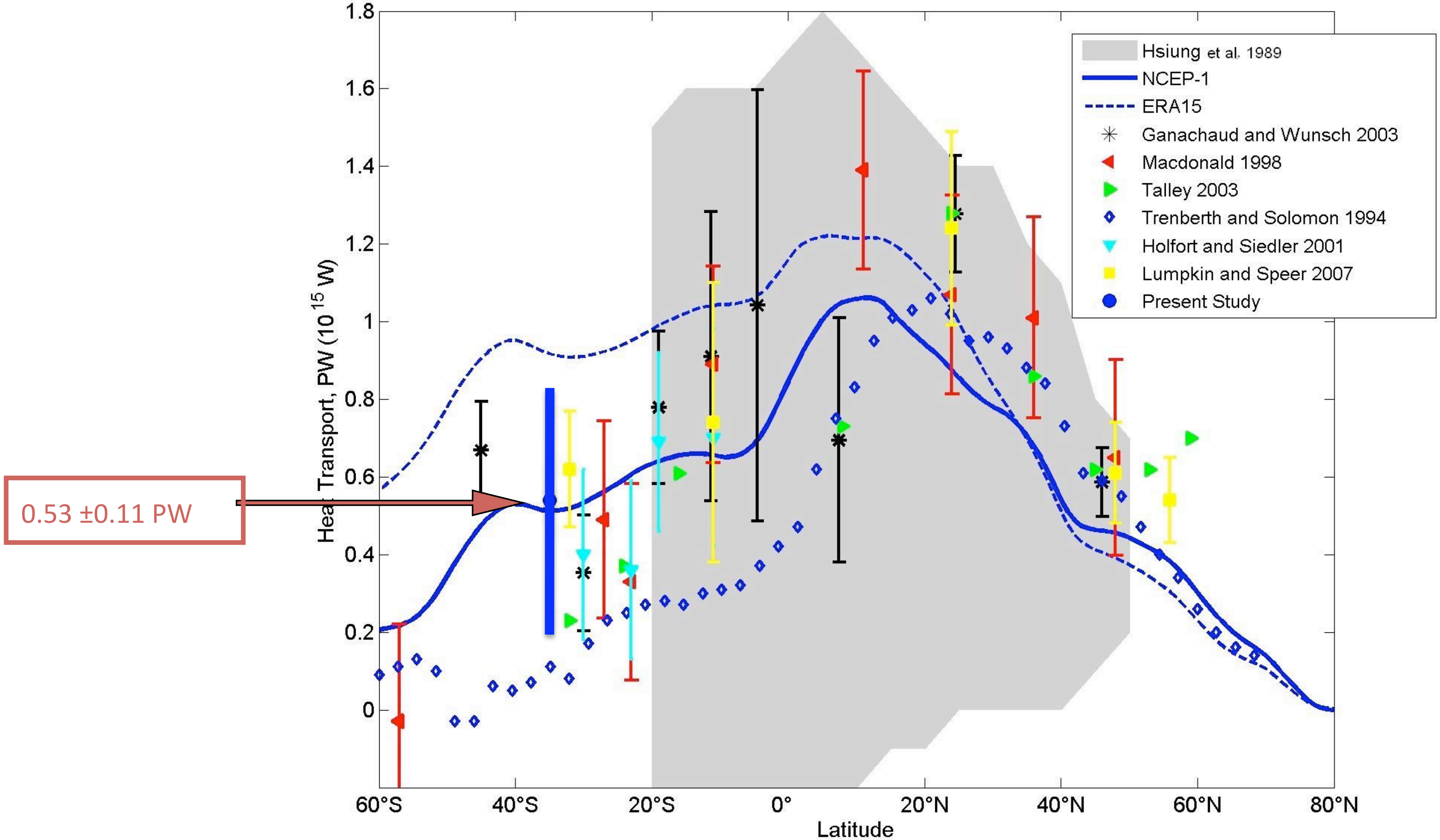
