South Atlantic Meridional Fluxes

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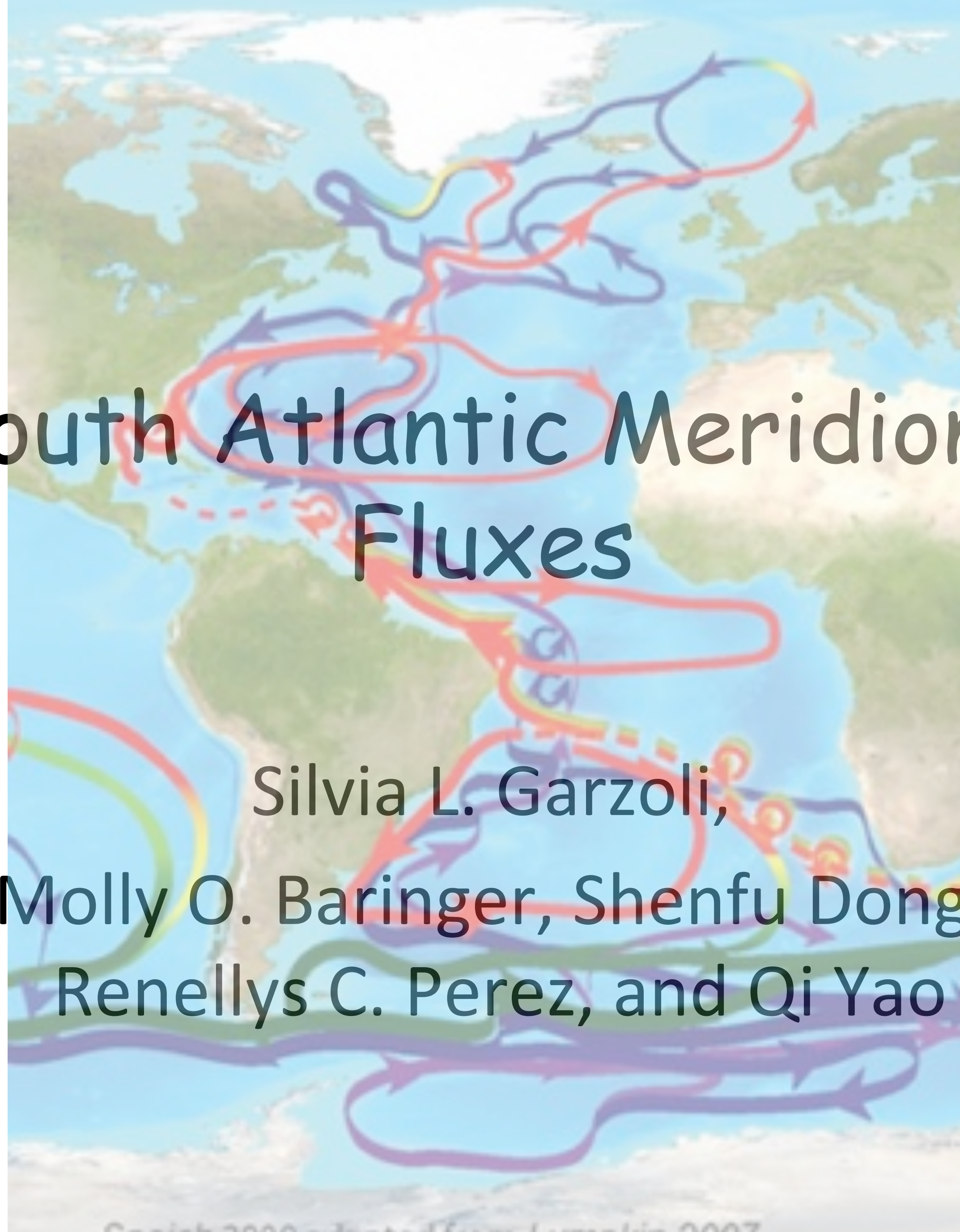
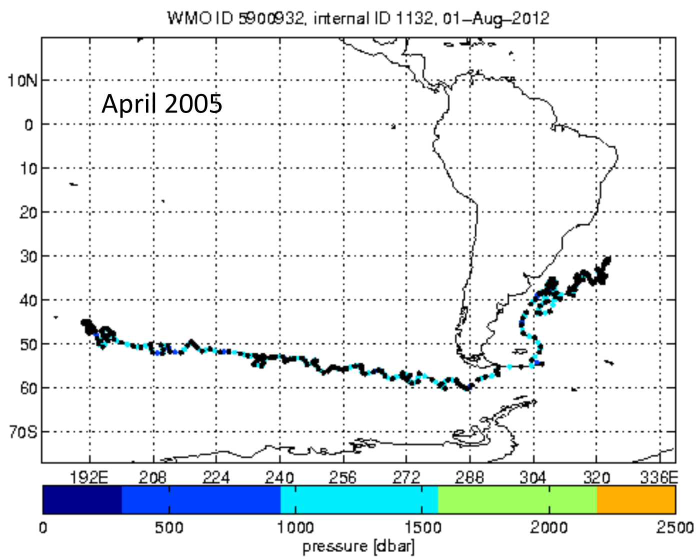


Speich 2009 adapted from Lumpkin 2007

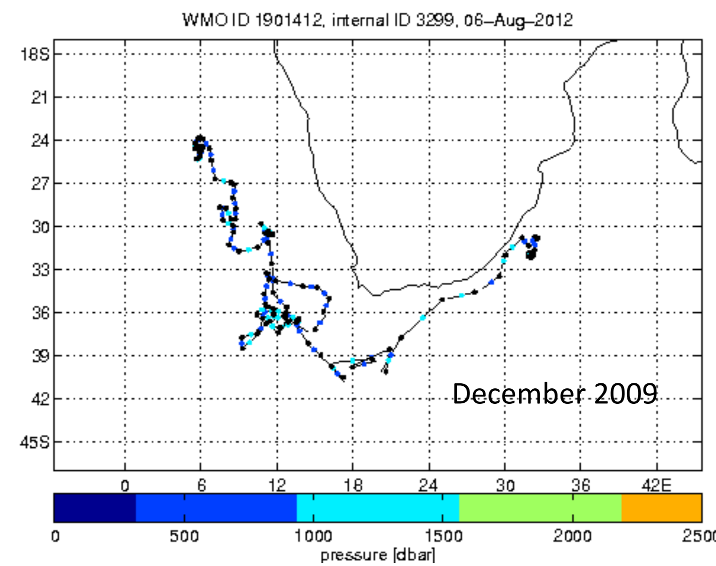
Motivation

✓ The South Atlantic is the only basin extending to high latitudes in which the heat transport is equatorward.

As such, it plays a unique role in the global energy balance, transporting heat from the poles to the equator as upper layer water spreads northward to compensate for the southward export of colder North Atlantic Deep Water.



Argo floats trajectories



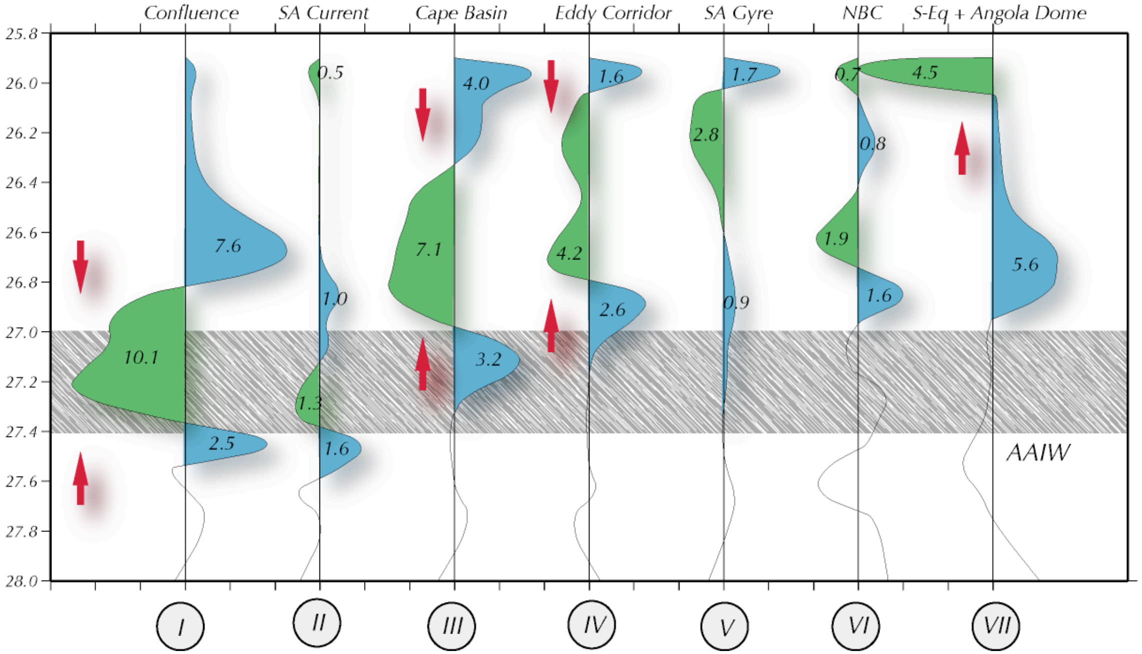
A portion of the South Atlantic upper waters is produced locally, but most of the South Atlantic upper waters are thought to originate in the Pacific and Indian oceans. At issue are not only the relative importance of these sources but also the mechanisms of entrainment.

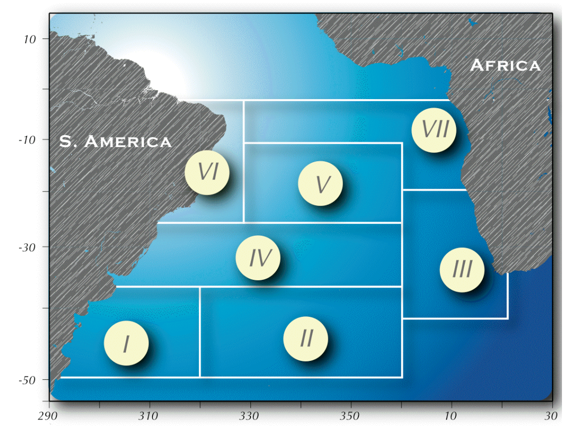
The ability to understand and quantify this northward flow is crucial to properly model and forecast weather and climate.

Motivation

South Atlantic: melting pot for water masses formed elsewhere.

✓ **The South Atlantic is not just a passive conduit for NADW and other deep water-masses formed in the North Atlantic and Southern Ocean, but instead actively participates in their transformation as they are exchanged with the other ocean basins**



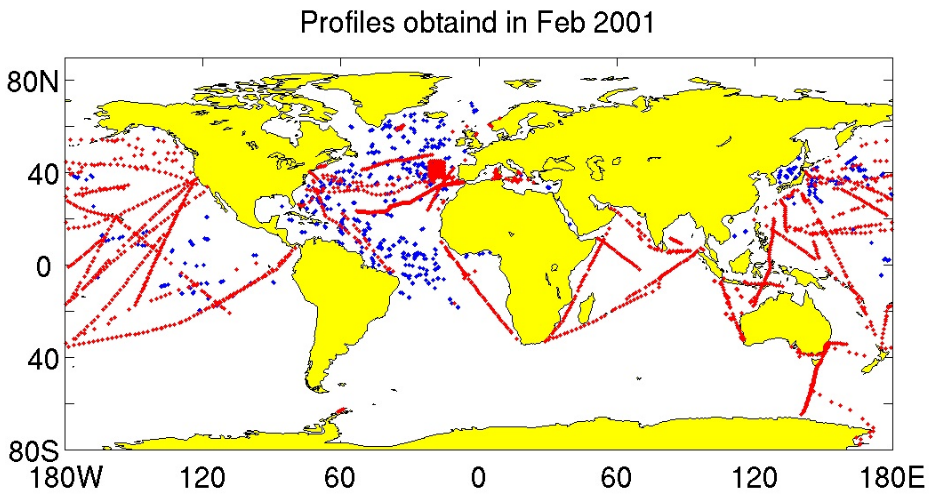


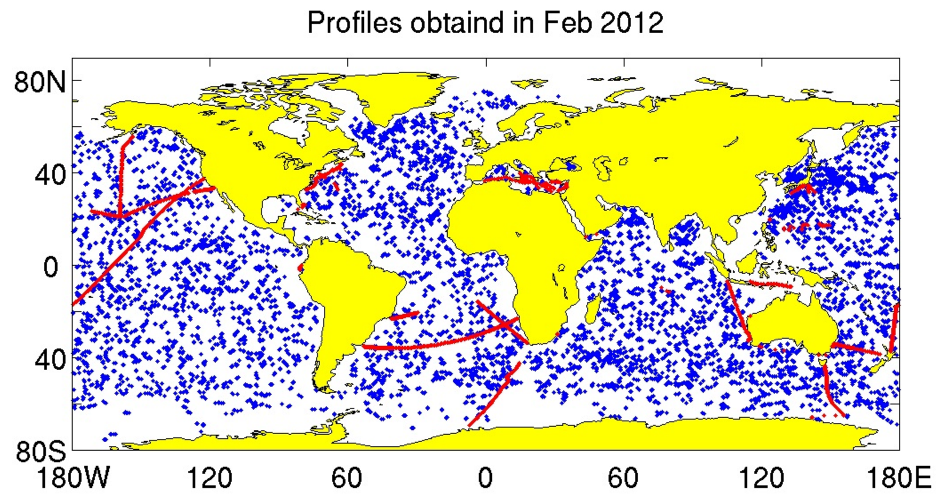
There is an active water mass transformation within the South Atlantic basin, and that a large portion of this transformation occurs in the highly energetic boundary regions.

(Garzoli & Matano, 2011)

Motivation

✓ **Disagreement between MHT estimates.**





XBT: 2,133 Argo: 822

XBT: 1,537 Argo: 10,447

Increase in data coverage in the South Atlantic (previously highly under sampled); improve the estimates of mean MHT and the AMOC in the region

✓ **Disagreements between models and observations:**

- Annual cycles of the total MHT
- The direction of the salt flux within the Atlantic sector

Objective

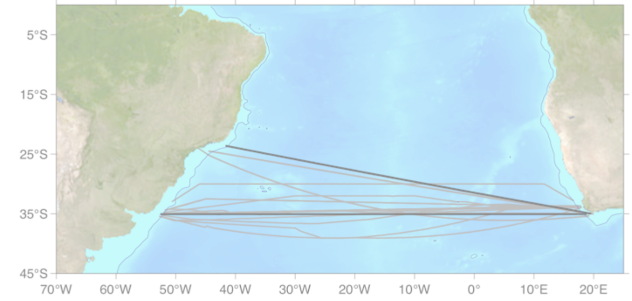
Further analyze the properties of meridional heat transport (MHT) and salt fluxes associated to the meridional overturning circulation (MOC) in the South Atlantic.

- Meridional Heat Transport
- Depth and strength of the AMOC
- Salt advection (Mov)
- Boundary currents transports and MOC

The Data

- Extension of previous analyzed XBT data along nominally 35°S (27 sections from September 2001 to November 2011)
- Improved climatology from CTD and Argo profile data collected in the region.

Baringer and Garzoli, 2007
Garzoli and Baringer, 2007
Dong et al., 2009



Meridional Heat Transport

Time series of the MHT from the data collected during 27 cruises nominally at 35°S. The mean estimate of the MHT is **0.54 PW** with a standard deviation of **0.14 PW**.