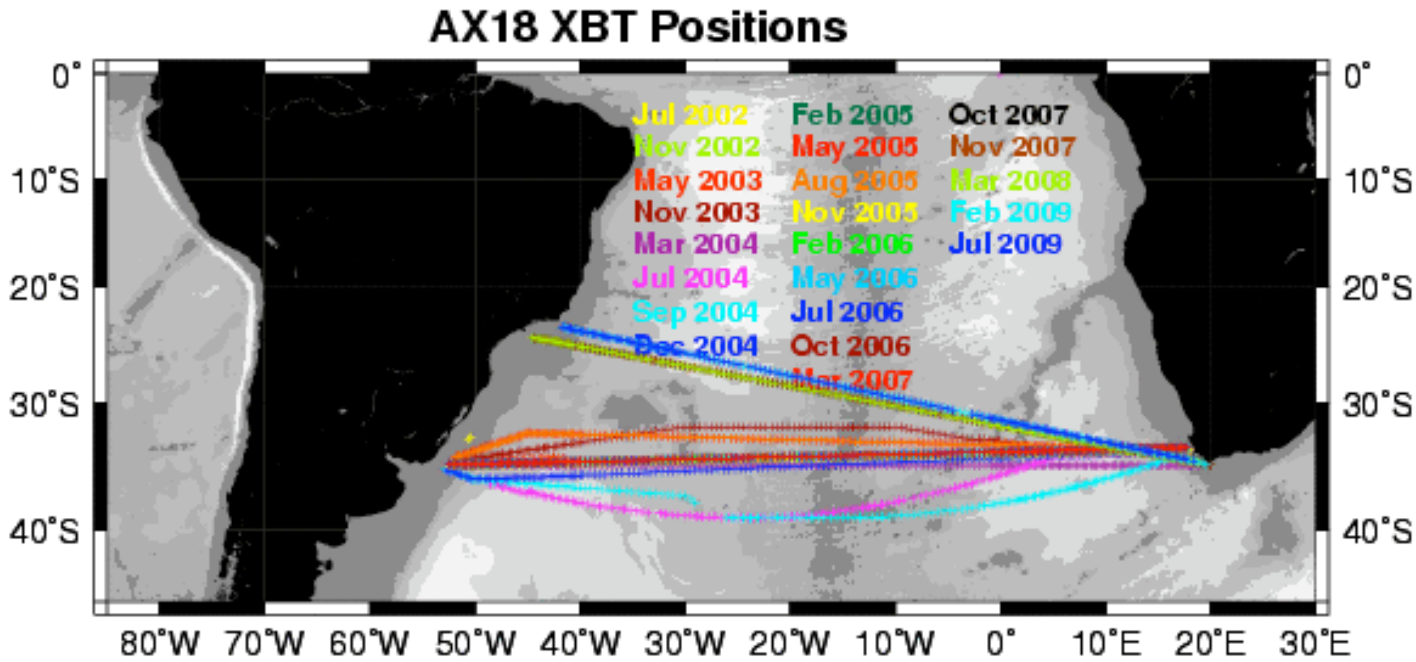
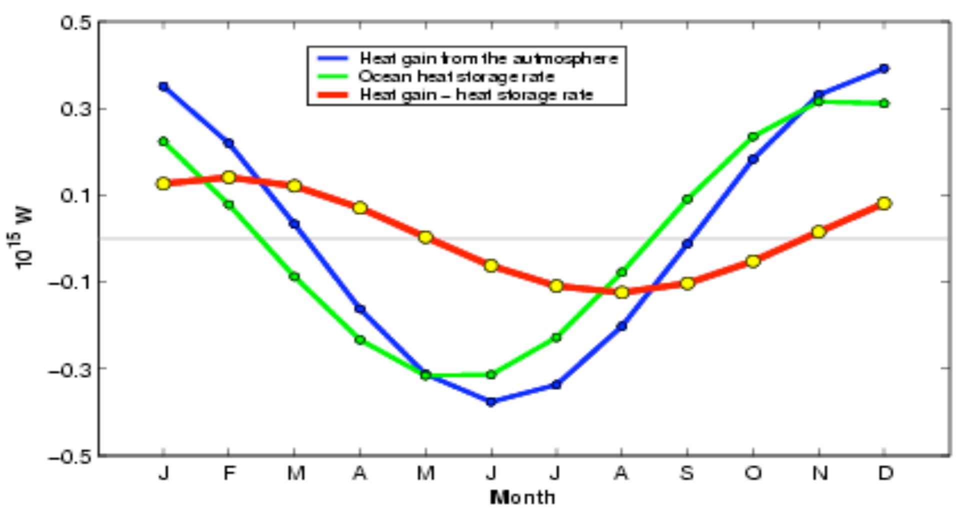
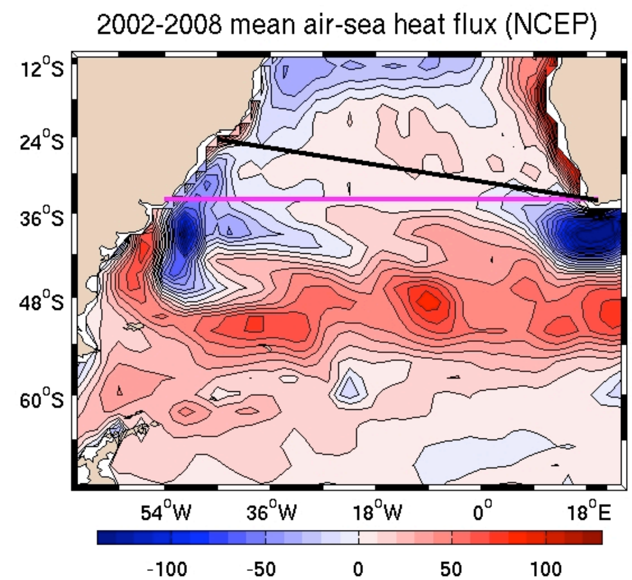