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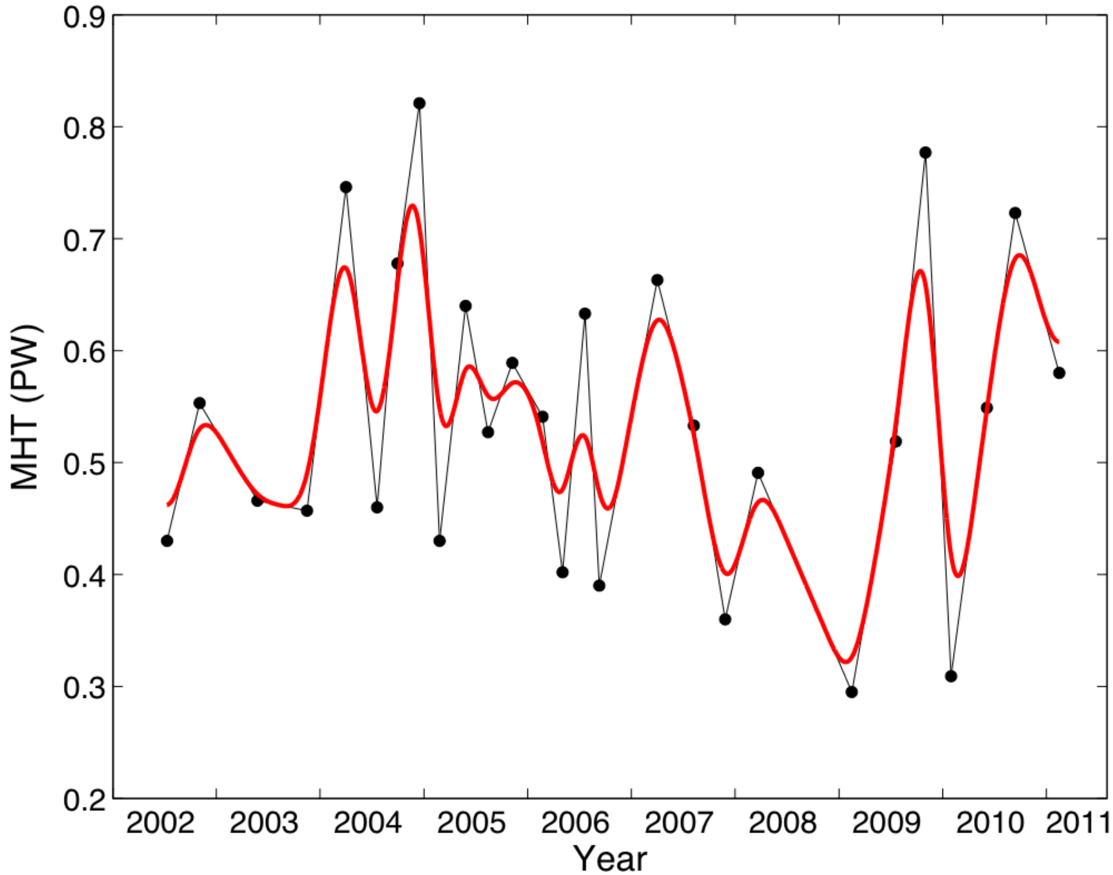
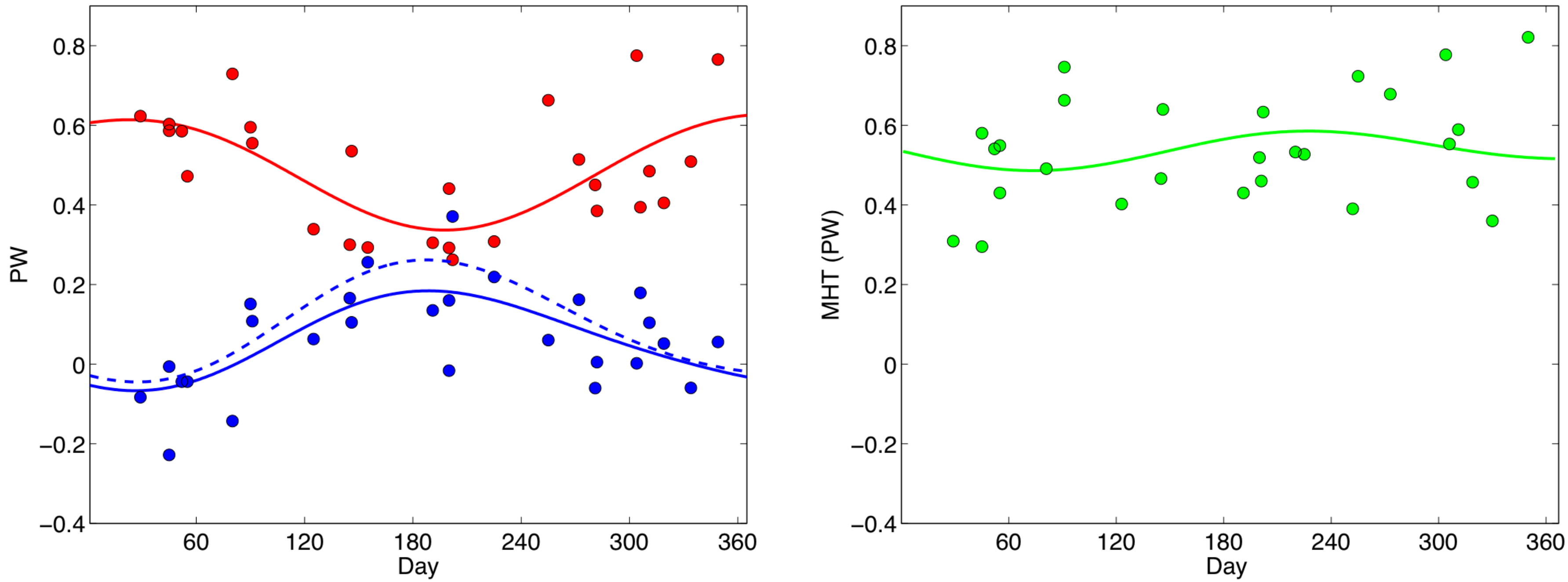


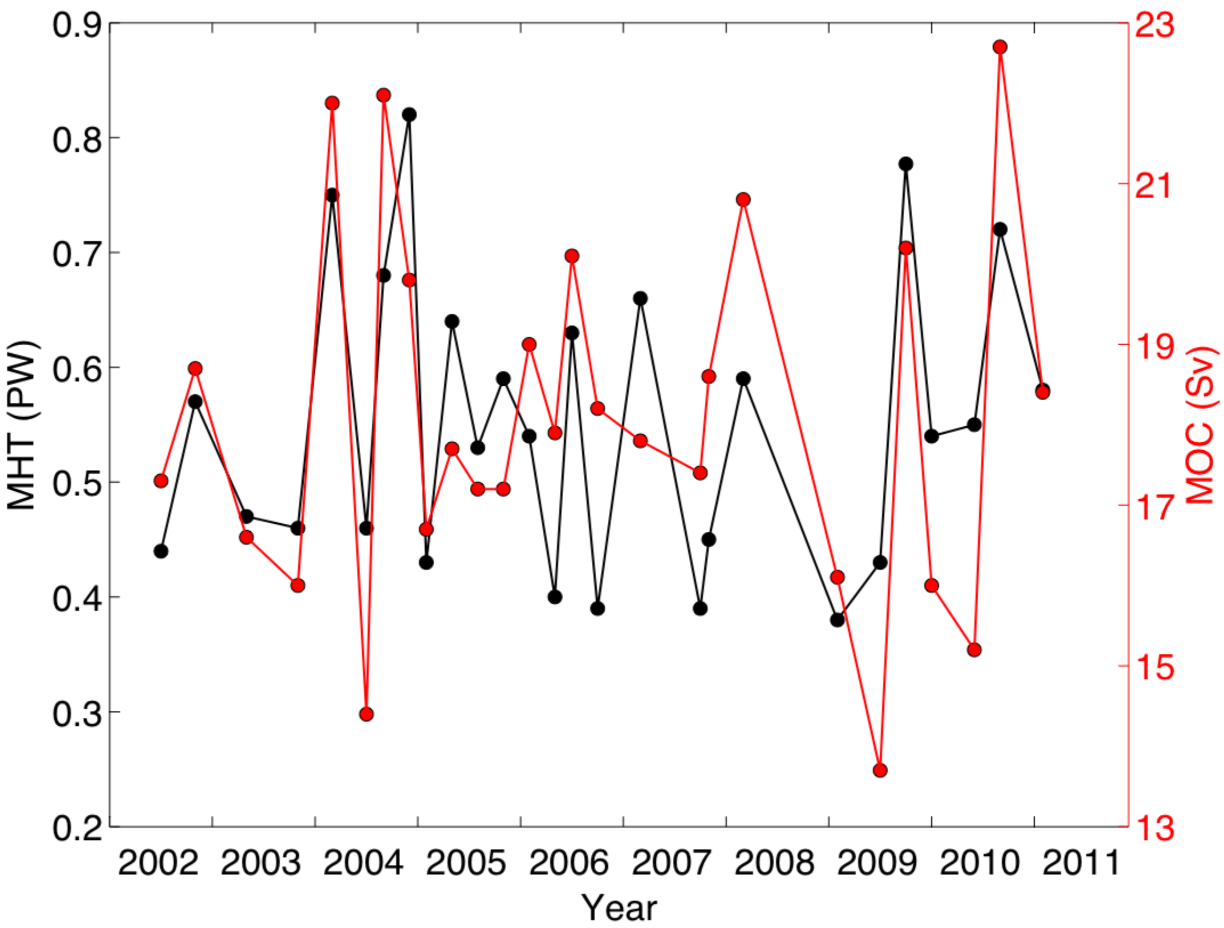
The observed variability is large, with values ranging from 0.30 PW to 0.82 PW, and despite the relatively small sample size no significant trend (-0.01± 0.2 per decade) is estimated from the 27 XBT sections

MHT Annual Cycle



Analysis of the variability of the different components of the MHT, the Ekman and geostrophic components, indicate that the annual cycle of the Ekman component varies with a similar magnitude but in the opposite direction to that of the geostrophic component. As a result, there is no significant annual cycle in the total MHT consistent with the results from the first 17 AX18 transects (Dong et al., 2009).

MOC



- MOC varies from 14.4 to 22.7 Sv
- Mean:18.1 Sv
- Stand. dev.: 2.3 Sv.

Correlation MHT MOC : 0.73

1 Sv in the MOC will lead to an increase of 0.04 ± 0.02 PW in the MHT

Depth of the observed maximum cumulative transports range between 1000 – 1400 m depth with an average of 1250 m, a value that is slightly deeper than the 1100 m found in the North Atlantic

M_{ov} (salt advection)

The MOC-salt feedbacks can be assessed from the sign of the latitudinal divergence of a parameter, M_{ov}, that at 35°S determines the basin scale MOC salt feedback. (Drijfhout, 2010 ; Drijfhout et al., 2011)

The Mov is defined as Drijfhout *et al.* (2011).

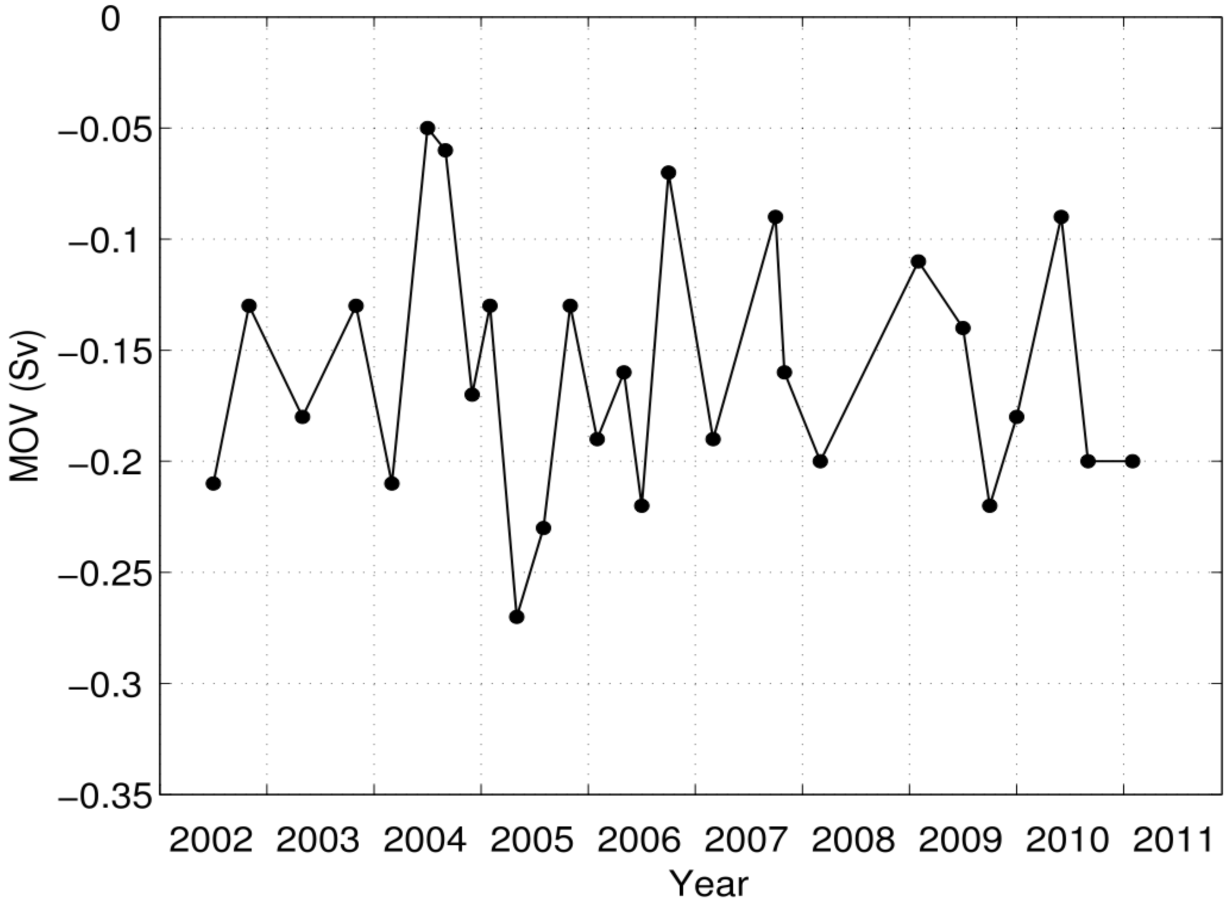
$$Mov = -\frac{1}{S_0}\int_{-\eta}^{0} V^* \langle S \rangle \mathrm{dz}$$

where S_0 is the mean salinity of the section, V* is the overturning component of the zonally integrated velocity across the section (by definition the vertical integral of V* is zero), <S> is the zonally averaged salinity (from the surface h to the bottom) that varies with depth.

When M_{ov} is positive, the MOC exports salt;

When the M_{ov} is negative the MOC exports fresh water.