0.53 ±0.11 PW
Heat Transport, PW (10^{15} W)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
60°S
40°S
20°S
0°
20°N
40°N
60°N
80°N
Latitude
Hsiung et al. 1989
NCEP-1
ERA15
Ganachaud and Wunsch 2003
Macdonald 1998
Talley 2003
Trenberth and Solomon 1994
Holfort and Siedler 2001
Lumpkin and Speer 2007
Present Study

Figure 13.

Heat Transport across 35°S

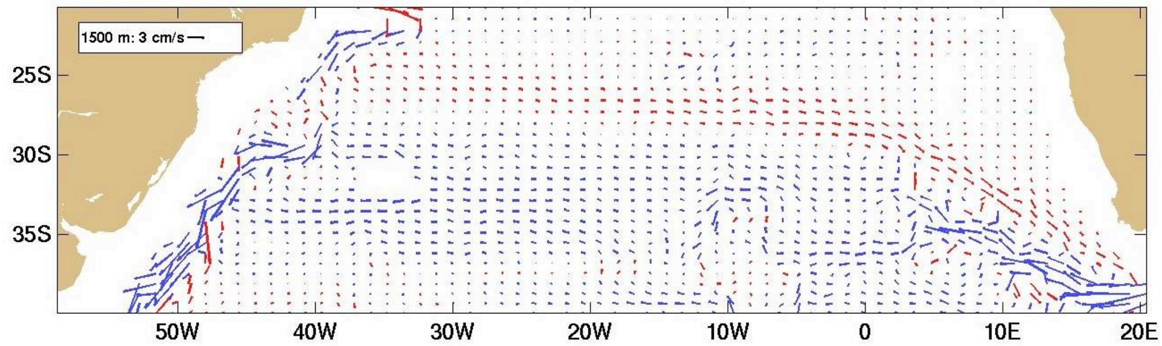




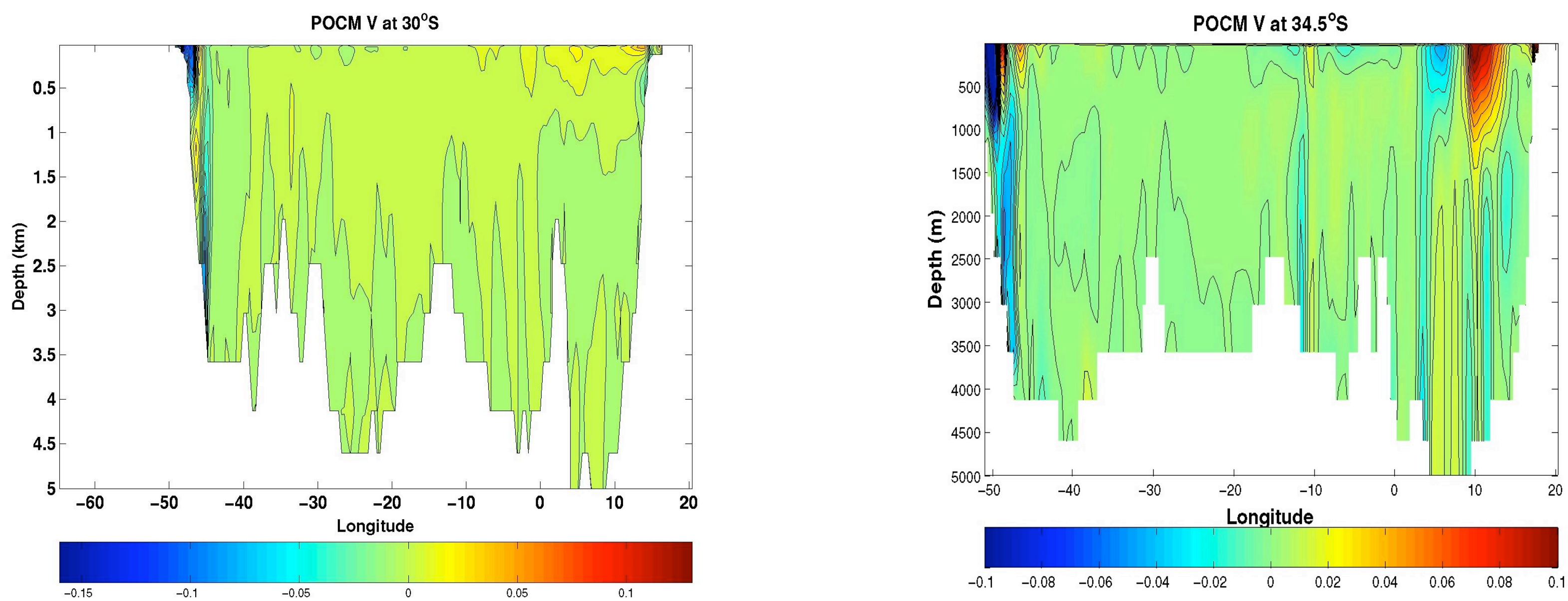


Observing the DWBC

One of the largest uncertainties in the measured heat transport is the lack of direct measurements of the barotropic component of the flow, which is largest to the west of 47°W. This is particularly important because at the western boundary the Malvinas Current and the Deep Western Boundary Current (DWBC) both flow in the same direction, creating a strong barotropic flow whose magnitude and variability are poorly known.



Mean model velocities at 1500 m depth from POCM model (Tokmakian and Challenor, 1999).



Model sections of the meridional velocity showing the DWBC at 30°S (left) and 34.5°S (right). Negative velocities indicate southward flow.