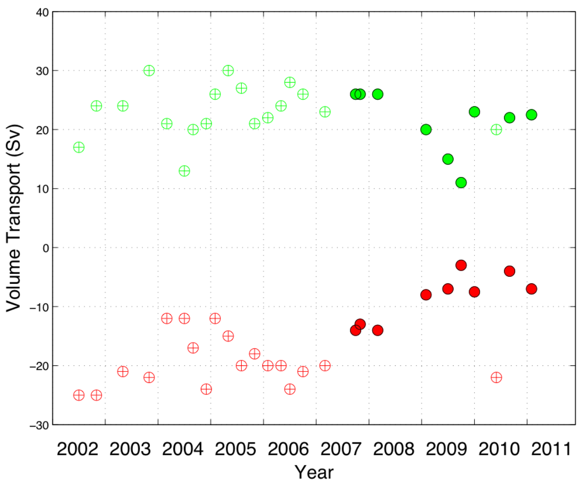
XBT sections: Mov varied from -0.28 to -0.05 Sv, Mean value of -0.16 Sv.

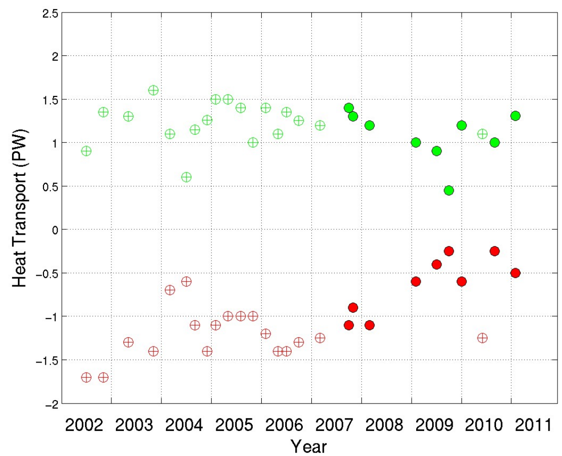


All of these Mov estimates from the observations, contrary to the models, feature a positive salt advection feedback (Mov< 0) suggesting that freshwater perturbations will be amplified and that the MOC is bistable, it might collapse due to a large enough freshwater perturbation.

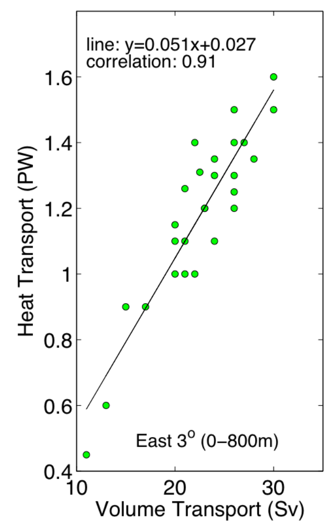
A10 WOCE line along 30°S: -0.15 Sv (1993) and -0.14 Sv (2003)
Argo climatological section 30 to 35°S: -0.11 Sv
WOCE CTD lines along 24°S: -0.09 Sv (1983) and -0.34 Sv (2009) (Bryden *et al.*, 2011)

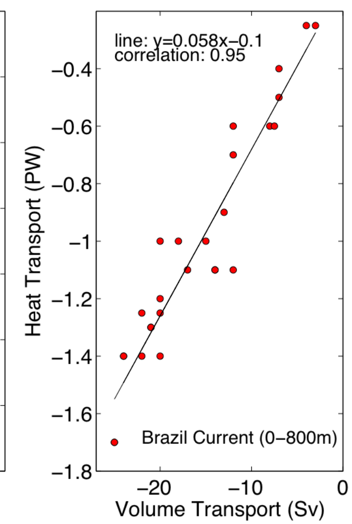
Volume transport at the boundaries





- Brazil Current increases its volume as it flows southward.
  mean value at 24°S = -8.6 ± 4.1 Sv
  at at 35°S = -19.4 ± 4.4 Sv.
- East of 3°S (northward flowing Benguela Current and Agulhas rings) the mean transport is = 22.5 Sv ± 4.7 Sv.





- Correlation between the volume transport and heat transport for the boundary currents (defined here as the integral from the surface to 800m).
- ΔVT of 1 Sv → ΔHT of 0.06 ± 0.01 PW for the Brazil Current and 0.05 ± 0.01 PW for the Benguela Current.
- No significant correlation between transports of the Brazil Current and the strength of the MOC (r = 0.09), suggesting that the Brazil Current is compensated by transport in other regions.

Summary of Results

- **Consistent estimates of MHT and MOC in the South Atlantic in the latitude band 30°S to 35°S.**

  MHT = 0.54 PW ± 0.14 PW.

  MOC = 18.1 Sv ± 2.3 Sv.

  Depth max transport =1250 m

- **Mov = -0.16 Sv** (salt is transmitted to the north)

Summary of Results

- **No significant correlation between transports of the Brazil Current and the strength of the MOC (r = 0.09), suggesting that the Brazil Current is compensated by transport in other regions, importance of the interior and the role of the Agulhas leakage.**
- **Important differences between observations and models,**
  - ✓ **absence of a seasonal cycle in the observed MHT* and the MOC,**
  - ✓ **the difference in the sign of the Mov.**

** Presentation this afternoon, "Causes for model-data differences in seasonal variations of the South Atlantic Meridional Overturning Circulation" by Shenfu Dong*

Further Results

- **Variability of the MHT in the South Atlantic since 1993**
  by Goni et al.

- **Time-Series of Freshwater Flux at 26N in the Atlantic Ocean**
  by Elaine McDonagh

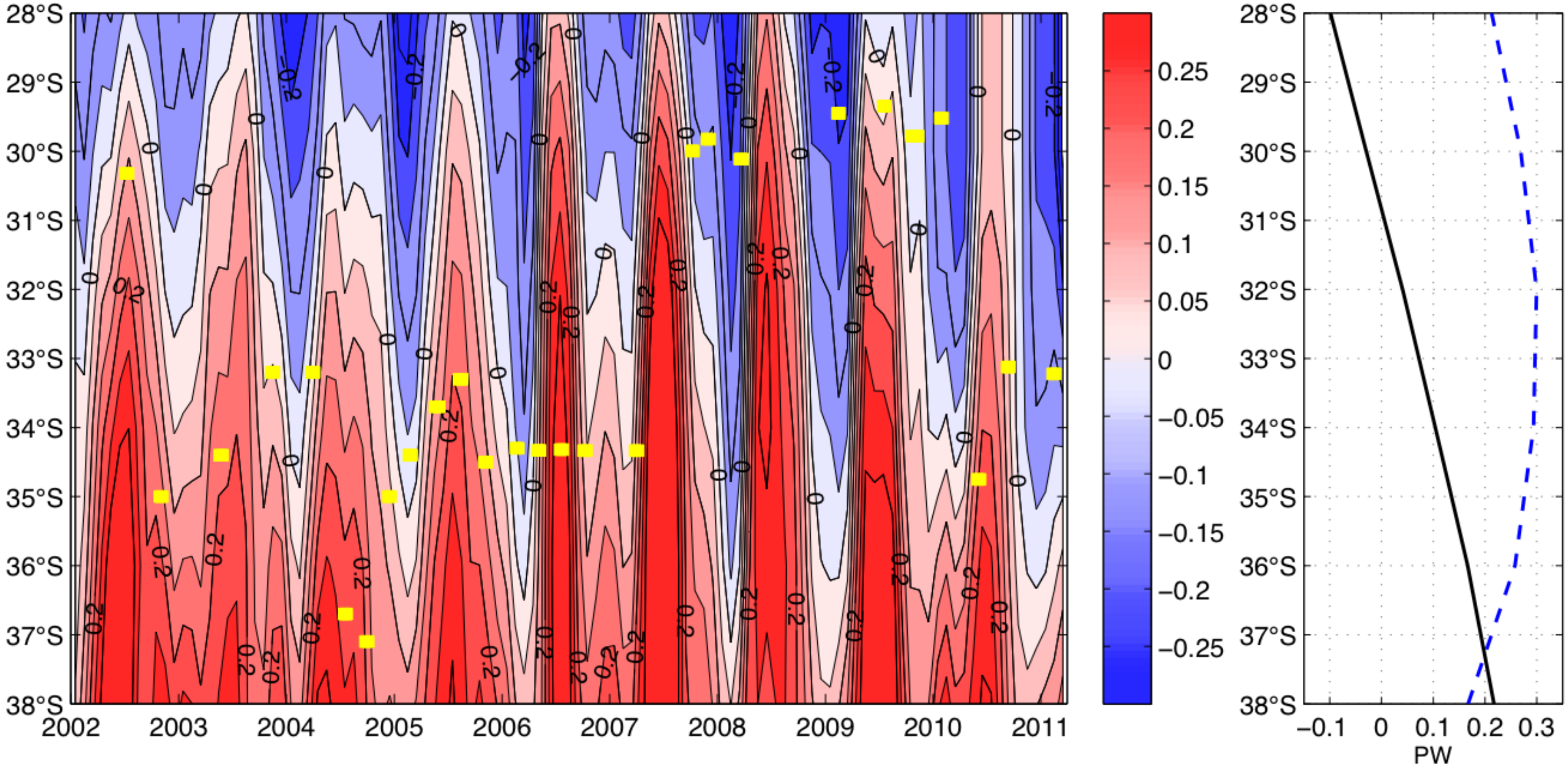
- **Inter-hemispheric comparison of meridional overturning circulation and meridional heat transport using high-resolution coupled climate and ocean-only simulations**
  by Renellys Perez

- **Brazillian SAMOC Project**
  by Edmo Campos

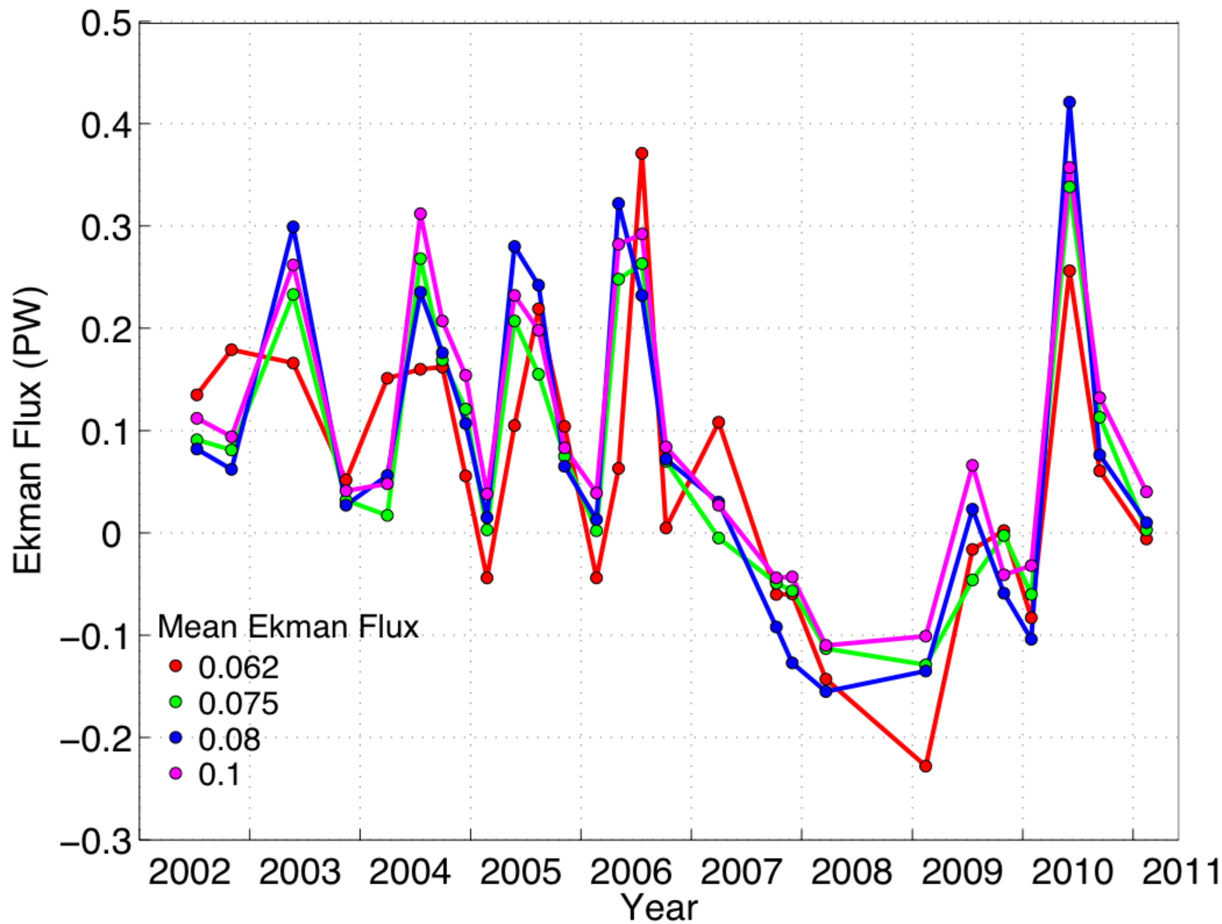
- **Boundary Current measurements at 34.5S in the South Atlantic: Preliminary results of MOC-related variability**
  by Chris Meinen

Thank you

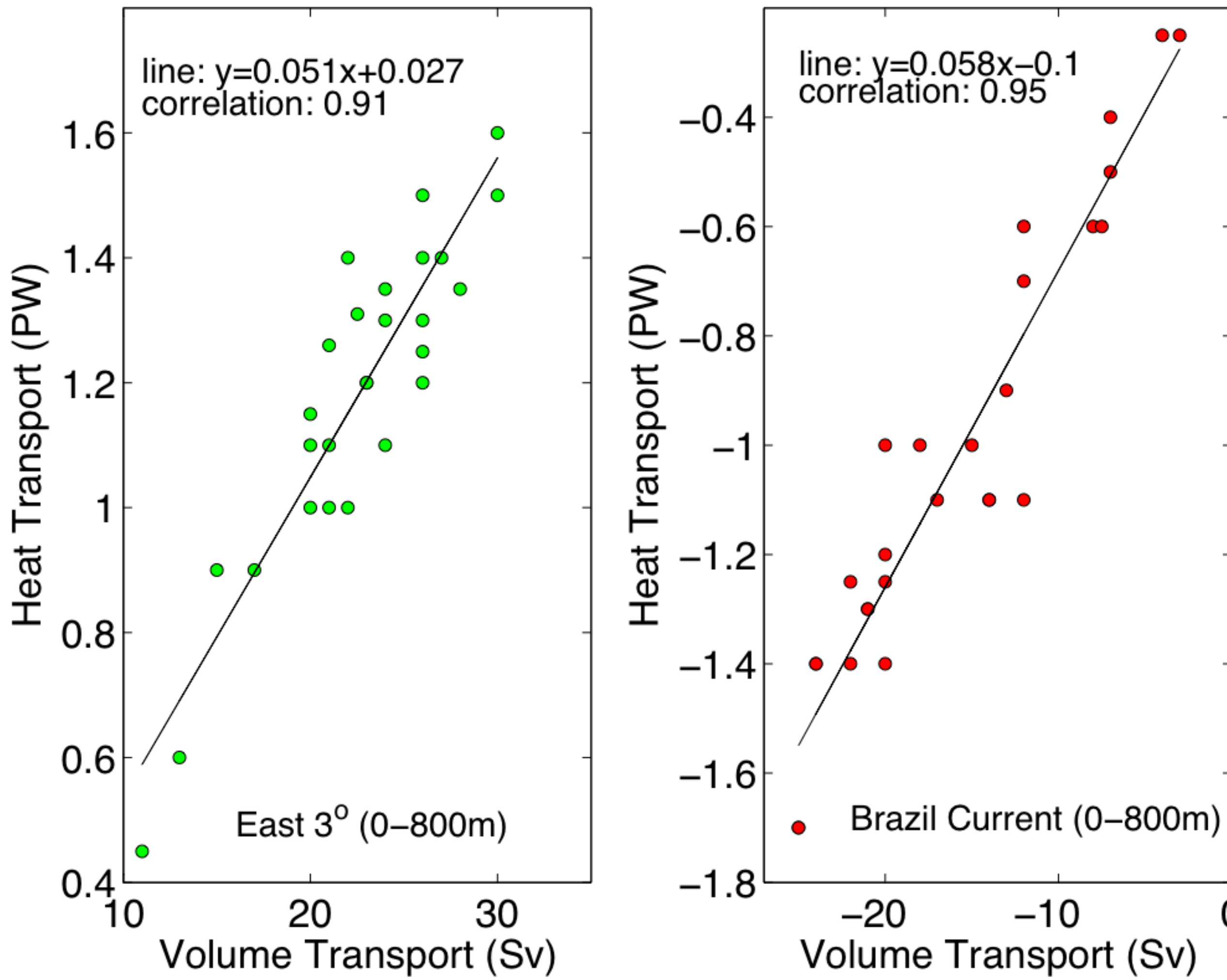
Additional slides



(left) Contoured monthly Ekman heat transport in PW derived from daily wind stress values with yellow squares highlighting the time and the mean latitude for the AX18 and AX18* transects. (right) The mean value of the Ekman heat transport are shown at the right (solid black line) and the amplitude of the seasonal cycle (dashed blue line) as a function of latitude. The Ekman component of the meridional heat flux between 38˚S and 28˚S was computed using the monthly WOA01 temperatures to determine the mixed layer temperature and NCEP daily wind products.

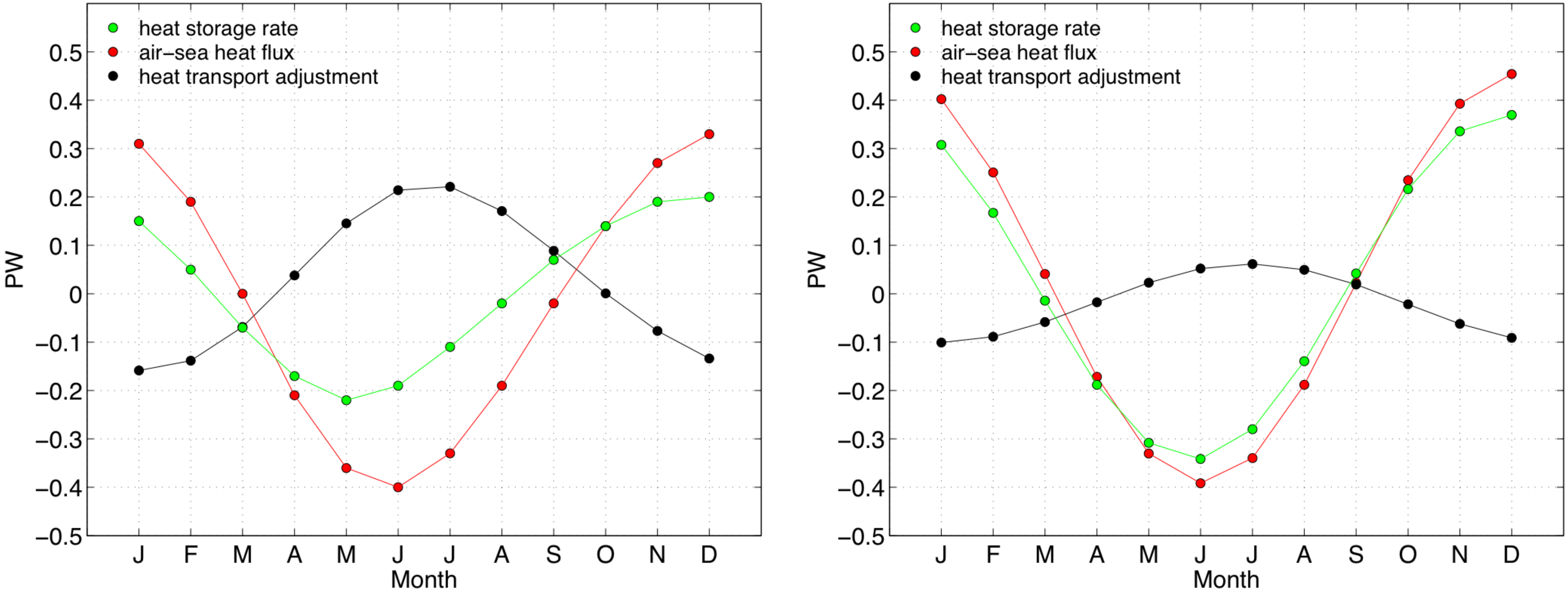


Ekman heat transport as a function of time obtained for the following wind products: 1) Hellerman and Rosenstein (1983) monthly winds (blue line), 2) ECMWF monthly winds (pink), 3) NCEP monthly winds (used by Baringer and Garzoli, 2007) (green), and 4) monthly values obtained from the NCEP daily winds (red, this paper) corresponding to the XBT transect dates. Note that the Ekman transport values are computed directly along each XBT section that vary in latitude.

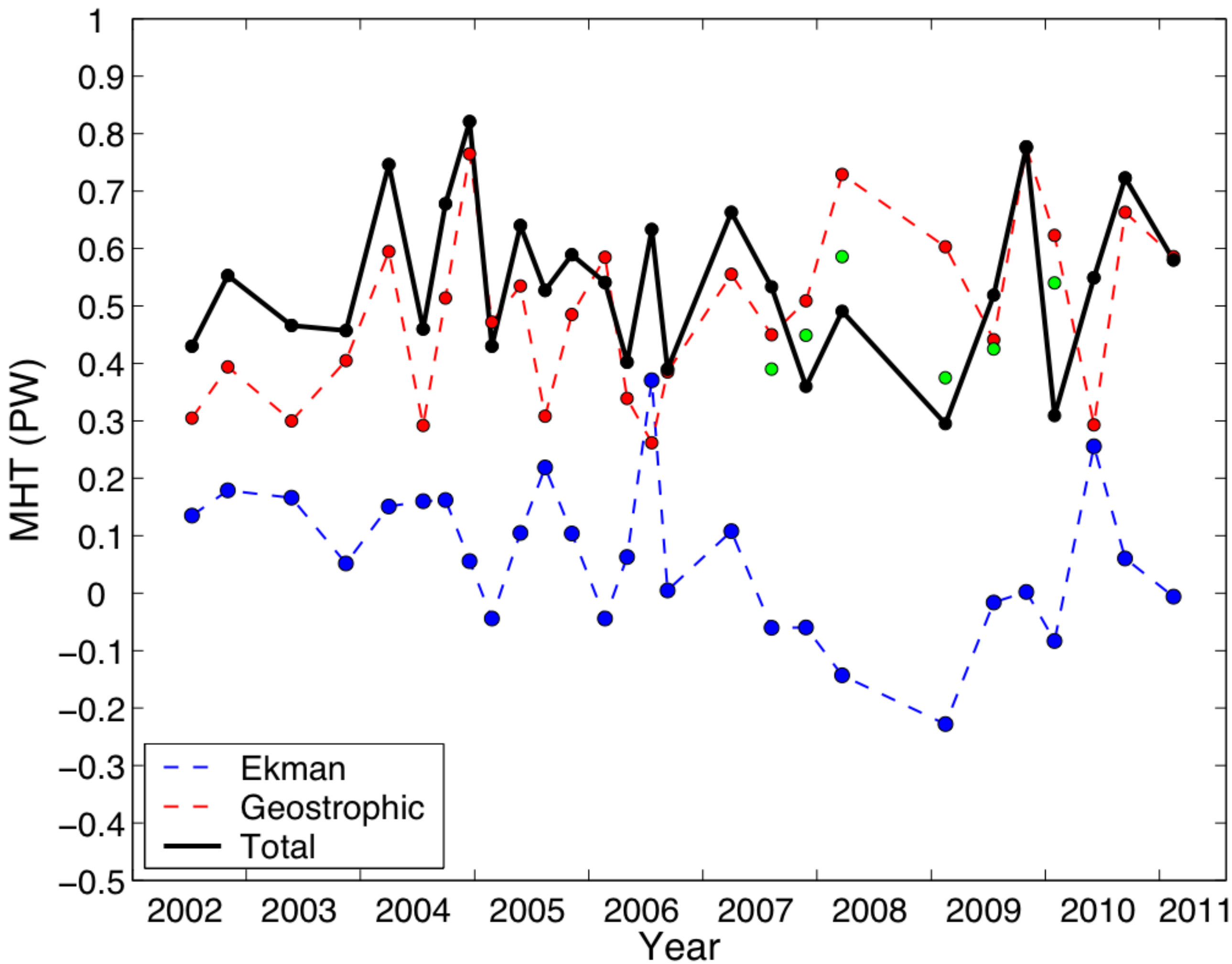


Correlation between heat and volume transport for the Brazil Current (left, green dots) and for the flow between 3°E and the African coast (right, red dots) at nominally 35°S. The green and red line is the linear relation between the variables in those two regions, respectively.

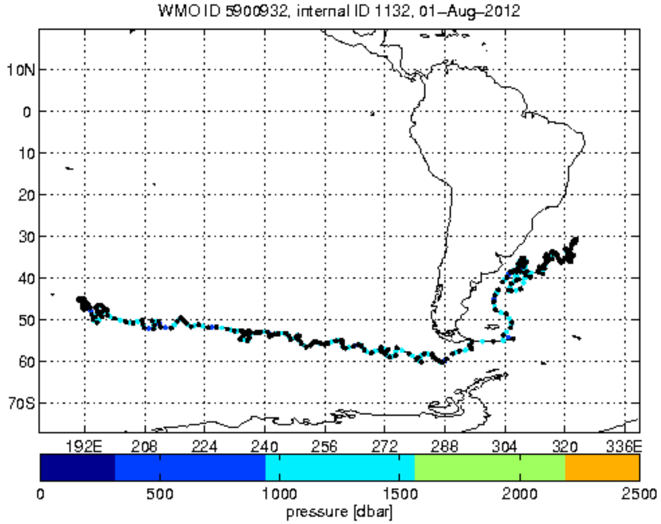
Products from the Ocean general circulation model For the Earth Simulator (OFES) used to validate the methodology used to extend the XBT record



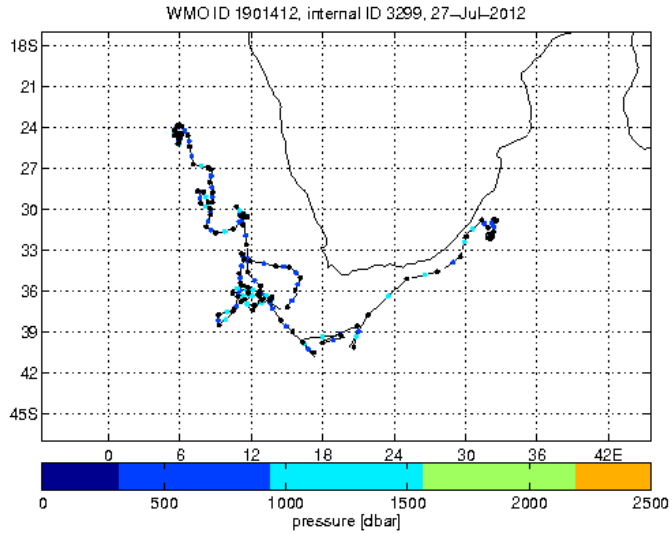
Heat adjustment from AX18* transect to AX18 transect obtained as the difference between the ocean heat storage rate and the heat gained from the atmosphere (within the box highlighted in Fig. 1): Annual cycle of the heat storage rate (green circles), air sea heat flux (red circles), and the heat transport adjustment (black circles) computed from the observations (left) and OFES (right).



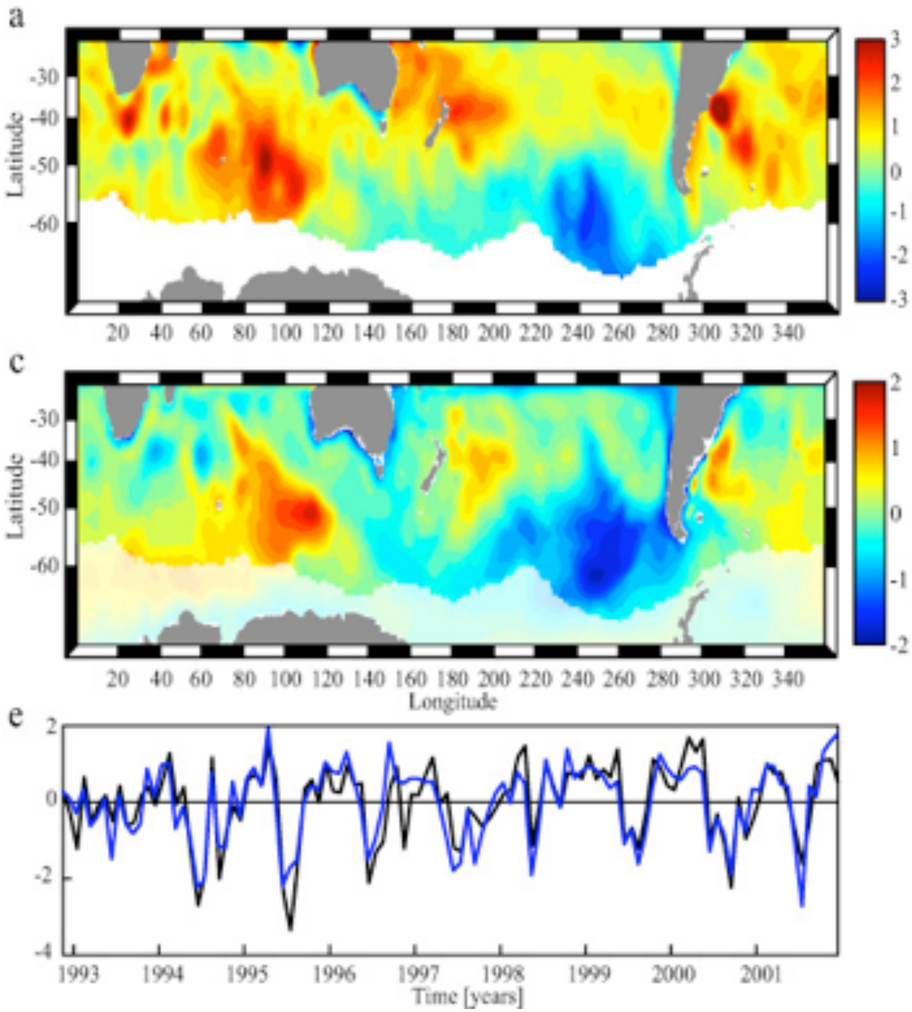
MHT as a function of time estimated from AX18 transects (solid black line). The geostrophic and Ekman components of the MHT are shown in red and blue, respectively. Green dots show the unadjusted values collected along AX18*



May 2005 to August 2012



January 2010 to August 2012



Results of the Principal Estimator Patterns between SSH and wind stress curl. Top: SSH anomalies, Middle: wind stress anomalies. Bottom: time dependence of the principal mode. Blue is from the POCM and black is from the AVISO data.